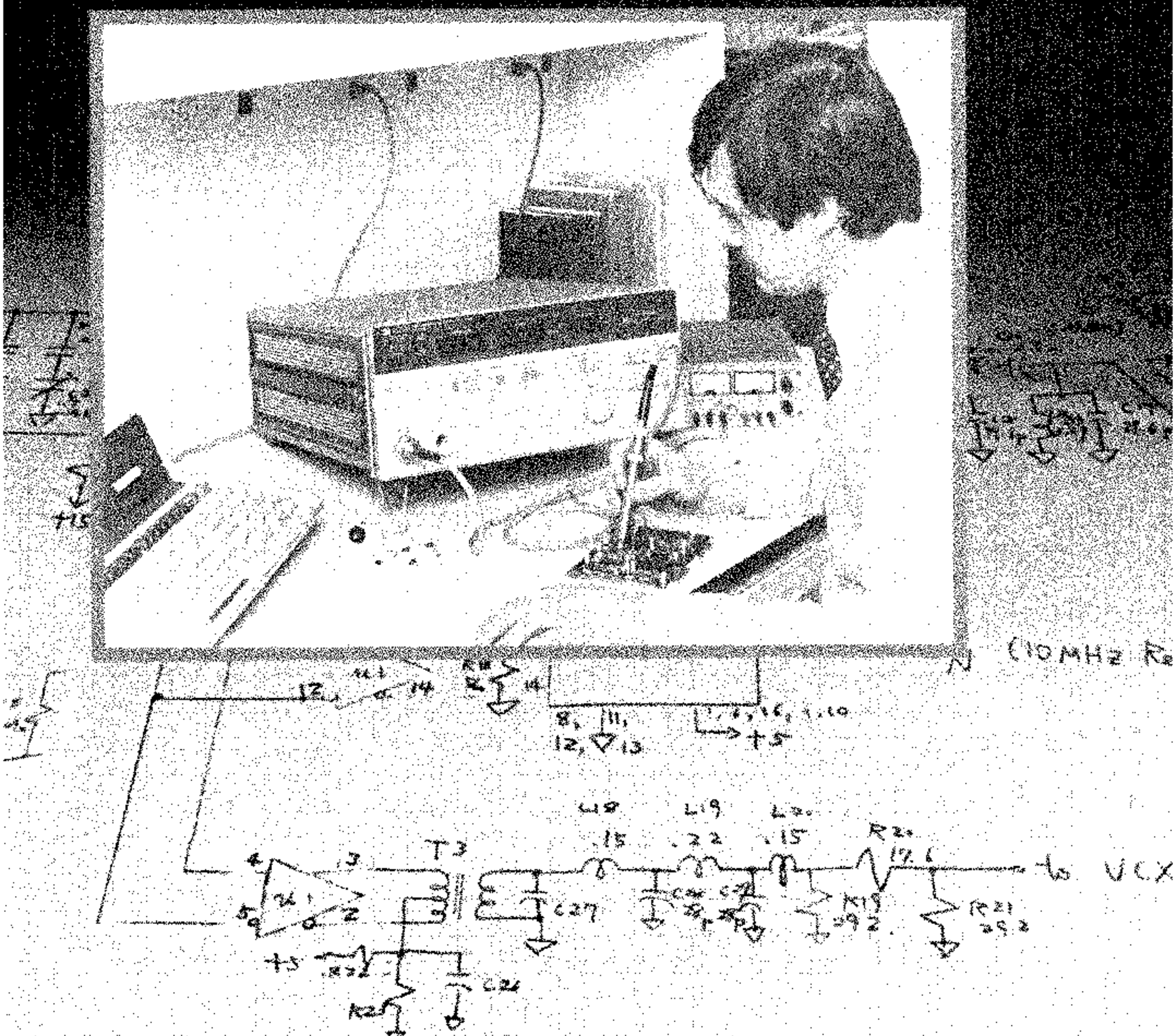
Application Note 317

Practical Design and Evaluation of High Frequency Circuits

Using the HP4193A Vector Impedance Meter



HEWLETT PACKARD

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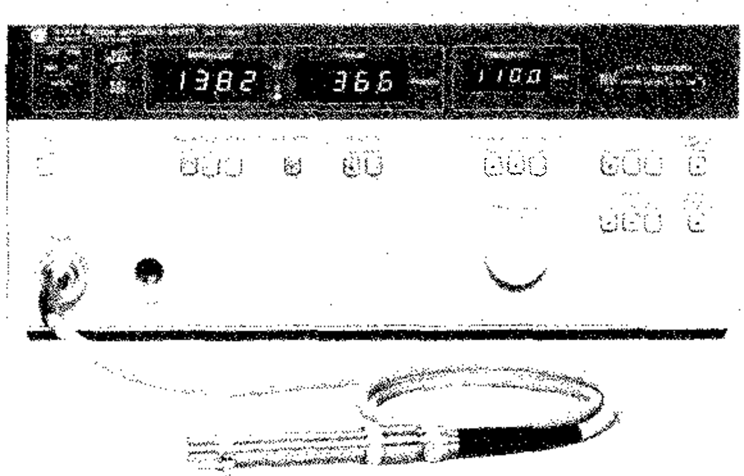


Figure 1-1. 4193A Vector Impedance Meter

1. INTRODUCTION

1.1 Preface

Have you ever designed an electronic circuit only to find that once it was built, it didn't work the way you intended it to. You have probably run into this sort of problem when working with electronic circuits that will operate somewhere between the HF and VHF bands. Such differences can usually be accounted for by three factors which affect circuit performance in the high frequency band, but not in the low frequency band. These factors include the following:

- Circuit components do not always work across an actual operational frequency range the way they theoretically should.
- At high frequency bands, printed circuit board patterns exhibit high impedance that cannot be ignored.
- The way components are packaged or laid out on the board will affect circuit operation.

This Application Note explains how to use the 4193A Vector Impedance Meter (Fig. 1-1) to solve these problems, and to achieve reliable and efficient design of video electronic circuits, and circuits which operate in the VHF band. In explaining the circuit design application of the 4193A, many actual examples are used. These include measuring component impedance at the desired operating frequency, measuring the input/output impedance of an assembled circuit, and measuring the output impedance of a power supply. The information included in this Application Note should prove useful in designing and packaging circuits for VTR, TV and other communications equipment.

1.2 4193A Outline

The 4193A is a grounded probe-type vector impedance meter. Its measurement frequency is continuously variable from 0.4 to 110MHz with 4-digit resolution. The instrument measures and digitally displays impedance magnitude $|Z|$ from 10 milliohms to 100 kilohms with 3.5 digit resolution, and phase from 0° to ±180° with 0.1° resolution. In addition, the automatic sweep feature provides many convenient functions for measuring frequency characteristics and operability. The 4193A can accurately measure impedance characteristics of not only individual circuit components, but also of entire assembled circuits, and can be effectively used at every stage of electronic circuit design. Main specifications are listed in Table 1-1.

Table 1-1. Key Specifications of 4193A

Test Signal	Frequency: 400 kHz to 110.0 MHz. 4 digit resolution Sweep: Manual or Automatic, Full Sweep or Partial Sweep
Measurement Range Resolution and Accuracy	$|Z|$: 0.01Ω to 120.0kΩ Maximum resolution: 10mΩ on 10.00Ω range Best accuracy: 3.0% θ: −180.0° ~ +180.0° Resolution: 0.1° Best accuracy: 3.2°
Displays	4 digit frequency display. 3½ digit impedance magnitude and phase displays.
Data Output/ Remote Control	HP-IB and recorder output of $|Z|$ θ and frequency

1.3 RF Circuit Design

When designing an electronic circuit, the main components must first be selected. Careful selection is important because the characteristics of components at rated frequencies may be quite different from those at actual operating frequencies. Parts which greatly affect circuit performance must be carefully evaluated before circuit assembly to ensure they will perform as desired. The impedance of lead wires and stray capacitance between components also affect circuit performance, requiring components to be evaluated at the actual operating frequency or frequency band, and with the lead wire cut to the lengths that will actually be used. After evaluating the individual components, the pattern in which the selected parts will be mounted on the printed circuit board must be evaluated. This becomes especially important for circuits operating at frequencies above 10MHz, because the impedance in the pattern and capacitance between patterns greatly affect circuit characteristics. Correct evaluation can effectively prevent unexpected phase shifts, signal attenuation, and oscillations. After assembling the components in the determined pattern, the circuit must be connected to a DC power source and tested for overall performance. Various problems may be encountered at this stage: the amplifier doesn't provide sufficient gain, the gain is not flat enough, or, for a filter, the cut-off frequencies do not match. One of the most common causes of these problems is that stray admittances generated between the packaged parts of patterns result in actual impedance values quite different from the expected ones. To solve this problem, input and output impedances and other characteristics must be measured with the circuit assembled, and without changing bias conditions. Thus, when designing an electronic circuit for operation in the RF band, the three most important factors to be evaluated are the characteristics of components at the actual operating frequency, the impedance of lead wires and printed circuit board patterns, and the stray capacitance between mounted circuit components. The 4193A Vector Impedance Meter measures component characteristics, pattern impedance, and stray capacitance easily and efficiently, and contributes greatly to reliable design of video circuits and circuits operating in the VHF band.

2. MEASUREMENT OF DISCRETE COMPONENTS FOR HIGH FREQUENCY CIRCUITS

2. 1 General

The most frequently encountered problems in high frequency circuit design are insufficient gain (amplifiers) and incorrect cutoff frequency (filters), both of which are usually caused by differences between the impedances and admittances of the design-stage circuit and those of the assembled circuit. At the component level, there are two main causes:

- Impedance frequency characteristics of the components themselves.
- Impedance of and capacitance between lead wires of individual circuit components.

In terms of the assembled circuit, there are also two main causes:

- Impedance of the printed pattern.
- Stray admittances between components and between patterns.

Components used in high-frequency electronic circuits should be evaluated for individual characteristics before assembly, and for impedance after assembly. The following explains how to make this evaluation.

2. 2 Component Frequency Characteristics Measurement

A great deal of useful information can be obtained by measuring the impedance characteristics of circuit components at the frequency which they are to operate. Fig. 2.1 shows an example of using the 4193A to measure the impedance frequency characteristics of a ceramic capacitor. If the capacitor were ideal, the curve would go down at the right. Instead, it shows a V-shaped characteristic. This happens because the capacitor itself includes inductive and resistive components. If equivalent circuit elements do not greatly depend on frequency characteristics, the R, C, and L values given in Fig. 2.2 can easily be estimated from the measurement results shown in Fig. 2.1.

The L and C reactances can be ignored in the area indicating resistance near the resonant frequency f_0 (approx. 5.8 MHz), where the phase is zero in Fig. 2.1. Since $1/G \gg R$, the capacitor can be regarded as a simple equivalent resistive circuit, whose equivalent series resistance (ESR) is 0.57 ohm.

$$R = 0.57 \text{ ohm} \qquad (2.1)$$

In the low-frequency capacitive area of Fig. 2.1, the L component can be ignored. Since parallel conductance G is also negligibly small compared to ωC, the capacitor can be regarded as an equivalent RC series circuit. Therefore, the value of C can be calculated from the following equation.

$$C \simeq \frac{1}{\omega\sqrt{|Z|^2 - R^2}} \qquad (2.2)$$

ω : Angular frequency = $2\pi f$
f : Measurement frequency (Hz) = 0.4 MHz
$|Z|$: Impedance magnitude (ohm) displayed on the 4193A
R : Equivalent series resistance (ohm)

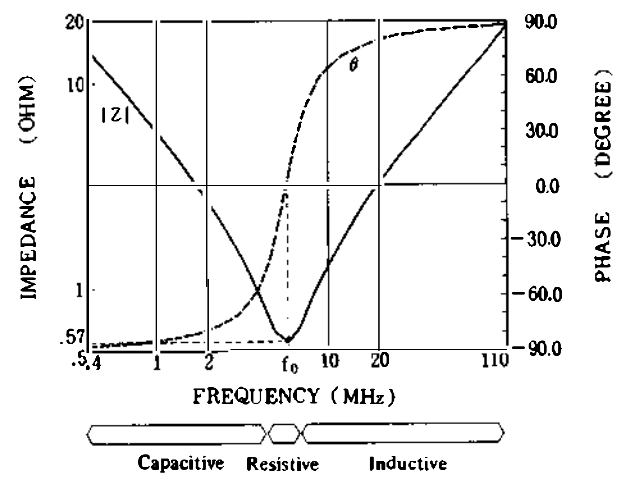
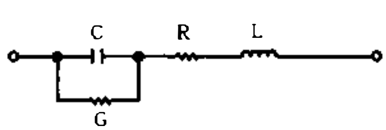
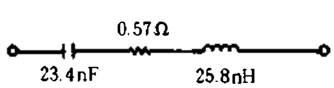


Figure 2.1. Frequency Characteristics of Ceramic Capacitor



(a) Equivalent Circuit



(b) Simplified Equivalent Circuit

Frequency Range	Equivalent circuit
Lower frequency	C ($\frac{1}{G} \gg R, \frac{1}{\omega C} \gg R$)
Around resonant frequency	R ($\frac{1}{G} \gg R, \left|\omega L - \frac{1}{\omega C}\right| \ll R$)
Higher frequency	L ($\frac{1}{G} \gg R, \omega L \gg R$)

(c) Example of Equivalent Circuit with Actual Values

Figure 2.2. Equivalent Circuits of Ceramic Capacitor

The following equation can be used in the frequency range where $|Z| \gg R$.

$$C \simeq \frac{1}{\omega|Z|} = \frac{1}{2\pi \times 0.4 \times 10^6 \times 17.00} = 23.4 \text{ nF} \qquad (2.3)$$

In the area of high-frequency inductance, the capacitive reactance can be ignored and an equivalent RL series circuit can be assumed. The value of L, then, is determined by the following equation.

$$L \simeq \frac{\sqrt{|Z|^2 - R^2}}{\omega} \qquad (2.4)$$

The following equation can be used in the frequency range where $|Z| \gg R$, and $f = 110$ MHz.

$$L \simeq \frac{|Z|}{\omega} = \frac{17.85}{2 \times \pi \times 110 \times 10^6} = 25.8 \text{ nH} \qquad (2.5)$$

From the above explanation, the equivalent circuit given in Fig. 2.2 can be expressed as b) or c) if the results of equations 2.1 to 2.5 are used.

The measurement results given in Fig. 2.1 indicate that the capacitor works well at frequencies of about 5 MHz or below. The limitation of capacitor performance can be checked by calculating the equivalent circuit constants as described above, and then used as a basic value for selecting parts or design data.

This method of capacitor evaluation is also applicable to resistors and coils. Fig. 2.3 shows how to calculate each equivalent circuit constant.

