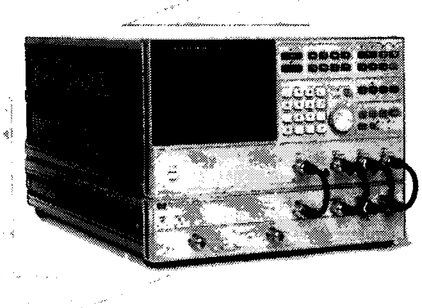

LOOP GAIN MEASUREMENTS WITH THE HP 3577A NETWORK ANALYZER

Measurement of loop gain provides useful insight into the operation of a negative feedback circuit. When properly derived, such measurements can verify desired bandwidth and flatness, as well as such stability parameters as gain and phase margin. This note describes several techniques for making these measurements, utilizing the HP 3577A Network Analyzer.

Conventional Approach

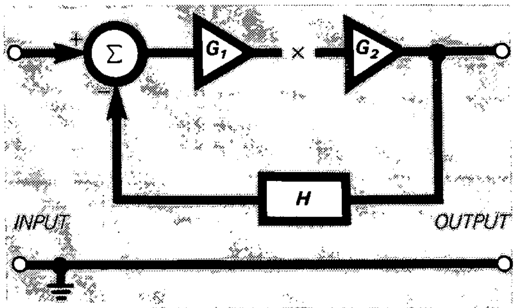

figure 1

In a typical feedback amplifier, such as shown in figure 1, loop gain is defined as G_1G_2H, the product of the feedforward and feedback paths. Loop gain can be measured quite simply by opening the loop at a point such as "X", applying a signal to amplifier G_2 and measuring the output of amplifier G_1. Because the location for "X" is theoretically unimportant, the loop can be opened wherever is most convenient.

For such a measurement to be valid, G_1 must be terminated in the load that it normally sees when the loop is closed. This could involve a simple resistive load, or it could require that a special network be designed to provide the proper complex impedance over the frequency range of interest.

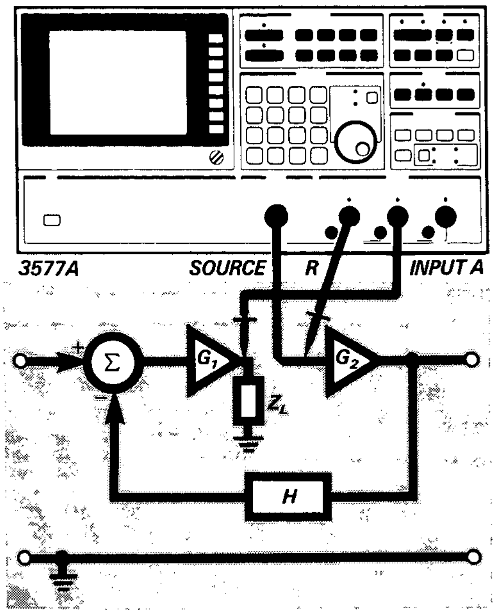

figure 2

INPUT : A/R

DISPLY FCN : LOG MAG (TRACE 1)
PHASE (TRACE 2)

FREQ : (AS REQUIRED)

AMPTD : (AS REQUIRED)

Once the circuit is configured, the 3577A can easily make the required measurements, with loop gain being simply the transfer function of the series-connected stages. As shown in figure 2, drive the input node with the analyzer's source, and monitor points X and Y with analyzer inputs R and A, respectively. To avoid disturbing the device under test, the use of high impedance probes is recommended. Standard X1 or X10 oscilloscope probes can be used in conjunction with the analyzer's 1 megaohm inputs, or active probes such as the HP 1120A can be employed.

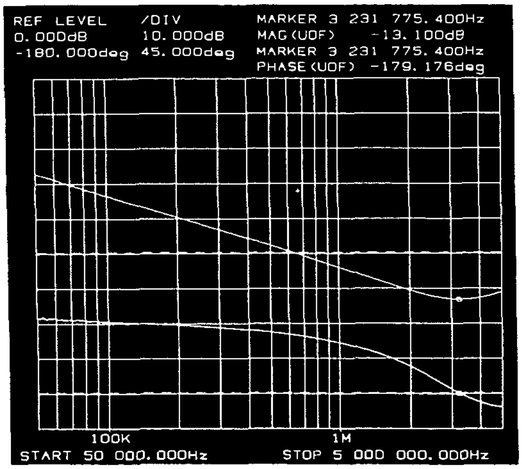

figure 3

In the example above, the dual trace display of the analyzer has been used to plot both the gain and phase of the circuit under test. The measurement shows a gain margin of 13 dB, that is, a loop gain of -13 dB at the frequency where the phase response is -180 degrees. In other words, at the frequency where the feedback becomes positive, there is 13 dB too little gain to support oscillation. The same plot also shows that the phase margin (measured at the unity gain frequency) is about 75 degrees.

