# Errata

**Document Title:** Input-output Impedance and Reflection Coefficient Measurements (AN 339-10)

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# Application Note 339-10

# Input/Output Impedance and Reflection Coefficient Measurements

## - HP 4194A Impedance Gain-Phase Analyzer -

## Introduction

Designing electronic circuits involves interconnecting basic circuit building blocks (amplifiers, filters, etc.), and a network circuit is formed at the interface (connection point), of the circuit building blocks. The impedance of each circuit component and the circuit impedance/transmission characteristics of these interface network circuits must be evaluated if the intended circuit characteristics are to be obtained. These characteristics must be measured quickly and precisely in order to minimize development time and cost. Especially, the input/output impedance or reflection coefficients of grounded circuits should be measured when evaluating impedance matching characteristics.

The HP 4194A has the ability to measure the impedance of components and the transmission characteristics of circuits, making evaluating impedance matching characteristics a snap. The HP 4194A when combined with the HP 41941A/B Impedance Probe Kit can measure the impedance of grounded circuits over a frequency range of 10kHz to 100MHz with an accuracy of ±1.5%. The reflection coefficient and return loss can be derived using the HP 4194A's internal programming function (ASP).

As an example, the technique for measuring the Input/Output impedance and reflection coefficient of a negative feedback configuration amplifier will be described.

## Measuement Requirements and the HP 4194A's Solutions

### * Precise Measurement of Circuit Impedance

Evaluating circuit impedance requires making ground referenced measurements, which in the past have been performed using network analyzers with directional bridges. The problem has been that it is difficult to precisely measure the impedance of grounded devices.

With its powerful calibration capability using 0Ω, 0S, 50Ω standards, the HP 4194A combined with the HP 41941A/B features a superior measurement accuracy of ±1.5% for grounded measurements over a frequency range of 10kHz to 100MHz.

### * Reflection Coefficient, Return Loss Calculation, and Automatic Evaluation

The reflection coefficient and return loss can also be obtained, using the HP 4194A's internal math function, from the measured impedance measurement data. The measurement data and the calculated data can be displayed in three formats on the HP 4194A's color display as you choose, e.g., impedance vs. frequency, reflection coefficient vs. frequency, $\Gamma_x$ vs. $\Gamma_y$ characteristics by using the Auto Sequence Program (ASP) function. In addition, the HP 4194A gives you automatic evaluation capabilities of circuit impedance through impedance measurement, reflection coefficient calculation, and plotting without an external computer.

Thus, you can evaluate circuits by measuring and calculating input/output impedance, reflection coefficient and return loss.

### Input/Output Impedance Measurements

Input/Output impedance measurements are useful for evaluating circuit performance as a function of frequency and signal level when two circuits are interfaced.

After calibration, you can probe devices directly using the impedance probe as shown in Figure 1.

A typical example of an input impedance measurement of a negative feedback amplifier using the HP 4194A with the HP 41941A/B is shown in Figure 2 (the output impedance characteristics are shown in Figure 3). Hard copies are easily obtained by performing a direct dump to a plotter or printer. The input impedance of this circuit is approximately 50Ω. Therefore the test circuit should be designed for 50Ω matching so as not to cause reflections.

The HP 4194A can quickly measure circuit impedances and display the measurement data to improve efficiency of measurements and analysis.

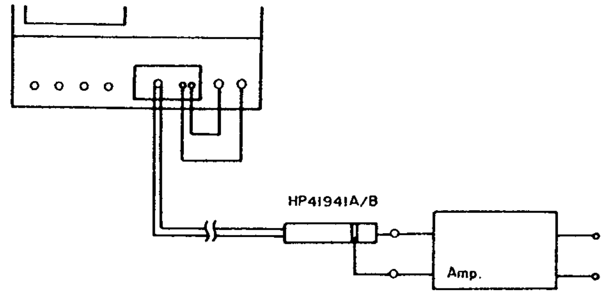


Figure 1. Measurement Setup
(HP 4194A + HP 41941A/B)