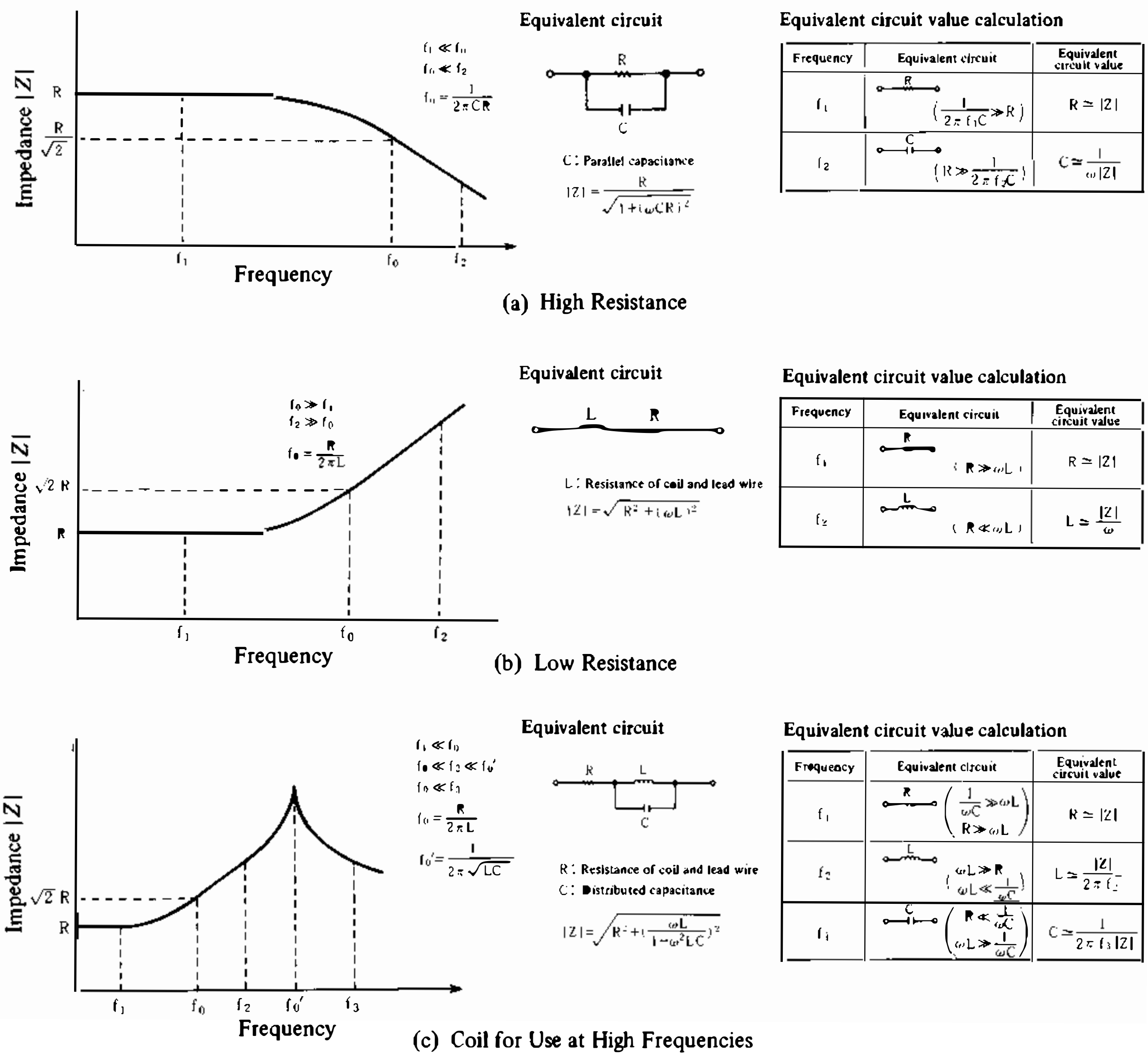


Figure 2.3. Frequency Characteristics and Equivalent Circuit for Circuit Components

2.3 4193A Test Fixture for Discrete Component Measurement

For reliable measurement of a circuit component in the video or VHF band, it is important to put the component in as close to actually assembled status as possible, and to use a suitable test fixture. The 4193A provides a variety of fixtures (Fig. 2.4) for measuring chip, radial lead, and axial lead components, and components of other shapes.

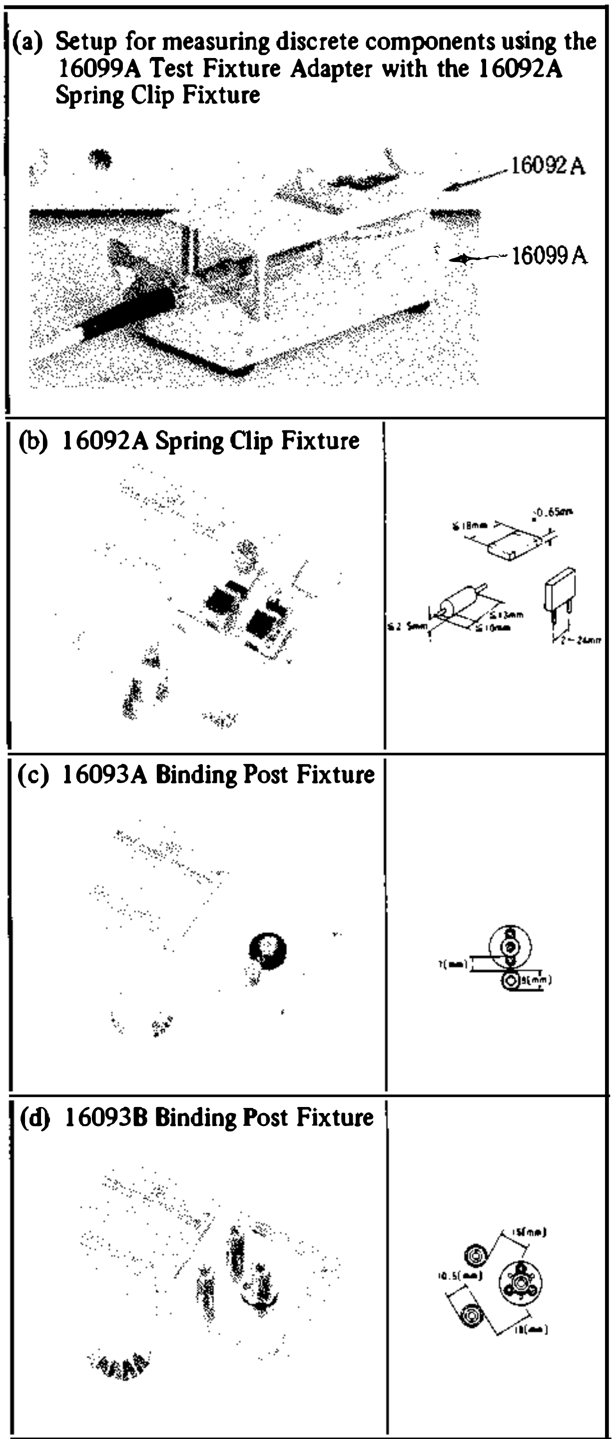


Figure 2.4. Test Fixtures for the 4193A

Fig. 2.4 (a) shows the 4193A attached to the 16099A Test Fixture Adapter, upon which is mounted a discrete component test fixture. Three types of component test fixtures are available, as shown in (b), (c) and (d) of Fig. 2.4. The numbers given in the figure indicate the distance between terminals, or the maximum measurable component dimensions. Because its measurement terminals are movable, the 16092A Test Fixture, shown in (b) of Fig. 2.4, can be used to measure components with lead wires as long as those to be actually used. Fig. 2.5 shows the results of two measurements made on the same ceramic capacitor. Lead wire length differs by about 1 cm for purposes of measurement. Since there are big differences in resonance frequencies and impedance values, the lead wires must be as long as will actually be used.

Fig. 2.6 shows a component mounting adapter which connects directly to the probe. Components are connected between the center terminal and either of the two outer terminals. Spacing between the center terminal and each outer terminal is 13.5 mm and 20 mm, respectively.

Fig. 2.7 shows a probe socket designed for board mounting and for user-fabricated test fixtures. Almost any type of fixture can be connected for measurement.

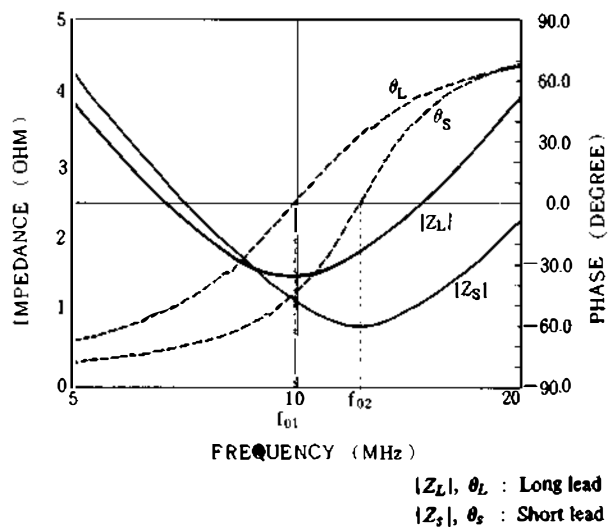


Figure 2.5. Lead-Length Dependency of Frequency Characteristics of Discrete Components

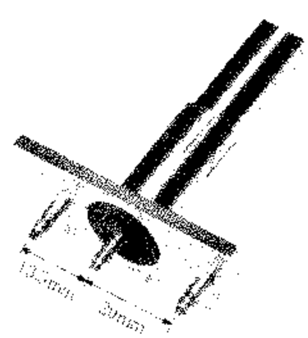
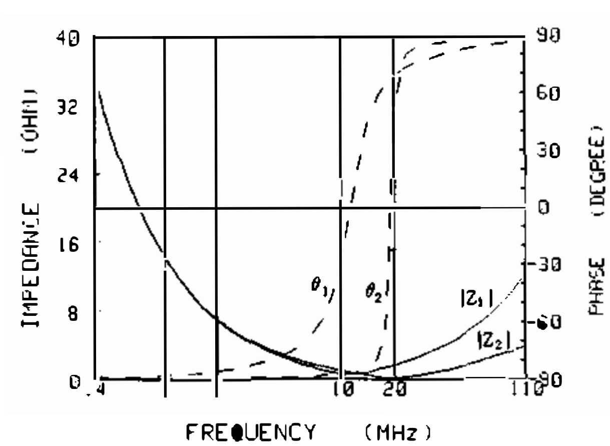


Figure 2.6. Component Mounting Adapter

Figure 2.7. Probe Socket

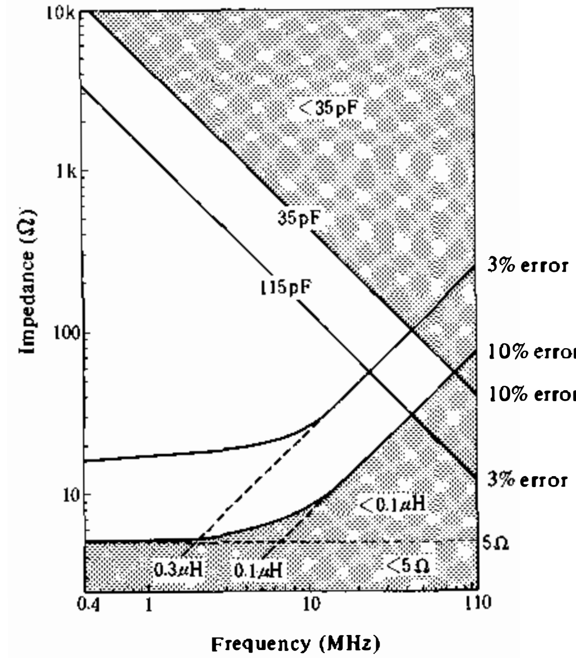
2. 4 Compensation for Test Fixture Residuals

In some cases, the residual impedance in a test fixture causes error when measuring the impedance of a circuit component. If this effect can be compensated, a more accurate measurement can be obtained. Fig. 2.8 compares values of impedance characteristics with and without residual impedance compensation. Compensation for residual impedance raises the resonant frequency by about 8 MHz, and lowers the resonant impedance by about 0.5 ohm. Eliminating the error caused by the test fixture results in the correct value. The impedance range in which correct values can be obtained if residual impedance is compensated is shown in Fig. 2.9. (A sample program for automatic residual impedance compensation via the HP-IB is given in the Appendix (p. 19).



$|Z_1|$, θ_1 : Not compensated
$|Z_2|$, θ_2 : Compensated

Figure 2.8. Residual Impedance Compensation for Frequency Characteristics of Ceramic Capacitor



☐ : Range where the residual error is less than 10%

▩ : Range where the residual error is 10% or more (must be compensated)

Whenever the residual error caused by the fixture is to be minimized, compensation is necessary.

Figure 2.9. Additional Error due to Residual Impedance when the 16092A is attached to the 16099A

• How to compensate for residual impedance

Measured impedance values displayed on the 4193A include the impedance of the DUT plus the residual impedance of the test fixture. See Fig. 2.10. To obtain the true impedance of the DUT, the following method can be used.

1. Short circuit terminals A and B, and note the values displayed on the 4193A as $|Z_s|$ and θ_s (R_0 and X_0 measurements). Shorting rings are furnished with the 16092A and 16093A/B for this purpose.

$$Z_s \simeq R_0 + jX_0 \quad \text{(Impedance of shorting ring} \ll |R_0 + jX_0|) \qquad (2.6)$$

2. Perform measurement with terminals A and B open, and note the values displayed on the 4193A as $|Z_0|$ and θ_0 (G_0 and B_0 measurements).

$$Z_0 \simeq \frac{1}{G_0 + jB_0} \quad \left(|G_0 + jB_0| \ll \frac{1}{|R_0 + jX_0|}\right) \qquad (2.7)$$

3. Connect the component to be measured to terminals A and B, and note the values displayed on the 4193A as $|Z_m|$ and θ_m.

4. The actual impedance of the component is Z_x/θ_x, and is calculated as follows:

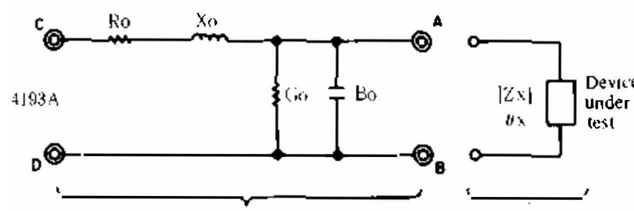
$$|Z_x| = \sqrt{R^2 + X^2} \qquad (2.8)$$

$$\theta_x = \tan^{-1}\frac{X}{R} \qquad (2.9)$$

where

$$R = \frac{(|Z_0|\cos\theta_m - |Z_m|\cos\theta_0)\cdot|Z_m|\cdot|Z_0|}{(|Z_0|\cos\theta_m - |Z_m|\cos\theta_0)^2 + (|Z_0|\sin\theta_m - |Z_m|\sin\theta_0)^2} - |Z_s|\cos\theta_s \qquad (2.10)$$

$$X = \frac{(|Z_0|\sin\theta_m - |Z_m|\sin\theta_0)\cdot|Z_m|\cdot|Z_0|}{(|Z_0|\cos\theta_m - |Z_m|\cos\theta_0)^2 + (|Z_0|\sin\theta_m - |Z_m|\sin\theta_0)^2} - |Z_s|\sin\theta_s \qquad (2.11)$$



Residual Impedance of Test Fixture Including Test Probe

- R_0 : Residual resistance
- X_0 : Residual reactance
- G_0 : Residual conductance
- B_0 : Residual susceptance
- $|Z_x|$: Impedance magnitude of DUT
- θ_x : Phase of DUT

Figure 2.10. Equivalent Circuit of Test Fixture

3. IN-CIRCUIT IMPEDANCE MEASUREMENT

In addition to measuring discrete components, as explained in Section 2, it is also important to measure the impedance of the assembled circuit if it is to operate at high frequencies. The following explains how to use the 4193A for this kind of evaluation.

3. 1 Input/Output Impedance Measurement

A high-frequency circuit often exhibits characteristics that differ significantly from theoretical ones because of board pattern impedances, and because of stray capacitances between mounted components. This results in, for example, insufficient amplifier output or incorrect filter cutoff frequency. One of the causes is that the actual input and output impedance values are different from the theoretical ones.

