Errata

Title & Document Type: Loop Gain Measurements with the 3577A Network Analyzer
Product Note 3577A-2

Manual Part Number: 3577-5131

Revision Date: March 1983

HP References in this Manual

This manual may contain references to HP or Hewlett-Packard. Please note that Hewlett-Packard's former test and measurement, semiconductor products and chemical analysis businesses are now part of Agilent Technologies. We have made no changes to this manual copy. The HP XXXX referred to in this document is now the Agilent XXXX. For example, model number HP8648A is now model number Agilent 8648A.

About this Manual

We’ve added this manual to the Agilent website in an effort to help you support your product. This manual provides the best information we could find. It may be incomplete or contain dated information, and the scan quality may not be ideal. If we find a better copy in the future, we will add it to the Agilent website.

Support for Your Product

Agilent no longer sells or supports this product. You will find any other available product information on the Agilent Test & Measurement website:

www.tm.agilent.com

Search for the model number of this product, and the resulting product page will guide you to any available information. Our service centers may be able to perform calibration if no repair parts are needed, but no other support from Agilent is available.
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.

In a typical feedback amplifier, such as shown in figure 1, loop gain is defined as \( G_L G_F H \), 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 \( G_F \) and measuring the output of amplifier \( G_L \). Because the location for "X" is theoretically unimportant, the loop can be opened wherever is most convenient.

For such a measurement to be valid, \( G_L \) 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.

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 megohm inputs, or active probes such as the HP 1120A can be employed.
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.

Unfortunately, some systems cannot operate with their feedback loops open-ended 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.
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 (<0.1 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 analyzer 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.