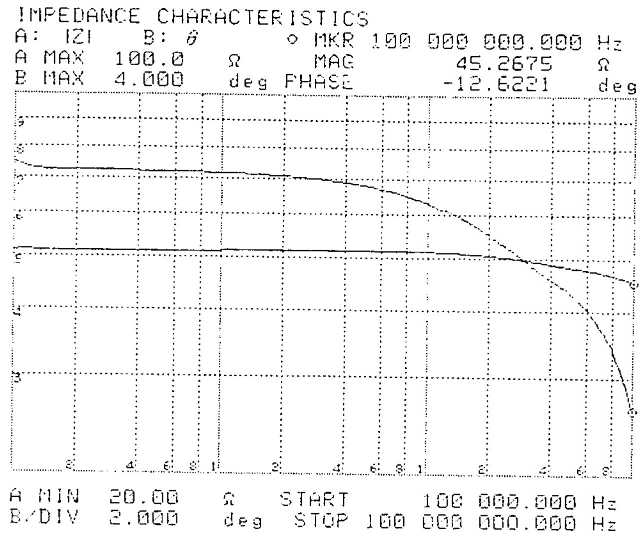


Figure 2. Input Impedance Characteristics

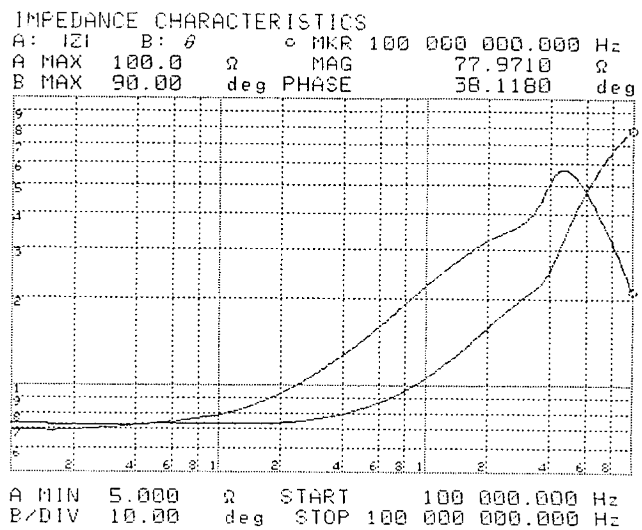


Figure 3. Output Impedance Characteristics

## Reflection Coefficient and Return Loss Derivation Using ASP

The reflection coefficient and return loss are computed using the following equations:

$$\Gamma = \frac{e_R}{e_I} = \frac{Z_2 - Z_1}{Z_2 + Z_1} = \Gamma_X + j\Gamma_Y$$

Return Loss = $-20\log|\Gamma|$

Where:

- $\Gamma$ = Voltage reflection coefficient
- $e_R$ = Reflected wave
- $e_I$ = Incident wave
- $Z_1$ = Output impedance (characteristics) of transmitting side
- $Z_2$ = Input impedance of receiving side
- $\Gamma_X$ = Real part of $\Gamma_V$
- $\Gamma_Y$ = Imaginary part of $\Gamma_V$

ASP was used to compute the reflection coefficient shown in Figure 4. The $\Gamma_X$-$\Gamma_Y$ characteristics of a negative feedback amplifier obtained using the HP 4194A's ASP function are shown in Figure 5. The $|\Gamma|$-f characteristics are shown in Figure 6, and the return loss characteristics are shown in Figure 7, and these can also be automatically displayed. The ASP subroutine shown in Figure 4 sets the impedance to 50Ω. The reflection coefficient in Figure 6 indicates a value close to zero, or very little reflection.