By measuring the input and output impedances, the following factors can be correctly evaluated:

- Amplifier or mixer impedance matching.
- Tuning amplifier frequency characteristics.

Two examples of how to solve the above problems are given below.

(1) Impedance Matching

Fig. 3.1 shows a hypothetical video amplifier circuit. Point Ⓐ is designed to match at 50 ohms. The filter used in amplifier 2 eliminates noise in the 300 MHz region, and is designed so that the characteristic impedance becomes 50 ohms. With the 4193A, impedance matching was checked at 50 ohms in the frequency range of 1 to 100MHz. The results shown in Fig. 3.2 were obtained.

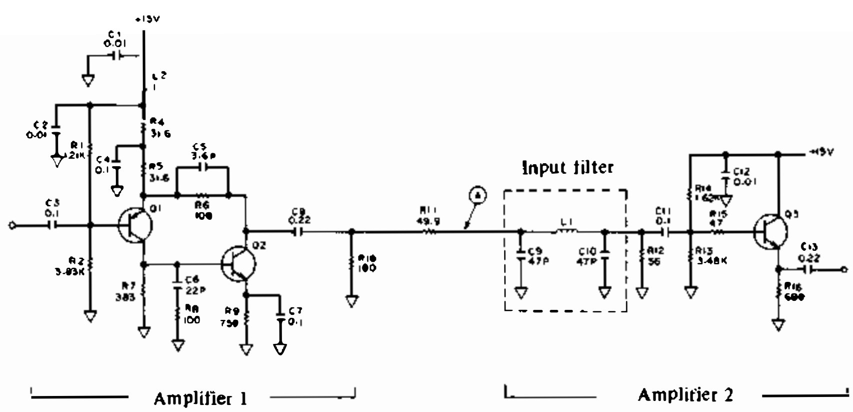
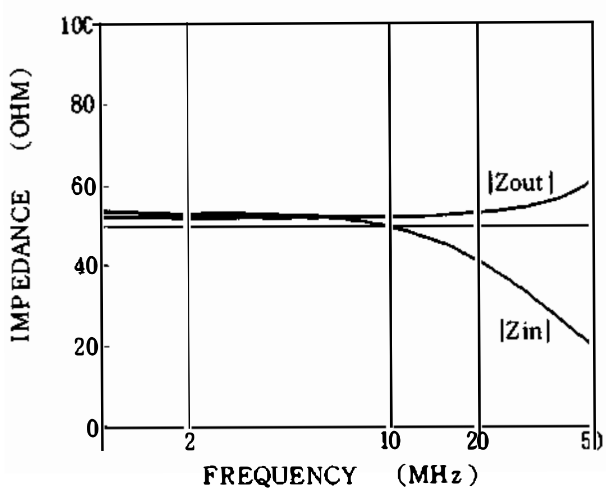


Figure 3.1. Video Frequency Band Amplifier



$|Z_{out}|$: Output impedance of amplifier 1
$|Z_{in}|$: Input impedance of amplifier 2

Figure 3.2. Impedance Matching between Amplifiers 1 and 2

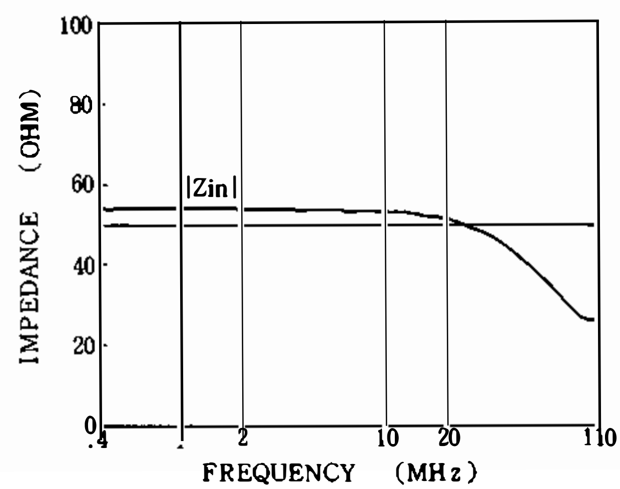


Figure 3.3. Frequency Characteristics of Video Amplifier shown in Figure 3.1 when C9 and C10 values are changed to 20pF in the input filter circuit

The two circuits were found to match at frequencies up to 10 MHz. However, the output and input impedances were 53 and 40 ohms at 20 MHz, and 61 and 18 ohms at 50 MHz, respectively. That is, they were found not to match at high frequencies. This disparity results because the distributed capacitance of inductor L1 becomes larger as the frequency increases, and because the characteristic impedance value changes. In this circuit, the frequency range is from 1 to 100 MHz, and the input impedance of amplifier 2 must be between 25 and 75 ohms to obtain the initial output level of amplifier 2. To satisfy this condition, the value of the input filter capacitor of amplifier 2 must be changed, while measuring the input impedance with the 4193A, until the optimum value is obtained. The value of 20 pF was found to be best for the 47 pF capacitor (Fig. 3.3). Since the filter cutoff frequency is 205 MHz at that value, noise in the 300 MHz area from amplifier 1 can be sufficiently suppressed.

In a circuit which requires matching between stages, the 4193A can be used to measure the impedance, evaluate the results, and if mismatching occurs, to get rid of the cause.

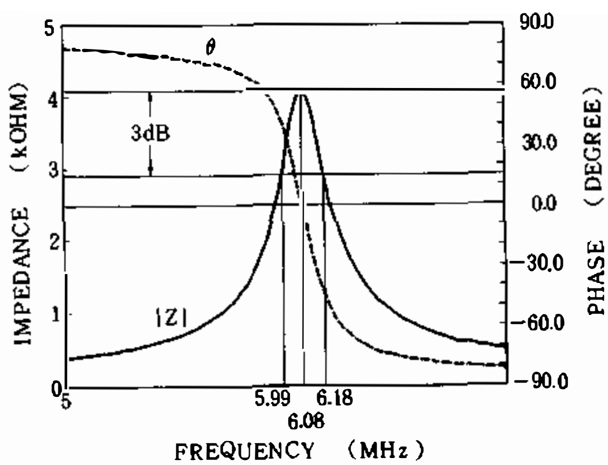


Figure 3.4. Output Impedance-Frequency Characteristics of a Tuned Amplifier

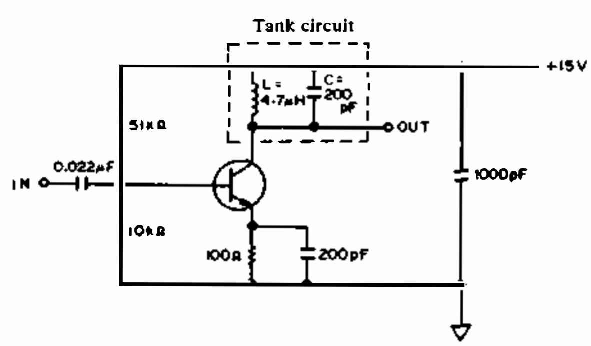


Figure 3.5. Tuned Amplifier Circuit

(2) Tuned Amplifier

In a tuned amplifier, because output impedance is generally proportional to gain, by measuring output impedance, characteristics such as resonant frequency and bandpass can be evaluated. Fig. 3.4 shows the results of using the 4193A to measure output impedance in order to find frequency characteristics of the tuned amplifier shown in Fig. 3.5. This amplifier should theoretically resonate at 5.2 MHz, but actually resonates at 6.08 MHz. The measured resonant frequency differs from the expected one because of pattern inductance and stray capacitance between patterns and components. From the measurement results shown in Fig. 3.4, the pass band and resonant frequency can be calculated as follows.

- Pass Band . . . . Frequency range between the −3 dB points on the curve: 5.99 MHz to 6.18 MHz
- Resonant frequency . . Frequency at which output voltage and current are in phase: 6.08 MHz

When the tank circuit is mounted, the circuit Q can be calculated from bandwidth ΔF and resonant frequency f_0 using the following equation.

$$Q = \frac{f_0}{\Delta F} = \frac{6.08}{6.18 - 5.99} = 32.0 \qquad (3.1)$$

When $L = 4.7\mu$H and $C = 200$ pF, the characteristics are as shown in Fig. 3.4. To change the resonant frequency to the desired value of 5.2 MHz, the following measures can be taken.

By setting the 4193A measurement frequency to 5.2 MHz and continually changing the value of the tuning capacitor, the phase display can be checked. When the phase is 0 degrees, 254 pF is the capacitor value to be used. Fig. 3.6 shows the output impedance characteristics at that time.

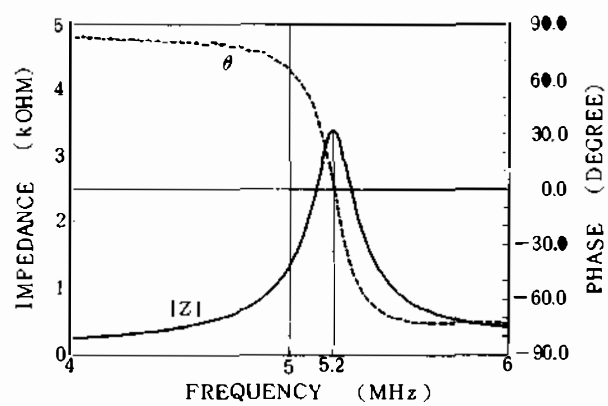


Figure 3.6. Output Impedance – Frequency Characteristics of the Improved Tuned Amplifier

3.2 Oscillator Circuit Design and Evaluation

Oscillator circuits, such as crystal oscillators, often do not work as designed. One of the causes is that the negative impedance of the circuit could not be measured accurately after circuit assembly. The 4193A can be used to calculate stable oscillation conditions from the negative impedance measurement and to determine the optimum value of the load impedance. As an example, the following describes how to do so for the 100 MHz crystal oscillator shown in Fig. 3.7.

The 100 MHz crystal oscillator circuit in the figure can be represented by the equivalent circuit shown in Fig. 3.8.

Condition for oscillation:

$$-\frac{1}{r}+\frac{1}{R_L} \leqq 0 \;(r \leqq R_L) \qquad (3.2)$$

Condition for no oscillation:

$$-\frac{1}{r}+\frac{1}{R_L} > 0 \;(r > R_L) \qquad (3.3)$$

When the condition given in equation 3.2 is satisfied, oscillation starts. When the condition given in equation 3.3 is satisfied, oscillation does not occur.

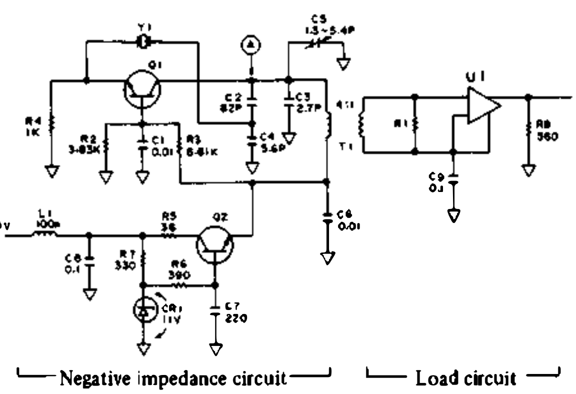


Figure 3.7. 100 MHz Crystal Oscillator Circuit

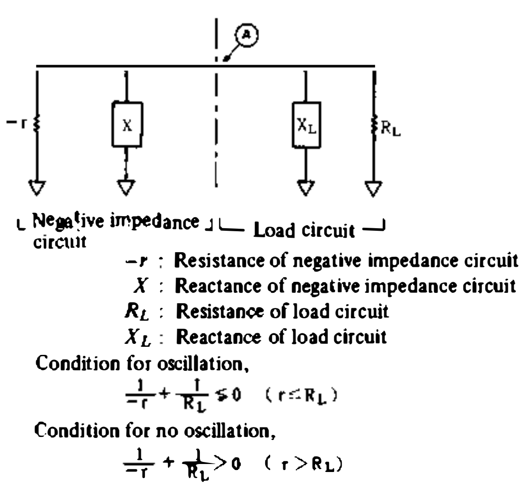


Figure 3.8. Equivalent Circuit and Oscillation Condition of Negative Resistance Oscillator

By disconnecting point A in Fig. 3.8 and measuring the negative impedance and the load impedance with the 4193A, it can be checked whether the oscillation condition and design margin are satisfied. If the oscillation condition is not satisfied, constants $-r$ or R_L can be changed to stabilize oscillation.

Refer again to the circuit diagram given in Fig. 3.7. Circuits R1 and U1 on the load side can be removed to check the oscillation condition and to measure the negative output impedance at point Ⓐ. The result is shown in Fig. 3.9. Oscillations may occur at points Ⓑ (100 MHz) and Ⓒ (100.04MHz) where the phase is −180°. Since the negative resistance ($-r_1$) at point Ⓑ is 320 ohms and ($-r_2$) at point Ⓑ is 820 ohms, the following two conditions must be satisfied to cause oscillation at 100MHzat point Ⓑ, and not at 100.04MHz at point Ⓒ. From the oscillation condition of equation 3.2,

$$320 \text{ ohms} \leqq R_L \;(r_1 \leqq R_L) \qquad (3.4)$$

and from equation 3.3,

$$820 \text{ ohms} > R_L \;(r_2 > R_L) \qquad (3.5)$$

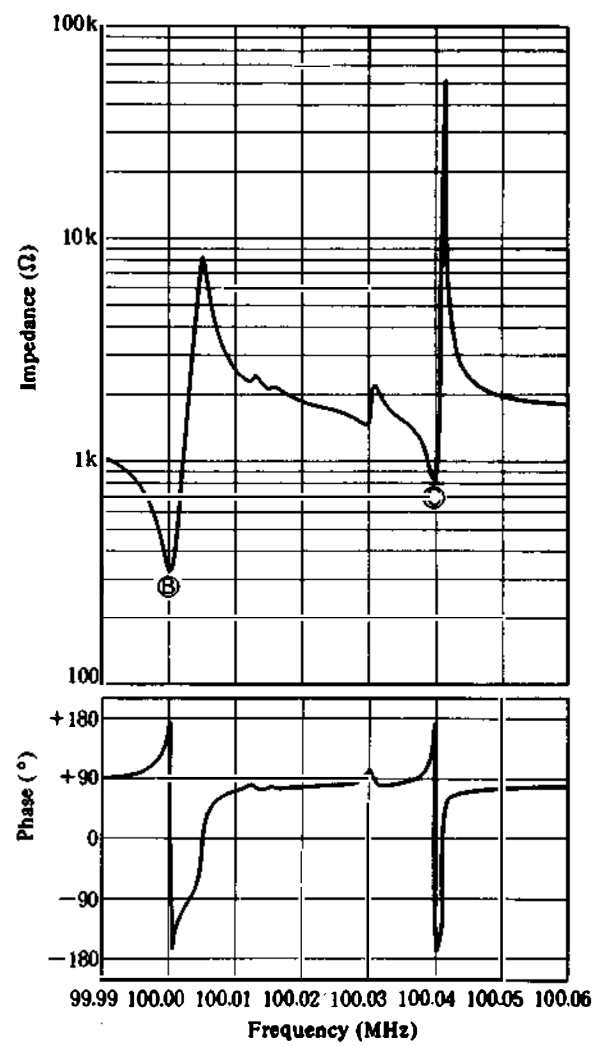


Figure 3.9. Negative Impedance Characteristics of Crystal Oscillator

Thus, a load impedance, R_L, which satisfies both conditions, must be used. The optimum value is about 600 ohms, which is between 320 and 820 ohms, taking into account design margins such as the diverse impedances of the crystal resonator and circuit components, and ambient temperature.