Closed Loop Approaches

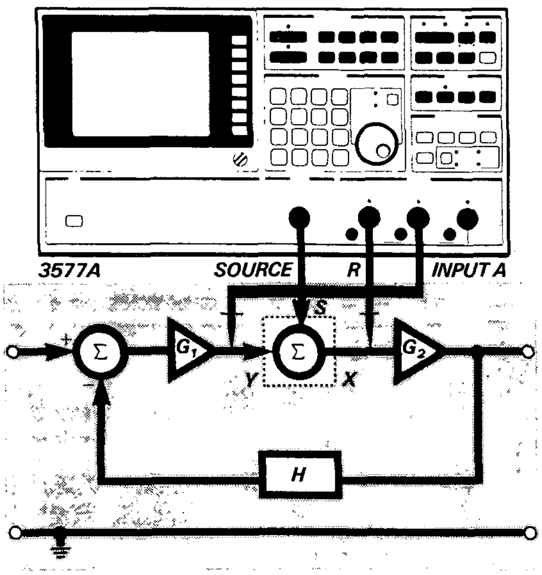

figure 4

INPUT *(USER DEFINED):* ***A/R * K1***

DISPLY FCN *:* ***LOG MAG (TRACE 1)***
PHASE (TRACE 2)

FREQ *:* ***(AS REQUIRED)***

AMPTD *:* ***(AS REQUIRED)***

DEFINE MATH *:* ***K1 (REAL) – 1.000***
K1 (IMAG) 0.000

Unfortunately, some systems cannot operate with their feedback loops opened in the manner just described. Power supplies, for example, will tend to produce high output voltages when feedback is disconnected, potentially damaging internal circuitry or tripping over-voltage protectors.

In these cases, loop gain can be measured without opening the loop, as shown in figure 4. With a test signal coupled into the circuit as shown, loop gain is again measured as the ratio of stimulus (input to G_2) to response (output from G_1).

Coupling the test stimulus into the loop is probably the hardest part of this approach. The test signal must be added to the loop at frequencies and amplitudes appropriate to the device under test, all without substantially altering the gain or frequency response of the loop.

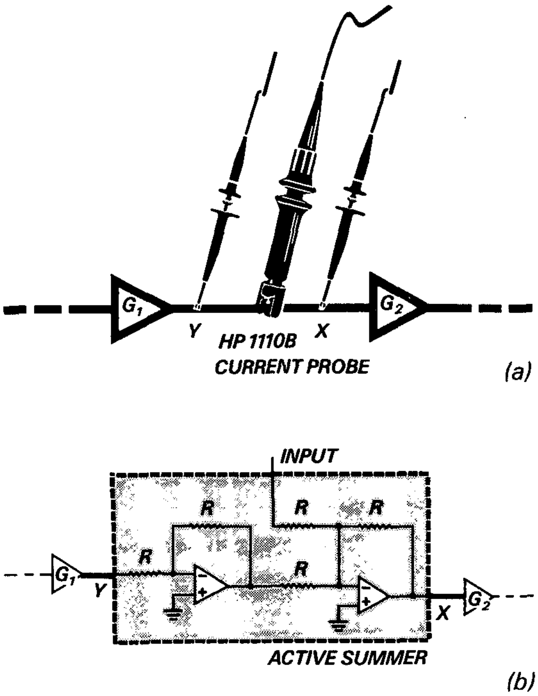

figure 5 Closed loop signal injection schemes

In some applications, a current probe such as the HP 1110B can be used to magnetically couple a signal into the circuit. The probe is clipped directly around a wire at some point where loop signals are confined to a single path. Its low output impedance (<.01 ohm) guarantees a minimum of disturbance to the circuit under test. The probe can then be driven from the analyzer's source output, with the anayzer inputs connected directly to the circuit on either side of the probe.

Limitations to the current probe technique are as follows:

1. In order to work properly, the probe must be used at a point where the driving impedance is quite low compared to the load impedance. A point between two amplifier stages will usually fit this requirement.

2. Because the probe is an inductive device, its response rolls off sharply at low frequencies. Test signal coupling becomes quite poor below about 1 kHz.

3. The efficiency of this current injection scheme is generally poor. In order to couple enough signal into the loop for an adequate signal to noise ratio, it may be necessary to pass the pickup wire through the probe cavity several times.

It may also be possible to add an active summing junction to the feedback loop, as shown in figure 5b. With care, such a circuit can be designed for use from DC to many megahertz. As suggested previously, it is necessary for this circuit to have unity gain, flat frequency response and minimal phase delay over the range of frequencies measured. Insert the summer into the loop and connect the analyzer inputs to points X and Y.

The major drawback to this approach is the added complexity of building an appropriate summing circuit and physically adding it to the device under test.

For both techniques, the choice of signal levels is quite important. With too high a stimulus level, individual loop stages may saturate, especially at frequencies where gain is high. With too little stimulus, the actual input signal (channel R) may drop below the noise level. With the 3577A, signal to noise ratio can be improved by using vector averaging or a narrower receiver bandwidth.

APPENDIX: Feedback Analysis —A Mathematical Basis

Given the general feedback circuit of figure 4, we can write the expression for the signal at point Y:

$$Y(f) = [S(f) + Y(f)] \times G_2(f) \times H(f) \times (-1) \times G_1(f)$$

therefore,

$$\frac{Y(f)}{S(f) + Y(f)} = -G_1(f)\,G_2(f)\,H(f).$$

But $S(f) + Y(f) = X(f)$, so

$$\frac{Y(f)}{X(f)} = -G_1(f)\,G_2(f)\,H(f),$$

the basis for the loop gain measurements described herein. The minus sign causes the phase of A/R to be offset by a constant 180 degrees, which can be readily corrected with the 3577A's vector math. Note that the equation for Y(f) assumes that stimulus signal S(f) appears entirely across the input to G_2 (i.e. none is absorbed by G_1). Hence, only summing techniques with some inherent isolation (such as those described above) should be used.

For more information, call your local HP sales office listed in the telephone directory white pages. Ask for the Electronic Instruments Department. Or write to Hewlett-Packard: U.S.A. - P.O. Box 10301, Palo Alto, CA 94303-0890. Europe - P.O. Box 999, 1180 AZ 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. Elsewhere in the world, write to Hewlett-Packard Intercontinental, 3495 Deer Creek Road, Palo Alto, CA 94304.

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