The HP 4194A's Marker function is used to read values at a specific frequency when analyzing these characteristics.

```
10 ! INPUT/OUTPUT IMPEDANCE MEASUREMENTS
20 RST
30 BEEP
40 DISP "SETUP INPUT Z MEASUREMENT"
50 PAUSE
60 CMT"INPUT IMPEDANCE CHARACTERISTICS"
70 FNC3;SWT2;ASC2;ITM2;OSC=0 DBM
80 SWTRG
90 AUTO;RA=A;RB=B
100 BEEP
110 DISP "SETUP OUTPUT Z MEASUREMENT"
120 PAUSE
130 CMT"OUTPUT IMPEDANCE CHARACTERISTICS"
140 SWTRG
150 AUTO;RC=A;RD=B
160 BEEP
170 DISP "SETUP GAMMA MEASUREMENTS"
180 PAUSE
190 CMT"GAMMA CHART"
200 UNIT0;DSP2;ASC1
210 AMAX=1;AMIN=-1;BMAX=1;BMIN=-1
220 FOR R0=1 TO 401
230  C(R0)=SIN(.9*R0);D(R0)=COS(.9*R0)
240 NEXT R0
250 SPAB1
260 E=RA*COS(RB)
270 F=RA*SIN(RB)
280 G=(E+50)*(E+50)+F*F;H=E*E+F*F-2500
290 RE=H/G;RF=(F*100)/G;A=RE;B=RF
300 BEEP
310 DISP "PRESS <CONT>"
320 CMT"GAMMA VS FREQUENCY"
330 PAUSE
340 DPB0;DSP1
350 RG=SQR(RE*RE+RF*RF);A=RG
360 AMAX=1;AMIN=0;BMAX=1;BMIN=0
370 BEEP
380 DISP "PRESS <CONT>"
390 PAUSE
400 CMT"RETURN LOSS VS FREQUENCY"
410 RH=-20*LOG(RG)
420 AUTO
430 BEEP
440 DISP "END"
450 END
```