Value R1 can then be determined from value R_L (600 ohms). The impedance on the load side from point A is about 16 times R1 (connected by transfonner T1; turns ratio 4 : 1) because the U1 input resistance can be ignored. Therefore, R1 is 37.5 ohms (= 600 ohms/16). If R1 is a discrete resistor with a standard value, 38.3 ohms, R_L is 612.8 ohms (38.3 ohms x 16) and fully satisfies the stability conditions at point A (equations 3.4 and 3.5).

Finally, R1 and U1, whose values are now known, can be installed, the negative impedance can be removed, and the impedance on the load side can be measured using the 4193A. The result is converted to the resistance shown in Fig. 3.10. The figure indicates that value R_L is around 600 ohms, and that stable oscillation can be obtained.

The 4193A can easily measure the usually hard-to-determine impedance characteristics of an assembled oscillator circuit such as this, or at least to determine circuit constants for securing stable oscillation, for preventing abnormal oscillations, and for designing highly reliable oscillator circuits. Figures 3.9 and 3.10 show measurements made with an external synthesizer connected and the frequency resolution raised. For details, refer to the apppendix (p. 18).

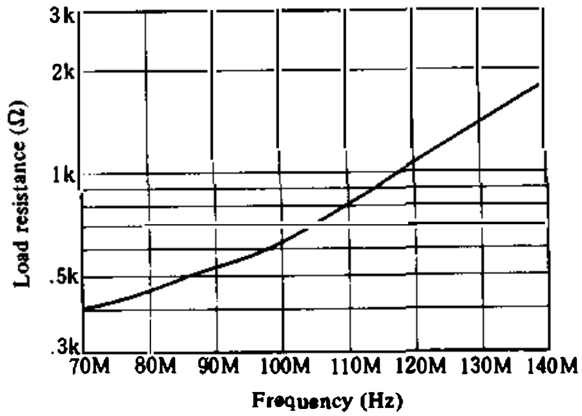
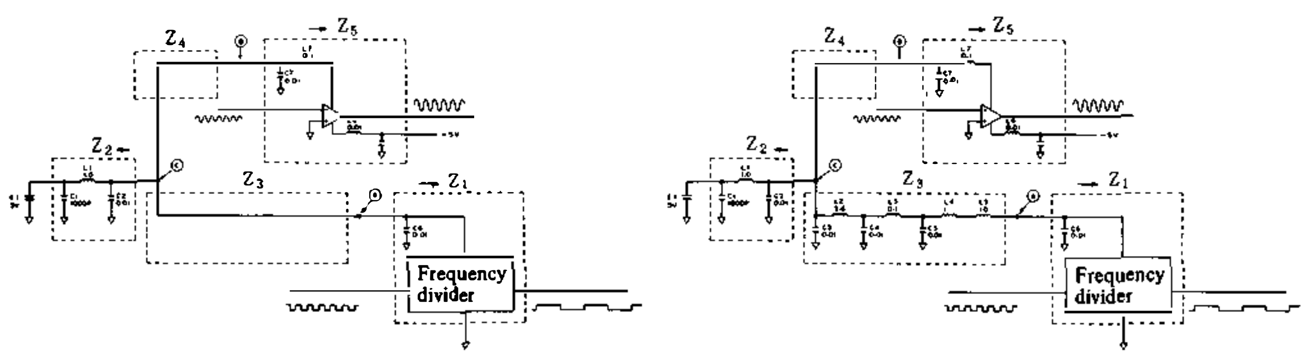


Figure 3.10. Frequency Characteristics of Load Resistance (R_L) Derived from Load Circuit Impedance

3.3 Power Source and Ground Pattern Impedance

In a hybrid circuit with both analog and digital sections, noise in the digital section may have adverse effects on the analog section when transmitted through the power source or ground line. In this case, the impedances of the power source and ground patterns can be used to prevent noise from getting through. To eliminate interference between circuits, power source line evaluation using the 4193A is especially important. In actual applications, the AC impedance should be large enough to attenuate noise on a line if the line lets noise pass easily, or absorbs noise because of the decoupling capacitor. The 4193A is useful for designing a pattern which does not transmit noise. This is done by measuring pattern impedances of the power source and ground systems over a frequency range of 0.4 to 110 MHz by simple probing.



Z_1 : Impedance of frequency divider at the power supply point

Z_2 : Output impedance of 5V supply

Z_3 : Printed pattern impedance between 5V supply and frequency divider

Z_4 : Printed pattern impedance between 5V supply and power supply point of amplifier

Z_5 : Impedance of amplifier at the power supply input

Figure 3.11. DC Power Supply Configuration for Mixed Analog and Digital Circuit

Fig. 3.11 shows frequency divider (digital) and amplifier (analog) circuits mounted on a printed circuit board. They are both powered from the same +5V power source. Z_1 contains decoupling capacitor C6, and Z_5 contains decoupling capacitor C7. The impedance value is large at high frequencies, and switching noise generated at Z_1 goes to point Ⓑ through the +5V power source pattern, and appears in the amplifier output as spurious noise. To check how much noise gets through, the switching frequency of the divider circuit, pattern impedances Z_3 and Z_4 between points Ⓐ and Ⓒ, and between points Ⓑ and Ⓒ, respectively, at the second harmonic, and ground impedances Z_1, Z_2, and Z_3 at points Ⓐ, Ⓑ, and Ⓒ, respectively, were measured with the 4193A. The results are listed in Table 3.1 (1). Using equation 3.6 to determine the noise transfer ratio, gave results of 16% to 70%.

$$B(t) = \frac{Z_2 \cdot Z_5 \cdot A(t)}{Z_3 (Z_2 + Z_4 + Z_5) + Z_2 (Z_4 + Z_5)} \quad (3.6)$$

$A(t)$: Noise generated at Z_1
$B(t)$: Noise transferred to Z_5

If the AC impedance of Z_3 is increased, noise can be attenuated. By inserting an inductor in series with the Z_3 pattern, and a bypass capacitor between the grounds (see Fig. 3.11), the resultant values become as listed in Table 3-1 (2). The noise transfer ratio improves to about 1% or less, spurious noise at the amplifier output decreases at the same ratio, and high-quality signals are thereby obtained.

Since the 4193A measures pattern impedances and quantitatively evaluates noise, it is a valuable tool for achieving more logical and efficient circuit design.

Table 3-1. Impedance Evaluation of DC Power Supplys

Frequency		Z_2 (Ω)	Z_3 (Ω)	Z_4 (Ω)	Z_5 (Ω)	Noise level at point Ⓑ / Noise level at point Ⓐ
7.5MHz	(1)	50	1.5	2	9	− 3.08dB
	(2)	50	450	2	9	− 35.9dB
10MHz	(1)	65	2.5	2.6	1.5	− 13.1dB
	(2)	65	600	2.6	1.5	− 52.6dB
15MHz	(1)	120	4	3.7	1.5	− 15.9dB
	(2)	120	970	3.7	1.5	− 56.6dB
20MHz	(1)	235	5.6	4.8	2.5	− 14.3dB
	(2)	235	1420	4.8	2.5	− 55.4dB

3.4 Pattern Inductor Design and Evaluation

Circuits often do not operate as designed at high frequencies because of pattern impedances. However, this need not always be a problem. Pattern impedances can sometimes be utilized for more effective circuit design because of three factors:

- They have high resonant frequencies, are stable as inductive elements, and are not frequency dependent.
- Not all desired inductor values can be created by coils.
- They are cheap and do not take up much board space.

The following explains how the 4193A is used to measure the pattern inductance of an LC filter.

In the low-pass filter for input to the video amplifier shown in Fig. 3.12, pattern type series inductor L1 (Fig. 3.13) was chosen in order to match the previous stage at 50-ohm impedance. This match is necessary because the filter's cut-off frequency is over 100MHz and cannot be increased any further. The designed value is 60nH, but lead inductance, distributed capacitance, pattern inductance, and other factors make it difficult to obtain the exact value when initially assembling the circuit. Here, the 4193A can be used to solve the problem. By making a trial pattern inductor value larger than the designed value, the initial impedance value can be found by shifting the 4193A probe tip (Fig. 3.14).

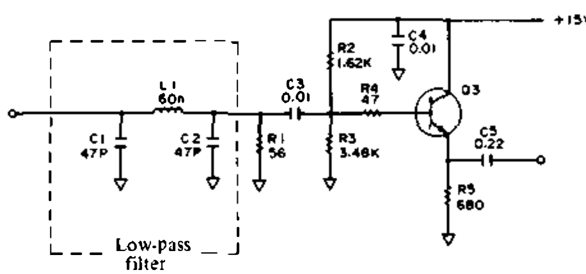


Figure 3.12. Low-pass Filter Circuit Used in Video Amplifier

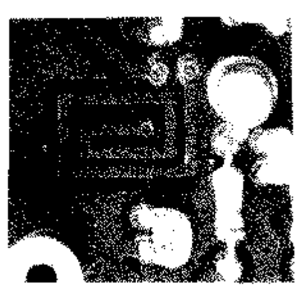


Figure 3.13. Printed Pattern Inductor

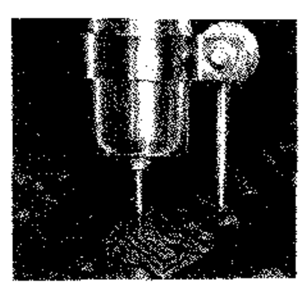


Figure 3.14. Pattern Impedance Measurement Using Test Probe of the 4193A

Conversely, by making the pattern area gradually smaller, the impedance can be measured step by step. In the 4193A, parameter conversion can be easily done by a controller via the HP-IB. The optimum value can be obtained by monitoring the inductance value directly. When designing a pattern with high inductance (≥ 1μH), the stray capacitance of the probe may affect measurement. The correct value can be obtained by compensating for the residual impedance (see paragraph 3.5 and appendix A (p. 15)). Fig. 3.15 shows the measured values of the trial pattern inductor created by using the parameter conversion program given in the appendix (p. 19) and gradually changing the measurement point. The point at which the measured value is almost the same as the designed value, 60nH, is found in the frequency range of 1 to 100 MHz. The 4193A proves very useful for measuring pattern inductance of a high-frequency electronic circuit like this or any other hybrid IC because of its high resolution (10 milliohms), wide measurement range, and easy-to-use probe.

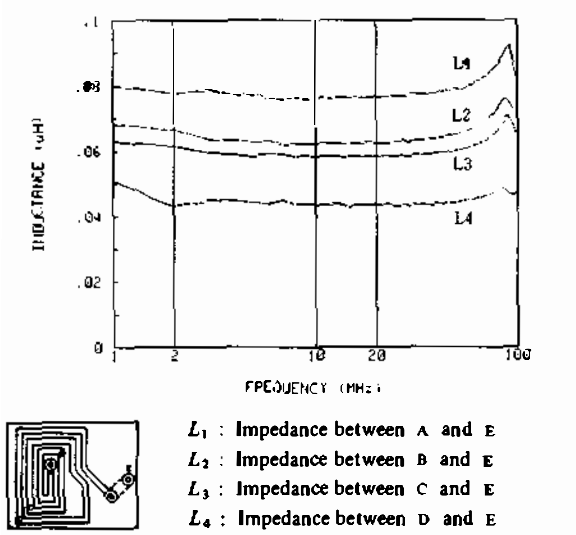


Figure 3.15. Helical Pattern Inductance Evaluation at Different Points on Pattern

3.5 Measuring Assembled Circuit Impedance

There are several points to note when measuring assembled circuit impedance, especially active circuits which must have high reliability. The four most important points for making measurements with the 4193A are as follows:

(1) Circuit Measurement Fixture and Residual Impedance Compensation

In addition to the component measurement test fixtures explained in Section 2.3, there are also circuit measurement test fixtures for the 4193A. Fig. 3.16 (a) shows a ground adapter which measures by directly probing circuit, and Fig. 3.16 (b) shows a ground lead used when there is no ground point near the measurement point. When the circuit measurement terminal is a BNC connector, the BNC adapter shown in Fig. 3.17 is used. The BNC adapter ground can be used as an N-type ground if removed. Residual impedances can be compensated for these fixtures in the same way as for discrete component test fixtures described in Section 2.4.

Figure 3.16. Ground Adapter (a) and Ground Lead (b)

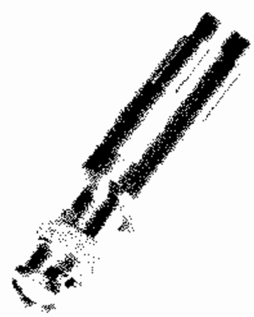


Figure 3.17. BNC Adapter

(2) Probe Withstand Voltage

When the probe is used to measure impedances in an active circuit the bias voltage of the circuit may have an adverse affect. The 4193A probe can handle up to 50V DC, and can measure almost any circuit without being damaged. However, this limit may be exceeded when measuring a circuit driven by high voltage or a high output electronic amplifier. In this case, correct measurement can be obtained without damaging the probe by using a blocking capacitor (refer to the appendix for the measurement method). Note that the AC withstand voltage of the probe is 5 Vrms.

(3) Measurement Signal Level

The 4193A measurement signal level changes according to the impedance measurement range, as listed in Table 3-2. If the range is fixed, the current level does not change regardless of the impedance measured. Therefore, a voltage equal to the product of displayed impedance value and measurement current is applied to the component being measured, and reaches its peak when the impedance value is highest.

Table 3-2. Relation between Measurement Signal Level and Impedance Range

Impedance range	10Ω	100Ω	1kΩ	10kΩ	100kΩ
Measurement current	100μA	100μA	100μA	50μA	10μA
Maximum signal level	2mV	20mV	200mV	1V	1.2V

If measured impedance value overrange (Or) is displayed, the voltage applied to the component exceeds the value in the table. This may reach 100 to 230mVrms on 10Ω to 1kΩ ranges, and 1 to 1.2Vrms on other ranges. Therefore, care must be taken when measuring voltage sensitive components. When measuring an assembled circuit, the measurement signal level must be carefully considered, especially for circuits that contain an amplifier. If the circuit saturates, or if the active point of an active element is changed drastically, the impedance may be measured under circuit conditions different from actual operating conditions. To guard against this, use an oscilloscope, and check the measurement points of the circuit before actual measurement to make sure that there is no distortion in the waveforms.

(4) Effects of Operation Signals on Circuit Measurement

When measuring circuit impedance with the 4193A, ideally, the circuit should be free from operating signals or noise. However, this is impossible for some circuits. For circuits with AC signals (e.g., active circuits such as synthesizers or signal generators), the measured value may become unstable. To obtain stable results with the 4193A despite the AC signals or noise, the following two points should be considered.

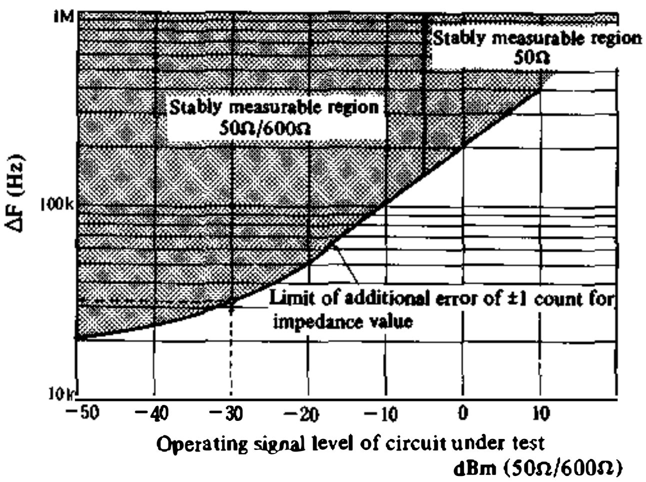
1. Difference between frequency of operating signal in the circuit and the 4193A measurement frequency.
2. Level of operating signal going through the circuit.

1. **Frequency condition**

   If the operating frequency of the circuit to be measured is too close to the 4193A measurement frequency, measured values fluctuate and the correct value cannot be obtained. Therefore, it is necessary to set a difference between them. This difference, called ΔF, changes according to the signal level of the circuit to be measured. Fig. 3.18 gives reference data indicating the relationships between signal level and ΔF. Note how much difference must be set between their frequencies when the signal level does not change. This is near the fundamental wave of the 4193A measurement signal, but also applies to harmonics. Therefore, the following harmonics and signal frequency of the circuit to be measured must have at least the ΔF shown in Fig. 3.18.

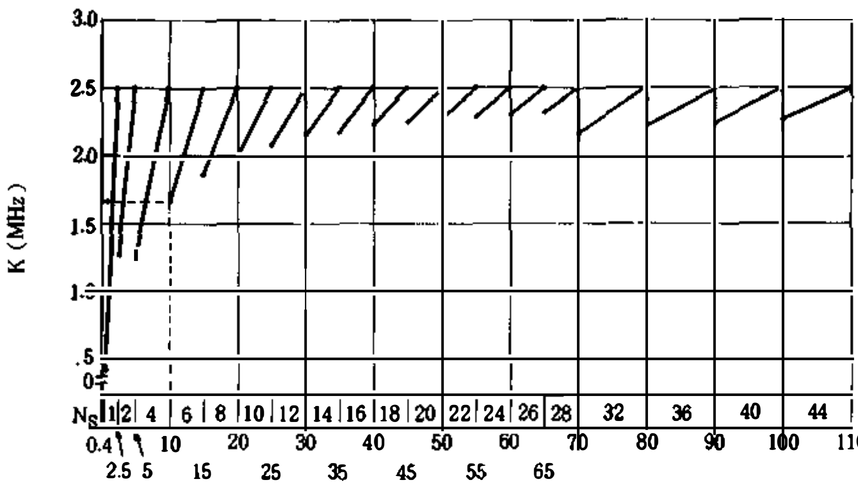
$$F = n \times K \ (n = 1, 2, \ldots) \qquad (3.7)$$

F: 4193A harmonics
K: See Fig. 3.19



(ΔF: Frequency difference between test frequency of the 4193A and operating signal frequency of circuit under test)

Figure 3.18. Relation between Minimum Frequency Difference (ΔF) and Operating Signal Level of Circuit under Test



$K = (f_s + 9.765 \times 10^{-3})/N_s$

f_s : Test frequency of the 4193A in MHz

N_s : Sampling number

Figure 3.19. Relation of Constant *K* to Test Frequency of 4193A

2. **Level of operating signal passing through circuit**
The second point necessary for stable measurement is the level of the signal passing through the circuit. The maximum allowable signal level in the circuit loosely depends on the impedance of the component to be measured, as shown in Fig. 3.20. For example, if the impedance is 10-ohm, the level of the signal passing through the circuit must be lower than −10 dBm. If higher, measurement values may fluctuate.

Check whether the following example satisfies the above condition (indicated by dashed lines in Fig. 3.18 to 3.20).

Measurement conditions:
Operating frequency .... 10MHz (assume there are no harmonics)
Operation signal level .... −30 dBm
Impedance .... 10 ohms

If the measurement is made at a frequency as close to the operating frequency as possible, ΔF is 30 to 35 kHz as calculated from Fig. 3.18. Then, suppose that the 4193A measurement frequency is set to 10.04MHz. Here, 8.3748 and 10.0498 MHz are found to be the 4193A harmonics closest to 10MHz from equation 3.7 and Fig. 3.19. These values satisfy the ΔF condition because they are more than 35 kHz away from the operating frequency, 10 MHz, of the component to be measured. Also, since the 10-ohm impedance is in the stable area of Fig. 3.20 when the operation signal is −30 dBm, stable measurement is possible at 10.04 MHz. Note that measurement is always stable if the level of a signal passing through a circuit is −80 dB or lower than the 4193A measurement signal.

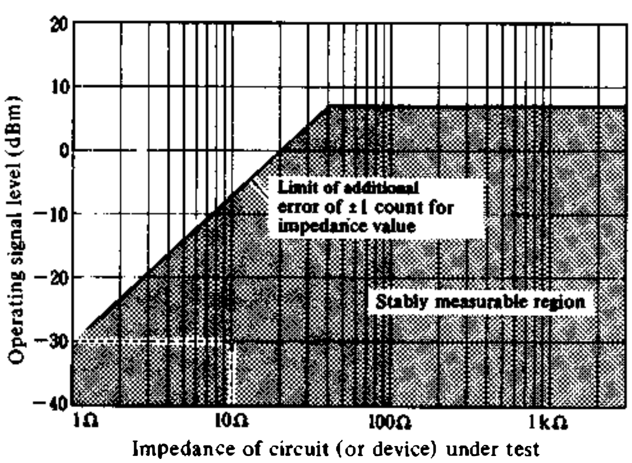


Figure 3.20. Relation between Operating Signal Level and Impedance Value of Circuit under Test

APPENDIXES

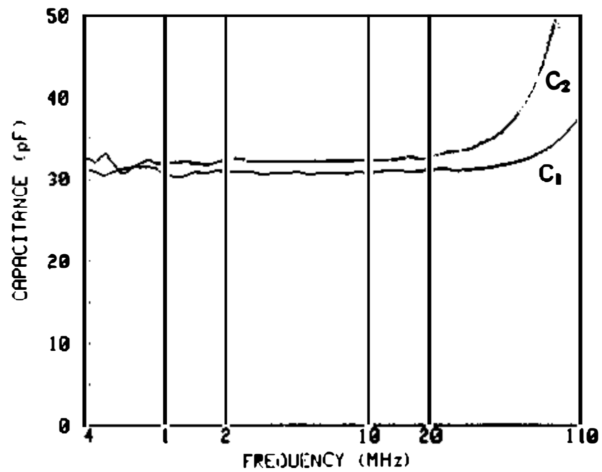
A. HP-IB System Applications

By connecting the 4193A to a controller via the HP-IB, measurement and data processing can be done automatically. The following describes a measurement example in which the residual impedance of a test fixture is compensated by a simple system structure as shown in Fig. A-1. Parameter conversion is also done. Residual impedance compensation was already explained in Section 2.4. Parameter conversion can be calculated from the 4193A measurement data ($|Z|$ and θ) given in Table A-1. Fig. A-2 (p. 16) is a flowchart for compensation and conversion using the 9845B desk-top computer, and shows six cases of representative automatic parameter conversion. The results are given in Fig. A-3. This program is very efficient because parameter conversion can be done without having to compensate for residual impedance. For a device or test fixture which does not require such compensation, parameter conversion can be done immediately.

Table A-1. Table of Parameter Conversion

Parameters	Equivalent Circuits	Symbols	Conversion equations
Series resistance		R_S	$\|Z\| \cdot \cos\theta$
Series reactance		X	$\|Z\| \cdot \sin\theta$
Conductance		G	$\cos\theta / \|Z\|$
Susceptance		B	$-\sin\theta / \|Z\|$
Series inductance		L_S	$\|Z\| \cdot \sin\theta / (2\pi f)$
Series capacitance		C_S	$-1/(2\pi f \cdot \|Z\| \cdot \sin\theta)$
Parallel inductance		L_P	$\|Z\| / (2\pi f \cdot \sin\theta)$
Parallel capacitance		C_P	$-\sin\theta / (2\pi f \cdot \|Z\|)$
Quality factor		Q	$\|\tan\theta\|$
Dissipation factor		D	$\tan\delta = \|1/\tan\theta\|$
Admittance		$\|Y\|, \theta_Y$	$\|Y\| = 1/\|Z\|,\ \theta_Y = -\theta$

f : Test frequency
$|Z|$: Impedance magnitude readings
θ : Phase readings



C_1: with residuals compensated
C_2: without compensation

Figure A-3. Effect of Residual Compensation

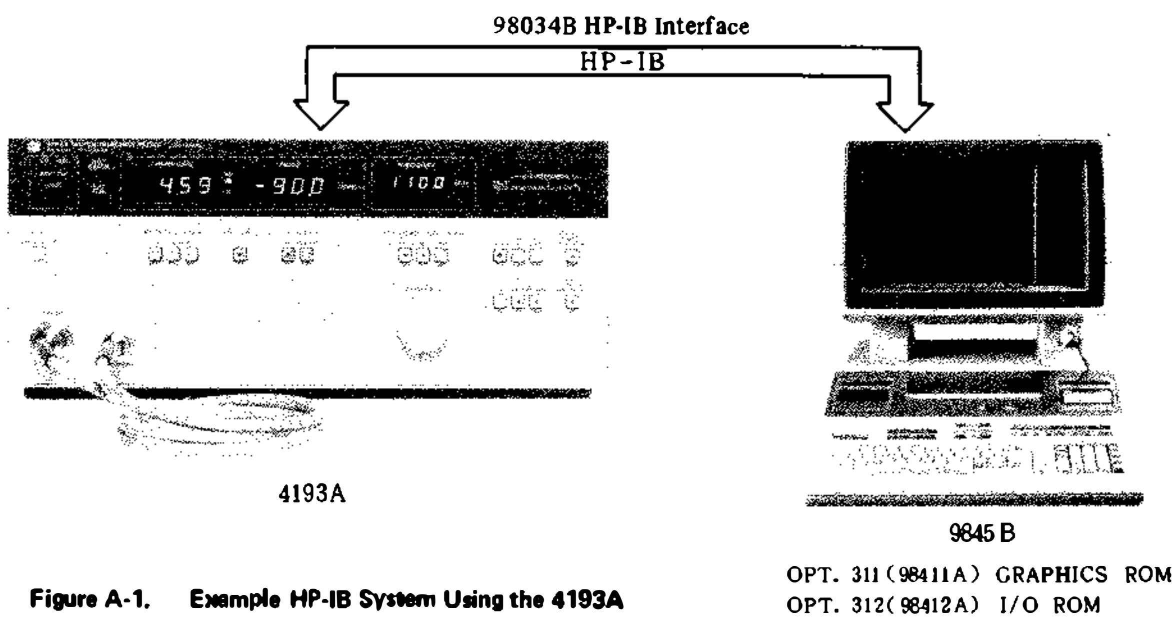


Figure A-1. Example HP-IB System Using the 4193A

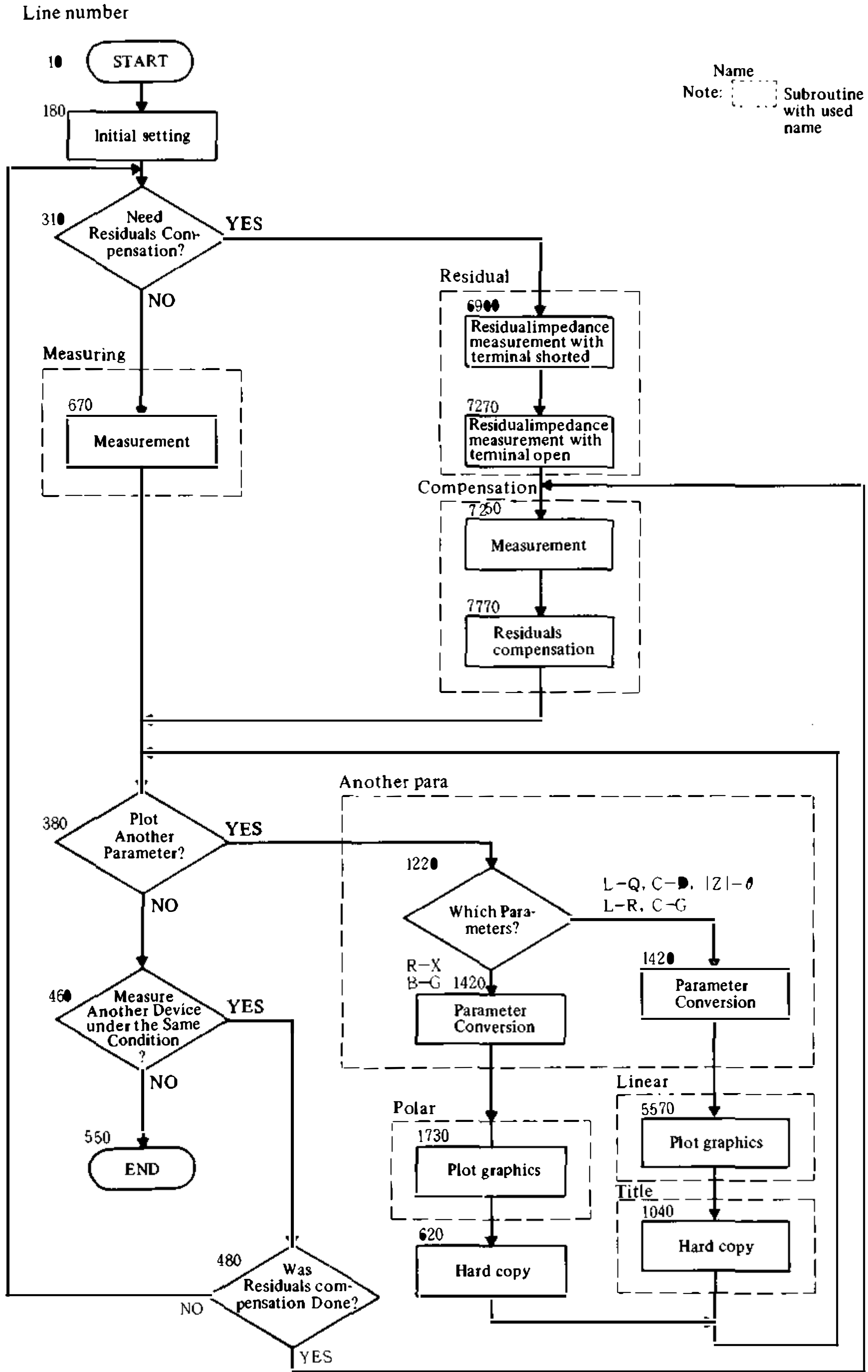


Figure A-2. Flow Chart for Residual Impedance Compensation and Parameter Conversion Program

B. Measuring Impedance of Components Biased at Over 50V DC

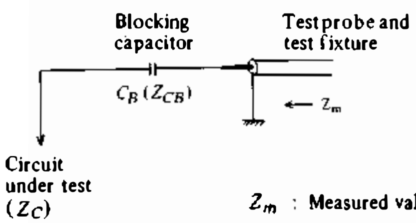
The 4193A probe can safely handle up to 50V DC or 5Vrms AC. Use the following methods for values over 50V DC to prevent damage to the probe.

(1) Circuit Measurement

If a circuit has a bias voltage of over 50V, insert a blocking capacitor (C_B) between the probe and circuit before measurement (Fig. B-1). The impedance $[1/(2\pi f\ C_B)]$ of capacitor C_B must be negligible at the measurement frequency in order to compare it with that of the circuit to be measured. Note that a 4193A measurement value includes C_B if the value is not small enough. When this occurs, apply the same voltage to be applied to the circuit to C_B, and check that it does not fail. Then measure with the 4193A to obtain the value of vector impedance Z_{CB}. After that, measure circuit impedance Z_m through capacitor C_B and compute $Z_m - Z_{CB}$ to obtain the value of component impedance Z_C.