Figure 4. ASP Reflection Coefficient Program

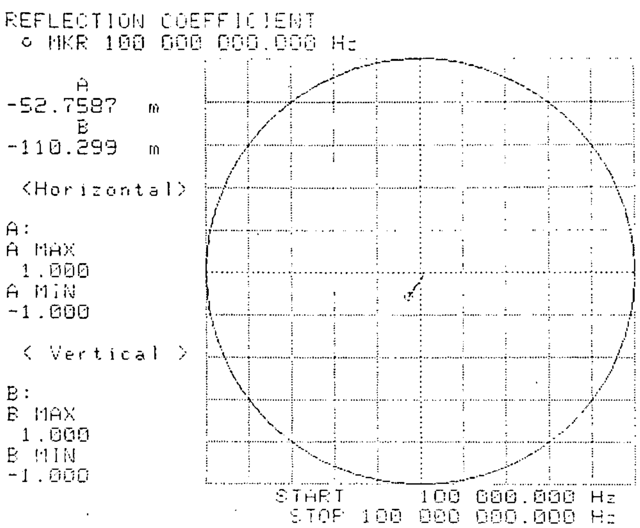


Figure 5. Γx-Γy Characteristics

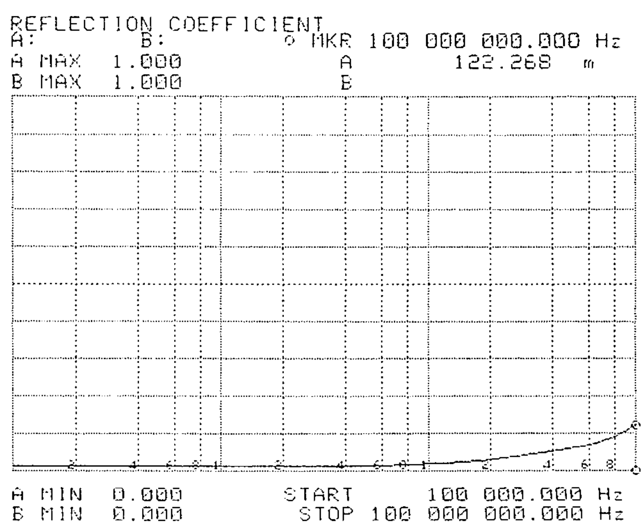


Figure 6. |Γ|-F Characteristics

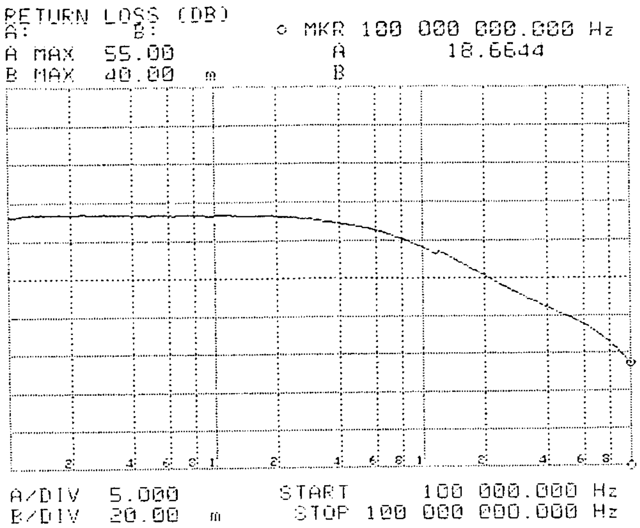


Figure 7. Return Loss

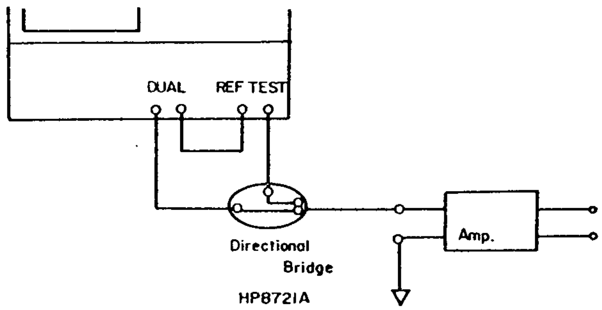


Figure 8. Measurement Setup

(HP 4194A + HP 8721A)

## Conclusion

Reflection coefficient measurements are made possible by combining the HP 8721A Directional bridge with the HP 4194A and making Gain-Phase measurements (See Figure 8). The impedance probe function with 0Ω/0S/50Ω compensation is available to reduce the error due to the directional bridge.

You can select the evaluation method appropriate for measuring and calculating the impedance characteristics, reflection coefficient, and return loss. The high measurement accuracy, the wide measurement capabilities, and the ASP programming function of the HP 4194A and 41941A/B combination will reduce the development time and cost, and the investment needed for making complex Input/Output impedance & reflection coefficient measurements and calculations.

For more information, call your local HP sales office listed in the telephone directory white pages. Ask for the Electronic Instrument Department, or write to Hewlett-Packard: **U.S.A.** - P.O. Box 10301, Palo Alto, CA 94303-0890. **Europe** - Hewlett-Packard S.A., P.O. Box 529, 1180 AM Amstelveen, The Netherlands. **Canada** - 6877 Goreway Drive, Mississauga, L4V 1M8, Ontario. **Japan** - Yokogawa-Hewlett-Packard Ltd., 3-29-21, Takaido-Higashi, Suginami-ku, Tokyo 168. **Far East** - Hewlett-Packard Asia Headquarters, 47/F China Resources Building, 26 Harbour Road, Wanchai Hong Kong. **Australasia** - Hewlett-Packard Australia Ltd., 31-41 Joseph Street, Blackburn, Victoria 3130 Australia. **Latin America** - Hewlett-Packard Latin America Headquarters, 3495 Deer Creek Rd., Palo Alto, CA 94304. For all other areas, please write to: Hewlett-Packard Intercontinental Headquarters, 3495 Deer Creek Rd., Palo Alto, CA 94304.

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