(2) Component Measurement

When measuring a component with a voltage over 50V, use the bias circuit shown in Fig. B-2. Here, the impedance of capacitor C_B must be negligible as described in (1). If the C_B impedance is too large, compensate in the same way as described in (1). Conversely, the impedance, $\sqrt{R^2 + \omega^2 L^2}$, of the bias circuit must be sufficiently large in comparison with that of the component, because the two are in parallel.



Z_m : Measured value

Z_{CB} : Impedance of blocking capacitor

Z_C : Impednace of circuit under test

$|Z_{CB}| = 1/2\pi f C_B$ (f: Test frequency)

when the impedance of blocking capacitor is negligible compared to that of circuit under test:

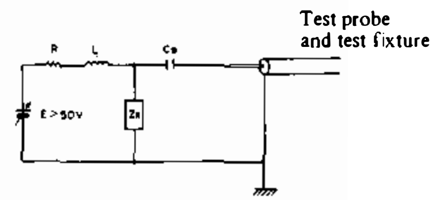
$(|Z_{CB}| \ll |Z_C|)$

$$Z_C \simeq Z_m$$

when the impedance of blocking capacitor is not negligible:

$$Z_C = Z_m - Z_{CB}$$

Figure B-1. Measurement of Active Circuits Biased at Over 50V DC



Z_x : Impedance of device under test

C_B : Blocking capacitor

R, L : Series resistance and inductance for bias voltage source

$|Z_{CB}| = 1/2\pi f C_B$ (f: Test frequency)

Condition that the measured value is equal to the impedance value of DUT is as follows:

$$|Z_{CB}| \ll |Z_x|$$

$$\sqrt{R^2 + (2\pi f L)^2} \gg |Z_x|$$

Figure B-2. Measurement of Components Biased at Over 50VDC

C. How to Increase Test Frequency Resolution (External Synthesizer Application)

The 4193A frequency resolution is 4 digits, but must be improved when measuring high Q devices, such as crystals. The frequency resolution can be improved by connecting an external synthesizer to the 4193A as shown in Fig. C-1. The external synthesizer affects only the frequency resolution. The measurement signal level and other characteristics are all determined by the 4193A. It is best to make the synthesizer frequency as close to that of the 4193A as possible, but, for the absolute impedance value $|Z|$, a difference of 10 MHz or less is small enough for accurate measurement. The phase should be compensated using the following equation.

$$\theta_r = \theta_m + 0.72\ (f_0 - f_1)$$

f_0 : 4193A set frequency in MHz
f_1 : External synthesizer set frequency in MHz
θ_m : 4193A display value
θ_r : Compensated real phase value

The limit of frequency resolution provided by an external synthesizer depends on the residual FM in the 4193A internal synthesizer (Fig. C-2).

Notes

If a synthesizer capable of generating a frequency of 110 MHz or over is connected, the 4193A may be able to measure up to 140 MHz. Also, if a synthesizer with higher frequency resolution than residual FM in the 4193A internal synthesizer us used, measurement is possible with lower frequency resolution than residual FM. In this case, however, accuracy of the measured value cannot be guaranteed.

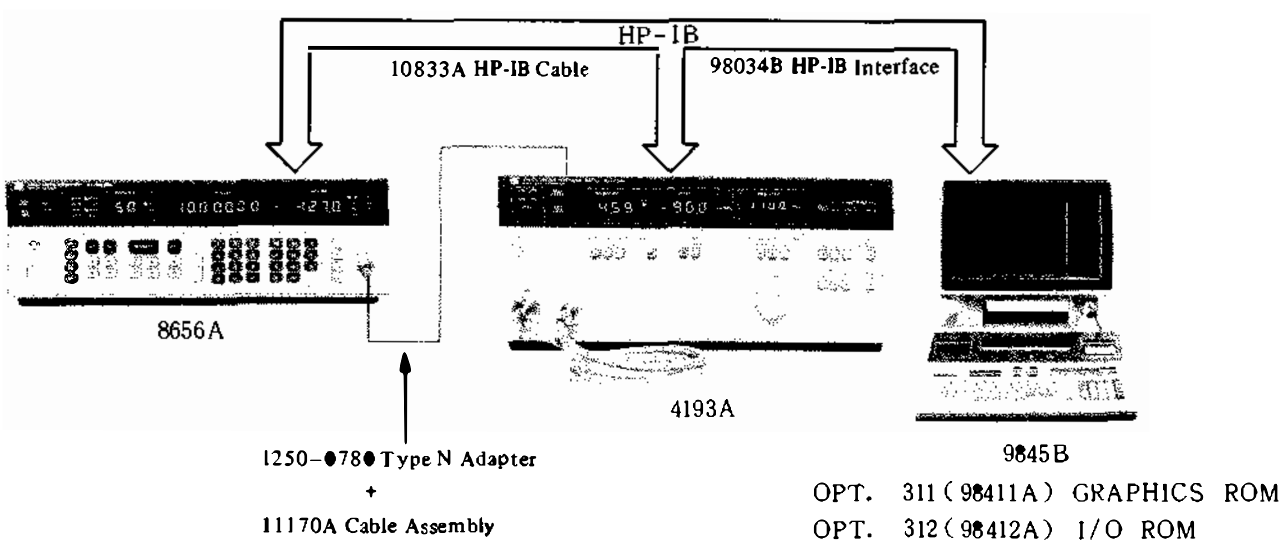


Figure C-1. How to Connect an External Synthesizer

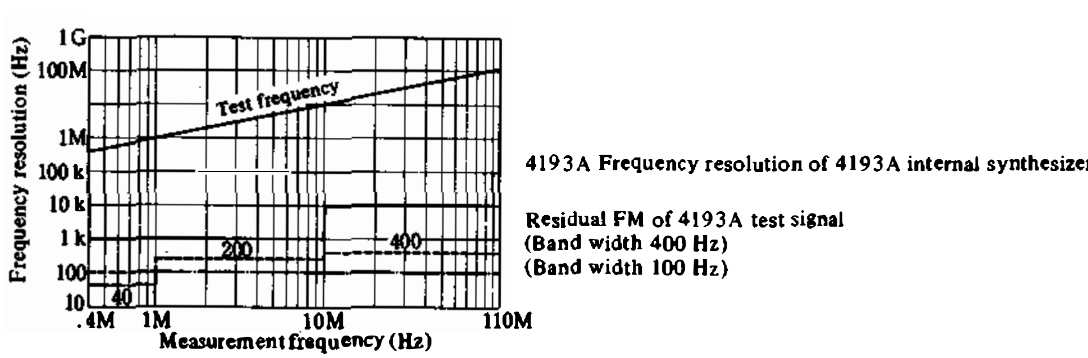


Figure C-2. Residual FM of Test Signal of 4193A

Sample Program Listings for 9845B (Residual Impedance Compensation and Parameter Conversion)

```
10    ! Tape              : 4193A APPLICATION (9845B)
20    ! File Name         : 4193AN
30    ! Application       : Residuals Compensation and Parameter Conversion
40    ! Auther            : Yasuo Satoh & M.O.     Date : JUNE 12,1982
50    ! Revision          : REV.    DATE          NOTE              .
60    !                      A      24FEB2        1st Edition
61    !                      B      12JUN2        2nd Edition
70    ! Linked Program    : none
80    ! Special Function Key File : none
90    ! Instrumentation :          MODEL-OPTION                ADDRESS.
100   !       Instrument  : 4193A Vector Impedance Meter         Z=717
110   !       Controller  : 9845B T W/#312, 980048                 7
120   !       Output      : CRT of 9845B/T
130   !
140   !
150   ! 4193A MEASURING TEST/4193A
160   !
170   !
180   STANDARD
190   Z=717    ! HP-IB ADDRESS CODE
200   Z1=16    ! PRINTER SELECT CODE
210   BEEP
220   INPUT "Input PRINTER SELECT CODE. (PRINTER =0,CRT=16)",Z1
230   V=Z1
240   PRINTER IS V
250   DIM A(1002),B(1002),C(1002),D(1002),E(1002),F(1002),G(1002),H(1002),I(1002
),J(1002),K(1002),L(1002),M(1002),N(1002),O(1002),P(1002),A$[30]
260   REMOTE Z
270   CLEAR Z
280   EXIT GRAPHICS
290   OUTPUT Z;"FMT2W3T1A1H1"
300   BEEP
310   INPUT "Need RESIDUALS COMPENSATION ? (Yes=1,No=0)",Y
320   IF Y=0 THEN 360
330   GOSUB Residual
340   GOSUB Compensation
350   GOTO 370
360   GOSUB Measuring
370   BEEP
380   IF Another=0 THEN INPUT "Do you need plot? (YES=1,NO=0)",K
381   IF Another=0 THEN 390
382   IF Another<>0 THEN INPUT "Plot another parameter? (YES=1,NO=0)",Another
390   EXIT GRAPHICS
400   T1=-1E20
410   T2=1E20
420   S1=-1E20
430   S2=1E20
440   IF (K=1) OR (Another=1) THEN GOTO 560
450   BEEP
460   INPUT "Measure ANOTHER DEVICE under the same condition ? (YES=1,NO=0)",P1
470   BEEP
480   IF P1=1 THEN INPUT "Measured the RESIDUALS ? (YES=1,NO=0)",K9
490   IF P1=0 THEN 540
500   IF K9=1 THEN GOSUB Compensation
510   IF K9=0 THEN GOTO 300
520   IF P1=0 THEN 540
521   IF Another<>0 THEN 381
530   GOTO 380
540   PRINT "Measurement completed."
550   END
560   B=0
561   K=0
565   Another=0
570   GOSUB Anotherpara
580   PLOTTER IS 13,"GRAPHICS"
590   GRAPHICS
600   IF (B=1) OR (B=2) THEN GOSUB Polar
610   IF (B=3) OR (B=4) OR (B=5) OR (B=6) OR (B=7) THEN GOSUB Linear
620   IF (B=1) OR (B=2) THEN DUMP GRAPHICS
630   IF (B=1) OR (B=2) THEN GOTO 380
640   GOSUB Title
641 Another=Another+1
650   GOTO 380
660   ! ************************* MEASURING ***********************************
670 Measuring:  OUTPUT Z;"FMT2A1H1T2W3"
680   BEEP
690   INPUT "Input DUT name (UP TO 30 CHARACTERS)",A$
700   BEEP
710   INPUT "Select SWEEP MODE. (PARTIAL=1,FULL=2)",W
720   IF W=2 THEN 900
730   BEEP
740   INPUT "Input START,STOP FREQ., in MHz.",F1,F2
750   IF F2>F1 THEN 800
760   BEEP
770   DISP "START FREQ. is higher than STOP FREQ. Press  CONT ."
780   PAUSE
790   GOTO 740
800   BEEP
810   INPUT "Input NUMBER OF STEPS ; 100 or 1000",F3
820   IF (F3=100) OR (F3=1000) THEN 860
830   DISP "NUMBER OF STEPS is incorrect. Press  CONT ."
840   PAUSE
850   GOTO 810
860   IF F3=1000 THEN 890
870   OUTPUT Z;"TF",F1,"EN","PF",F2,"EN","P1"
880   GOTO 900
890   OUTPUT Z;"TF",F1,"EN","PF",F2,"EN","P2"
900   IF W=2 THEN F1=.4
910   IF W=2 THEN F2=110
920   EXIT GRAPHICS
930   IF W=2 THEN F3=42
940   OUTPUT Z;"W",W
950   N=0
960   FOR I=1 TO F3+1
970  TRIGGER Z
980   ENTER Z;A11,A22,C(I),D(I),E11,P,F(I)
990   N=N+1
1000  DISP "Measuring"
1010  IF F(I)>=F2+1E6 THEN 1030
1020  NEXT I
1030  RETURN
1040 Title: ! *************** TITLE *******************************************
*
1050   PEN 1 ! *** PEN COLOR for TITLE ***
1060  SCALE -.2,1.2,-.2,1.2
1070  CLIP 0,1,0,1
1080  MOVE .5,1.15
1090  LORG 4
1100  IF LEN(A$)>10 THEN 1140
1110  CSIZE 6,.5
1120  LABEL "FREQUENCY CHARACTERISTICS for ";A$
1130  GOTO 1180
1140  CSIZE 6,.5
1150  LABEL "FREQUENCY CHARACTERISTICS for "
1160  MOVE .5,1.05
1170  LABEL A$
1180  PEN 0
1190   DUMP GRAPHICS
1200  RETURN
1210  ! ************************* ANOTHER  PARAMETER *************************
1220 Anotherpara:      PRINT "PARAMETER COMBINATION MENU"
1230  PRINT "PARAMETER","NUMBER"
1240  PRINT "   R-X   ","   1"
1250  PRINT "   G-B   ","   2"
1260  PRINT "   L-Q   ","   3"
1270  PRINT "   C-D   ","   4"
1280  PRINT "   L-R   ","   5"
1290  PRINT "   C-G   ","   6"
```

```
1300  PRINT "|Z|-PHASE","  ?"
1310  BEEP
1320  INPUT "Input PARAMETER COMBINATION NUMBER.",B
1330  GCLEAR
1340  FIXED 3
1350  IF B=1 THEN PRINT "STEP No.","FREQUENCY (MHz)","RESISTANCE (OHM)","REACTAN
CE (OHM)"
1360  IF B=2 THEN PRINT "STEP No.","FREQUENCY (MHz)","CONDUCTANCE (mS)","SUSCEPT
ANCE (mS)"
1370  IF B=3 THEN PRINT "STEP No.","FREQUENCY (MHz)","INDUCTANCE (uH)","QUALITY
FACTOR"
1380  IF B=4 THEN PRINT "STEP No.","FREQUENCY (MHz)","CAPACITANCE (pF)","DISSIPA
TION"
1390  IF B=5 THEN PRINT "STEP No.","FREQUENCY (MHz)","INDUCTANCE (uH)","RESISTAN
CE(OHM)"
1400  IF B=6 THEN PRINT "STEP No.","FREQUENCY (MHz)","CAPACITANCE (pF)","CONDUCT
ANCE (mS)"
1410  IF B=7 THEN PRINT "STEP No.","FREQUENCY (MHz)","MAGNITUDE (OHM)","PHASE (D
EGREE)"
1420  FOR I=1 TO N
1430  IF B=1 THEN A(I)=C(I)*COS(D(I))
1440  IF B=2 THEN A(I)=COS(D(I))/C(I)*1000
1450  IF B=3 THEN A(I)=C(I)*SIN(D(I))/2/PI/F(I)*1E6
1460  IF B=4 THEN A(I)=-1E12/2/PI/C(I)/SIN(D(I))/F(I)
1470  IF B=5 THEN A(I)=C(I)*SIN(D(I))/2/PI/F(I)*1E6
1480  IF B=6 THEN A(I)=-1E12/2/PI/C(I)/SIN(D(I))/F(I)
1490  IF B=7 THEN A(I)=C(I)
1500  IF B=1 THEN B(I)=C(I)*SIN(D(I))
1510  IF B=2 THEN B(I)=-SIN(D(I))/C(I)*1000
1520  IF (B=3) AND (COS(D(I))=0) THEN B(I)=ABS(SIN(D(I)))/1E-3
1530  IF (B=3) AND (COS(D(I))=0) THEN 1590
1540  IF B=3 THEN B(I)=ABS(SIN(D(I)))/ABS(COS(D(I)))
1550  IF B=4 THEN B(I)=TAN(ABS(90-ABS(D(I))))
1560  IF B=5 THEN B(I)=C(I)*COS(D(I))
1570  IF B=6 THEN B(I)=COS(D(I))/C(I)*1000
1580  IF B=7 THEN B(I)=D(I)
1590  IF T1<A(I) THEN T1=A(I)
1600  IF T2>A(I) THEN T2=A(I)
1610  IF S1<B(I) THEN S1=B(I)
1620  IF S2>B(I) THEN S2=B(I)
1630  PRINT I,F(I)/1E6,A(I),B(I)
1640  NEXT I
1650  PRINT "------------------------------------------------------------------------"
1660  PRINT "MAXIMUM=",,"A=";T1,"B=";S1
1670  PRINT "MINIMUM=",,"A=";T2,"B=";S2
1680  BEEP
1690  INPUT "Input MAXIMUM and MINIMUM value of A for graphic scaling",K1,K2
1700  INPUT "Input MAXIMUM and MINIMUM value of B for graphic scaling",L1,L2
1710  STANDARD
1720  RETURN
1730 Polar: ! +++++++++++++++ POLAR ++++++++++++++++!
1740  SCALE K2-(K1-K2)*.2,K1+(K1-K2)*.2,L2-(L1-L2)*.2,L1+(L1-L2)*.2
1750  CLIP K2,K1,L2,L1
1760  FRAME
1770  IF (K1<0) AND (L1<0) THEN 1870
1780  IF (K1<0) AND ((L2>0) OR (L2=0)) THEN 2190
1790  IF (K1>0) AND ((L1>0) OR (L1=0)) AND (L2<0) THEN 2530
1800  IF ((K2>0) OR (K2=0)) AND (L1<0) THEN 3040
1810  IF ((K2>0) OR (K2=0)) AND ((L2>0) OR (L2=0)) THEN 3370
1820  IF ((K2<0) OR (K2=0)) AND ((L1>0) OR (L1=0)) AND (L2<0) THEN 3700
1830  IF ((K1>0) OR (K1=0)) AND (K2<0) AND ((L2>0) OR (L2=0)) THEN 4100
1840  IF ((K1<0) OR (K1=0)) AND (K2<0) AND (L1<0) THEN 4490
1850  IF ((K1>0) OR (K1=0)) AND (K2<0) AND ((L1>0) OR (L1=0)) AND (L2<0) THEN 48
90
1860  ! +++++++++++++++++++  K1<0 AND L1<0  +++++++++++++++++++++++++++++++++++
1870  AXES (K1-K2)/10,(L1-L2)/10,K2,L2
1880  MOVE (K1+K2)/2,L2-(L1-L2)*.2
1890  CSIZE 4,.5
1900  DEG
1910  LORG 4
1920  GOSUB Name
1930  FOR I=0 TO 10 STEP 2
1940  MOVE K2+I*(K1-K2)/10,L2-(L1-L2)*.01
1950  CSIZE 4,.5
1960  LORG 6
1970  IF K2<-499 THEN 2000
1980  LABEL K2+I*(K1-K2)/10
1990  GOTO 2010
2000  LABEL (K2+I*(K1-K2)/10)/1000
2010  NEXT I
2020  MOVE K2-(K1-K2)*.2,(L1+L2)/2
2030  CSIZE 4,.5
2040  LDIR 90
2050  DEG
2060  LORG 6
2070  GOSUB Naming
2080  LDIR 0
2090  FOR I=0 TO 10 STEP 2
2100  MOVE K2-(K1-K2)*.01,L2+I*(L1-L2)/10
2110  CSIZE 4,.5
2120  LORG 8
2130  IF L2<-499 THEN 2160
2140  LABEL L2+I*(L1-L2)/10
2150  GOTO 2170
2160  LABEL (L2+I*(L1-L2)/10)/1000
2170  NEXT I
2180  GOTO 5350
2190  ! ++++++++++++++++++++ K1<0 AND L2>=0 ++++++++++++++++++++++++++
2200  AXES (K1-K2)/10,(L1-L2)/10,K2,L2
2210  MOVE (K1+K2)/2,L2-(L1-L2)*.2
2220  CSIZE 4,.5
2230  DEG
2240  LORG 4
2250  GOSUB Name
2260  FOR I=0 TO 10 STEP 2
2270  MOVE K2+I*(K1-K2)/10,L2-(L1-L2)*.01
2280  CSIZE 4,.5
2290  LORG 6
2300  IF K2<-499 THEN 2330
2310  LABEL K2+I*(K1-K2)/10
2320  GOTO 2340
2330  LABEL (K2+I*(K1-K2)/10)/1000
2340  NEXT I
2350  MOVE K2-(K1-K2)*.2,(L1+L2)/2
2360  CSIZE 4,.5
2370  LDIR 90
2380  DEG
2390  LORG 6
2400  GOSUB Naming
2410  LDIR 0
2420  FOR I=0 TO 10 STEP 2
2430  MOVE K2-(K1-K2)*.01,L2+I*(L1-L2)/10
2440  CSIZE 4,.5
2450  LORG 8
2460  IF L2<-499 THEN 141
2470  LABEL L2+I*(L1-L2)/10
2480  GOTO 2500
2490  LABEL (L2+I*(L1-L2)/10)/1000
2500  NEXT I
2510  GOTO 5350
2520  ! +++++++++++++++ K1<0 AND L1>=0 AND L2<0 +++++++++++++++++
2530  AXES (K1-K2)/10,(L1-L2)/10,K1,0
2540  MOVE K2+(K1-K2)*.01,(L2-L1)/20
2550  CSIZE 4,.5
2560  DEG
2570  LORG 3
2580  GOSUB Name
2590  FOR I=0 TO 10 STEP 2
2600  MOVE K2+I*(K1-K2)/10,(L2-L1)*.01
2610  CSIZE 4,.5
2620  LORG 6
2630  IF K2<-499 THEN 2660
```

```
2640 LABEL K2+I*(K1-K2)/10
2650 GOTO 2670
2660 LABEL (K2+(K1-K2)*I/10)/1000
2670 NEXT I
2680 MOVE K1+(K1-K2)*.2,(L1+L2)/2
2690 CSIZE 4,.5
2700 LDIR 90
2710 DEG
2720 LORG 4
2730 GOSUB Naming
2740 LDIR 0
2750 FOR I=0 TO 10*L1/(L1-L2) STEP 2
2760 MOVE K1+(K1-K2)*.01,I*(L1-L2)/10
2770 CSIZE 4,.5
2780 LORG 2
2790 IF (L2<-499) OR (L1>499) THEN 2820
2800 LABEL I*(L1-L2)/10
2810 GOTO 2830
2820 LABEL I*(L1-L2)/10/1000
2830 NEXT I
2840 MOVE K1+(K1-K2)*.01,L1
2850 IF L1>499 THEN 2870
2860 LABEL L1
2870 GOTO 2890
2880 LABEL L1/1000
2890 FOR I=0 TO 10*L2/(L1-L2) STEP -2
2900 MOVE K1+(K1-K2)*.01,I*(L1-L2)/10
2910 CSIZE 4,.5
2920 LORG 2
2930 IF (L2<-499) OR (L1>499) THEN 2960
2940 LABEL I*(L1-L2)/10
2950 GOTO 2970
2960 LABEL I*(L1-L2)/10000
2970 NEXT I
2980 MOVE K1+(K1-K2)*.01,L2
2990 IF L2<-499 THEN 3020
3000 LABEL L2
3010 GOTO 3030
3020 LABEL L2/1000
3030 GOTO 5350
3040 ! ++++++++++++++++++++ K2<=0 AND L1>0 ++++++++++++++++++++++++
3050 AXES (K1-K2)/10,(L1-L2)/10,K2,L2
3060 MOVE (K1+K2)/2,L2-(L1-L2)*.2
3070 CSIZE 4,.5
3080 DEG
3090 LORG 4
3100 GOSUB Name
3110 FOR I=0 TO 10 STEP 2
3120 MOVE K2+I*(K1-K2)/10,L2-(L1-L2)*.01
3130 CSIZE 4,.5
3140 LORG 6
3150 IF K1>499 THEN 3180
3160 LABEL K2+I*(K1-K2)/10
3170 GOTO 3190
3180 LABEL (K2+I*(K1-K2)/10)/1000
3190 NEXT I
3200 MOVE K2-(K1-K2)*.2,(L1+L2)/2
3210 CSIZE 4,.5
3220 LDIR 90
3230 DEG
3240 LORG 6
3250 GOSUB Naming
3260 LDIR 0
3270 FOR I=0 TO 10 STEP 2
3280 MOVE K2-(K1-K2)*.01,L2+I*(L1-L2)/10
3290 CSIZE 4,.5
3300 LORG 8
3310 IF L2<-499 THEN 3340
3320 LABEL L2+I*(L1-L2)/10
3330 GOTO 3350
3340 LABEL (L2+I*(L1-L2)/10)/1000
3350 NEXT I
3360 GOTO 5350
3370 ! ++++++++++++++++++++ K2>=0 AND L2>0 ++++++++++++++++++++++++
3380 AXES (K1-K2)/10,(L1-L2)/10,K2,L2
3390 MOVE (K1+K2)/2,L2-(L1-L2)*.2
3400 CSIZE 4,.5
3410 DEG
3420 LORG 4
3430 GOSUB Name
3440 FOR I=0 TO 10 STEP 2
3450 MOVE K2+I*(K1-K2)/10,L2-(L1-L2)*.01
3460 CSIZE 4,.5
3470 LORG 6
3480 IF K1>499 THEN 3510
3490 LABEL K2+I*(K1-K2)/10
3500 GOTO 3520
3510 LABEL (K2+I*(K1-K2)/10)/1000
3520 NEXT I
3530 MOVE K2-(K1-K2)*.2,(L1+L2)/2
3540 CSIZE 4,.5
3550 LDIR 90
3560 DEG
3570 LORG 6
3580 GOSUB Naming
3590 LDIR 0
3600 FOR I=0 TO 10 STEP 2
3610 MOVE K2-(K1-K2)*.01,L2+I*(L1-L2)/10
3620 CSIZE 4,.5
3630 LORG 8
3640 IF L1>499 THEN 3670
3650 LABEL L2+I*(L1-L2)/10
3660 GOTO 3680
3670 LABEL (L2+I*(L1-L2)/10)/1000
3680 NEXT I
3690 GOTO 5350
3700 ! ++++++++++++++++++++ K2>=0 AND L1<=0 AND L2<0 ++++++++++++++++++++++++
3710 AXES (K1-K2)/10,(L1-L2)/10,K2,0
3720 MOVE K1-(K1-K2)*.01,(L2-L1)*.1
3730 CSIZE 4,.5
3740 DEG
3750 LORG 9
3760 GOSUB Name
3770 FOR I=0 TO 10 STEP 2
3780 MOVE K2+I*(K1-K2)/10,(L2-L1)*.03
3790 CSIZE 4,.5
3800 LORG 6
3810 IF K1>499 THEN 3840
3820 LABEL K2+I*(K1-K2)/10
3830 GOTO 3850
3840 LABEL (K2+I*(K1-K2)/10)/1000
3850 NEXT I
3860 MOVE K2-(K1-K2)*.2,(L1+L2)/2
3870 CSIZE 4,.5
3880 LDIR 90
3890 DEG
3900 LORG 6
3910 GOSUB Naming
3920 LDIR 0
3930 FOR I=0 TO L1/(L1-L2)*10 STEP 2
3940 MOVE K2-(K1-K2)*.01,I*(L1-L2)/10
3950 CSIZE 4,.5
3960 LORG 8
3970 IF (L2<-499) OR (L1>499) THEN 4000
3980 LABEL I*(L1-L2)/10
3990 GOTO 4010
4000 LABEL I*(L1-L2)/10/1000
4010 NEXT I
4020 FOR I=0 TO L2*10/(L1-L2) STEP -2
4030 MOVE K2-(K1-K2)*.01,I*(L1-L2)/10
4040 IF L2<-499 THEN 4070
4050 LABEL I*(L1-L2)/10
```

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4060 GOTO 4080
4070 LABEL I*(L1-L2)/10000
4080 NEXT I
4090 GOTO 5350
4100 ! ++++++++++++++++++ K1>=0 AND K2<0 AND L2<=0 ++++++++++++++++++
4110 AXES (K1-K2)/10,(L1-L2)/10,0,L2
4120 MOVE (K1+K2)/2,L2-(L1-L2)*.2
4130 CSIZE 4,.5
4140 LORG 4
4150 GOSUB Name
4160 FOR I=0 TO K1*10/(K1-K2) STEP 2
4170 MOVE I*(K1-K2)/10,L2-(L1-L2)*.01
4180 CSIZE 4,.5
4190 LORG 6
4200 IF (K1>499) OR (K2<-499) THEN 4230
4210 LABEL I*(K1-K2)/10
4220 GOTO 4240
4230 LABEL I*(K1-K2)/10/1000
4240 NEXT I
4250 FOR I=0 TO K2*10/(K1-K2) STEP -2
4260 MOVE I*(K1-K2)/10,L2-(L1-L2)*.01
4270 IF K2<-499 THEN 4300
4280 LABEL I*(K1-K2)/10
4290 GOTO 4310
4300 LABEL I*(K1-K2)/10000
4310 NEXT I
4320 MOVE .03*(K2-K1),L1-(L1-L2)*.01
4330 CSIZE 4,.5
4340 LDIR 90
4350 DEG
4360 LORG 7
4370 GOSUB Naming
4380 LDIR 0
4390 FOR I=0 TO 10 STEP 2
4400 MOVE (K2-K1)*.02,L2+I*(L1-L2)/10
4410 CSIZE 4,.5
4420 LORG 8
4430 IF L1>499 THEN 4460
4440 LABEL L2+I*(L1-L2)/10
4450 GOTO 4470
4460 LABEL (L2+I*(L1-L2)/10)/1000
4470 NEXT I
4480 GOTO 5350
4490 ! ++++++++++++++++ K1<=0 AND K2<0 AND L1<0 +++++++++++++++
4500 AXES (K1-K2)/10,(L1-L2)/10,0,L2
4510 MOVE (K1+K2)/2,L2-(L1-L2)*.2
4520 CSIZE 4,.5
4530 DEG
4540 LORG 4
4550 GOSUB Name
4560 FOR I=0 TO K1*10/(K1-K2) STEP 2
4570 MOVE I*(K1-K2)/10,L2-(L1-L2)*.05
4580 CSIZE 4,.5
4590 LORG 4
4600 IF (K2<-499) OR (K1>499) THEN 4630
4610 LABEL I*K1/10
4620 GOTO 4640
4630 LABEL I*K1/10/1000
4640 NEXT I
4650 FOR I=0 TO K2*10/(K1-K2) STEP -2
4660 MOVE I*(K1-K2)/10,L2-(L1-L2)*.05
4670 IF K2>499 THEN 4700
4680 LABEL I*K2/10
4690 GOTO 4710
4700 LABEL I*K2/10000
4710 NEXT I
4720 MOVE .05*(K1-K2),L2+(L1-L2)*.1
4730 CSIZE 4,.5
4740 LDIR 90
4750 DEG
4760 LORG 1
4770 GOSUB Naming
4780 LDIR 0
4790 FOR I=0 TO 10 STEP 2
4800 MOVE .03*(K2-K1),L2+I*(L1-L2)/10
4810 CSIZE 4,.5
4820 LORG 8
4830 IF L2<-499 THEN 4860
4840 LABEL L2+I*(L1-L2)/10
4850 GOTO 4870
4860 LABEL (L2+I*(L1-L2)/10)/1000
4870 NEXT I
4880 GOTO 5350
4890 ! +++++++++++ K1>=0 AND K2<0 AND L1>=0 AND L2<0 ++++++++++++
4900 AXES (K1-K2)/10,(L1-L2)/10,0,0
4910 MOVE K1-(K1-K2)*.01,(L2-L1)*.05
4920 CSIZE 4,.5
4930 DEG
4940 LORG 7
4950 GOSUB Name
4960 FOR I=0 TO K1*10/(K1-K2) STEP 2
4970 MOVE I*(K1-K2)/10,(L1-L2)*.03
4980 CSIZE 4,.5
4990 LORG 4
5000 IF K1>499 THEN 5030
5010 LABEL I*(K1-K2)/10
5020 GOTO 5040
5030 LABEL I*(K1-K2)/10/1000
5040 NEXT I
5050 FOR I=0 TO K2*10/(K1-K2) STEP -2
5060 MOVE I*(K1-K2)/10,(L1-L2)*.03
5070 IF K2<-499 THEN 5100
5080 LABEL I*(K1-K2)/10
5090 GOTO 5110
5100 LABEL I*(K1-K2)/10000
5110 NEXT I
5120 MOVE .05*(K1-K2),L1-(L1-L2)*.01
5130 CSIZE 4,.5
5140 LDIR 90
5150 DEG
5160 LORG 7
5170 GOSUB Naming
5180 LDIR 0
5190 FOR I=0 TO L1*10/(L1-L2) STEP 2
5200 MOVE .03*(K2-K1),I*(L1-L2)/10
5210 CSIZE 4,.5
5220 LORG 8
5230 IF L1>499 THEN 5260
5240 LABEL I*(L1-L2)/10
5250 GOTO 5270
5260 LABEL I*(L1-L2)/10/1000
5270 NEXT I
5280 FOR I=0 TO L2*10/(L1-L2) STEP -2
5290 MOVE .03*(K2-K1),I*(L1-L2)/10
5300 IF L2<-499 THEN 5330
5310 LABEL I*(L1-L2)/10
5320 GOTO 5340
5330 LABEL I*(L1-L2)/10000
5340 NEXT I
5350 ! --------------------- PLOT ----------------------
5360 MOVE A(1),B(1)
5370 FOR I=1 TO N
5380 DRAW A(I),B(I)
5390 NEXT I
5400 RETURN
5410 Name: ! ---------------- NAMING -----------------------
5420  IF (K2<-499) OR (K1>499) THEN 5460
5430  IF B=1 THEN LABEL "RESISTANCE (OHM)"
5440  IF B=2 THEN LABEL "CONDUCTANCE (mS)"
5450  GOTO 5480
5460  IF B=1 THEN LABEL "RESISTANCE (KOHM)"
5470  IF B=2 THEN LABEL "CONDUCTANCE (S)"
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```
5480    RETURN
5490    ! ==================== NAMING ==========================!
5500 Naming:IF (L2<-499) OR (L1>499) THEN 5540
5510    IF B=1 THEN LABEL "REACTANCE (OHM)"
5520    IF B=2 THEN LABEL "SUSCEPTANCE (mS)"
5530    GOTO 5560
5540    IF B=1 THEN LABEL "REACTANCE (KOHM)"
5550    IF B=2 THEN LABEL "SUSCEPTANCE (S)"
5560    RETURN
5570 Linear: ! ++++++++++++++++++ LINEAR ++++++++++++++++++++++++++++++++++
5580    BEEP
5590    INPUT "LOG PLOT OR LINEAR PLOT FOR FREQUENCY. (LOG=0,LINEAR=1)",A
5600    SCALE -.2,1.2,K2-(K1-K2)*.2,K1+(K1-K2)*.2
5610    CLIP 0,1,K2,K1
5620    IF A=1 THEN GOSUB Frequency
5630    IF A=1 THEN 5890
5640    IF (K1<0) OR (K2>0) THEN 5670
5650    AXES 0,(K1-K2)/10,0,0
5660    GOTO 5680
5670    AXES 0,(K1-K2)/10,0,K2
5680    FRAME
5690    FOR I=0 TO 5
5700    IF I=0 THEN X=.4
5710    IF I=1 THEN X=1
5720    IF I=2 THEN X=2
5730    IF I=3 THEN X=10
5740    IF I=4 THEN X=20
5750    IF I=5 THEN X=110
5760    IF X>F2 THEN X=F2
5770    IF X<F1 THEN X=F1
5780    MOVE (LGT(X)-LGT(F1))/(LGT(F2)-LGT(F1)),K1
5790    DRAW (LGT(X)-LGT(F1))/(LGT(F2)-LGT(F1)),K2
5800    MOVE (LGT(X)-LGT(F1))/(LGT(F2)-LGT(F1)),K2-(K1-K2)*.01
5810    CSIZE 4,.5
5820    LORG 6
5830    LABEL X
5840    NEXT I
5850    MOVE .5,K2-(K1-K2)*.2
5860    CSIZE 4,.5
5870    LORG 4
5880    LABEL "FREQUENCY (MHz)"
5890    LORG 8
5900    IF (K2>0) OR (K1<0) THEN 6130
5910    FOR I=0 TO K1*10/(K1-K2) STEP 2
5920    MOVE -.01,I*(K1-K2)/10
5930    LABEL I*(K1-K2)/10
5940    NEXT I
5950    FOR I=0 TO K2*10/(K1-K2) STEP -2
5960    MOVE -.01,I*(K1-K2)/10
5970    LABEL I*(K1-K2)/10
5980    NEXT I
5990    MOVE -.01,K1
6000    LABEL K1
6010    MOVE -.01,K2
6020    LABEL K2
6030    MOVE -.2,(K1+K2)/2
6040    DEG
6050    LDIR 90
6060    LORG 6
6070    CSIZE 4,.5
6080    IF (B=3) OR (B=5) THEN LABEL "INDUCTANCE (uH)"
6090    IF (B=4) OR (B=6) THEN LABEL "CAPACITANCE (pF)"
6100    IF B=7 THEN LABEL "IMPEDANCE (OHM)"
6110    LDIR 0
6120    GOTO 6470
6130    FOR I=0 TO 10 STEP 2
6140    MOVE -.01,K2+(K1-K2)/10*I
6150    LABEL K2+(K1-K2)/10*I
6160    NEXT I
6170    GOTO 6030
6180    SCALE -.2,1.2,L2-(L1-L2)*.2,L1+(L1-L2)*.2
6190    CLIP 0,1,L2,L1
6200    IF B=7 THEN AXES 0,(L1-L2)/18,1,(L1+L2)/2
6210    GOTO 6230
6220    AXES 0,(L1-L2)/10,1,L2
6230    LORG 2
6240    CSIZE 4,.5
6250    IF B=7 THEN 6310
6260    FOR I=0 TO 10 STEP 2
6270    MOVE 1.01,L2+I*(L1-L2)/10
6280    LABEL L2+I*(L1-L2)/10
6290    NEXT I
6300    GOTO 6350
6310    FOR I=0 TO 6
6320    MOVE 1.01,L2+I*(L1-L2)/6
6321    FIXED 1
6330    LABEL L2+I*(L1-L2)/6
6340    NEXT I
6350    DEG
6360    LDIR 90
6370    CSIZE 4,.5
6380    LORG 4
6390    MOVE 1.2,(L1+L2)/2
6400    IF B=3 THEN LABEL "QUALITY FACTOR"
6410    IF B=4 THEN LABEL "DISSIPATION"
6420    IF B=5 THEN LABEL "RESISTANCE (OHM)"
6430    IF B=6 THEN LABEL "CONDUCTANCE (mS)"
6440    IF B=7 THEN LABEL "PHASE (DEGREE)"
6450    LDIR 0
6460    GOTO 6560
6470    ! ------------------ PLOT ----------------
6480    MOVE 0,A(1)
6490    LINE TYPE 1
6500    FOR I=1 TO N
6510    IF A=0 THEN F=(LGT(F(I)/1E6)-LGT(F1))/(LGT(F2)-LGT(F1))
6520    IF A=1 THEN F=(F(I)/1E6-F1)/(F2-F1)
6530    DRAW F,A(I)
6540    NEXT I
6550    GOTO 6180
6560    MOVE 0,B(1)
6570    LINE TYPE 7
6580    FOR I=1 TO N
6590    IF A=0 THEN F=(LGT(F(I)/1E6)-LGT(F1))/(LGT(F2)-LGT(F1))
6600    IF A=1 THEN F=(F(I)/1E6-F1)/(F2-F1)
6610    DRAW F,B(I)
6620    NEXT I
6630    LINE TYPE 1
6640    RETURN
6650    ! XXXXXXXXXXXXXXXXXXXXX FREQUENCY XXXXXXXXXXXXXXXXXXXXXXXXX!
6660 Frequency:  IF (K1<=0) OR (K2>=0) THEN 6690
6670    AXES .1,(K1-K2)/10,0,0
6680    GOTO 6700
6690    AXES .1,(K1-K2)/10,0,K2
6700    FRAME
6710    IF K1*K2>=0 THEN MOVE .5,K2-(K1-K2)*.2
6720    IF K1*K2<0 THEN MOVE .5,(K2-K1)*.1
6730    LORG 4
6740    CSIZE 4,.5
6750    LABEL "FREQUENCY (MHz)"
6760    IF K1*K2>=0 THEN 6830
6770    LORG 4
6780    FOR I=0 TO 10 STEP 2
6790    MOVE I/10,(K1-K2)*.01
6800    LABEL F1+(F2-F1)*I/10
6810    NEXT I
6820    GOTO 6880
6830    LORG 6
6840    FOR I=0 TO 10 STEP 2
6850    MOVE I/10,K2-(K1-K2)*.01
6860    LABEL F1+(F2-F1)*I/10
6870    NEXT I
6880    RETURN
```

```
6890  ! ------------------- RESIDUAL COMPENSATION ------------------ !
6900 Residual:     BEEP
6910  DEG
6920  DISP "Short the test fixture terminals. Then press  CONT ."
6930  PAUSE
6940  BEEP
6950  INPUT "Select SWEEP MODE. (PARTIAL=1,FULL=2)",W
6960  IF W=2 THEN 7100
6970  BEEP
6980  INPUT "Input START,STOP FREQ.,in MHz.",F1,F2
6990  IF F1 F2 THEN 7040
7000  BEEP
7010  DISP "START FREQ.is higher than STOP FREQ. Press  CONT ."
7020  PAUSE
7030  GOTO 6980
7040  BEEP
7050  INPUT "Input NUMBER OF STEPS : 100 OR 1000.",F3
7060  IF F3=1000 THEN 7090
7070  OUTPUT Z;"TF",F1,"EN","PF",F2,"EN","P1"
7080  GOTO 7100
7090  OUTPUT Z;"TF",F1,"EN","PF",F2,"EN","P2"
7100  IF W=2 THEN F=.4
7110  IF W=2 THEN F2=110
7120  IF W=2 THEN F3=42
7130  EXIT GRAPHICS
7140  IF W=2 THEN 7170
7150  OUTPUT Z;"W1"
7160  GOTO 7180
7170  OUTPUT Z;"W2"
7180  DISP "Measuring"
7190  FOR I=1 TO F3+1
7200  TRIGGER Z
7210  ENTER Z;A,A,I(I),J(I),A,A,F(I)
7220  ! PRINT I,I(I),J(I),F(I)
7230  IF J(I)<-90 THEN J(I)=-89.9
7240  N=N+1
7250  IF F(I)=F2*1E6 THEN 7280
7260  NEXT I
7270  ! ==================== OPEN MEASUREMENT ==================!
7280  BEEP
7290  DISP "Connect nothing to the test fixture terminals. Then press  CONT ."
7300  PAUSE
7310  DISP "Measuring"
7320  IF W=2 THEN 7370
7330  IF F3=1000 THEN 7360
7340  OUTPUT Z;"TF",F1,"EN","PF",F2,"EN","P1"
7350  GOTO 7370
7360  OUTPUT Z;"TF",F1,"EN","PF",F2,"EN","P2"
7370  IF W=2 THEN F1=.4
7380  IF W=2 THEN F2=110
7390  IF W=2 THEN F3=42
7400  IF W=2 THEN 7430
7410  OUTPUT Z;"W1"
7420  GOTO 7440
7430  OUTPUT Z;"W2"
7440  N=0
7450  FOR I=1 TO F3+1
7460  TRIGGER Z
7470  ENTER Z;A,A,O(I),P(I),A,A,F(I)
7480  N=N+1
7490  IF F(I)=F2*1E6 THEN 7501
7500  NEXT I
7501  Resdata=1
7510  RETURN
7520 Compensation: ! ================ DUT MEASUREMENT ================!
7530  BEEP
7531  IF Resdata  0 THEN 7540
7532  DISP "CAUTION : NO RESIDUAL DATA. Press  CONT "
7533  PAUSE
7534  Resdata=Resdata+1
7535  GOSUB Residual
7540  OUTPUT Z;"H1"
7550  DISP "Connect DUT to the test fixture terminal. Then press  CONT ."
7555  PAUSE
7560  INPUT "Input DUT name (UP TO 30 CHARACTERS)",A$
7570  IF W=2 THEN 7620
7580  IF F3=1000 THEN 7610
7590  OUTPUT Z;"TF",F1,"EN","PF",F2,"EN","P1"
7600  GOTO 7620
7610  OUTPUT Z;"TF",F1,"EN","PF",F2,"EN","P2"
7620  IF W=2 THEN F1=.4
7630  IF W=2 THEN F2=110
7640  IF W=2 THEN F3=42
7650  IF W=2 THEN 7690
7660  OUTPUT Z;"W1"
7670  GOTO 7690
7680  OUTPUT Z;"W2"
7690  N=0
7700  FOR I=1 TO F3+1
7710  TRIGGER Z
7720  ENTER Z;A,A,G(I),H(I),A,A,F(I)
7730  DISP "Measuring"
7740  N=N+1
7750  IF F(I)=F2*1E6 THEN 7770
7760  NEXT I
7770  ! --------------- RESIDUAL COMPENSATION ---------------
7780   FIXED 3
7790   PRINT "STEP No.","FREQUENCY (MHz)","MAGNITUDE (OHMS)","PHASE (DEGREE)"
7800   FOR I=1 TO F3+1
7810   K(I)=O(I)*G(I)*(O(I)*COS(H(I))-G(I)*COS(P(I)))/((O(I)*(I(I)...
N(P(I)))^2)
7820   L(I)=O(I)*COS(H(I))-G(I)*COS(P(I))...
7830   M(I)=O(I)*SIN(H(I))-G(I)*SIN(P(I))...
7840   C(I)=SQR(M(I)^2+L(I)^2)
7850   IF L(I)=0 THEN L(I)=.01
7851   IF (SGN(L(I))=1) AND (SGN(M(I))=1) THEN 7860
7852   IF (SGN(L(I))=1) AND (SGN(M(I))=-1) THEN 7860
7853   D(I)=ATN(M(I)/L(I))-180
7854   GOTO 7870
7860   D(I)=ATN(M(I)/L(I))
7870   PRINT I,F(I)/1E6,C(I),D(I)
7880   IF T<C(I) THEN T=C(I)
7890   IF S<ABS(D(I)) THEN S=ABS(D(I))
7900   NEXT I
7910   STANDARD
7920   RETURN
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HEWLETT PACKARD

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