


LOOP GAIN MEASUREMENTS WITH  WAVE ANALYZERS

Until recently, measurements of loop gain in negative feedback circuits required that the feedback loop be opened at a particular point, and then a load impedance be inserted to duplicate the closed loop impedance at that point. The loop gain could then be determined by the conventional technique of measuring the ratio of the output to the input voltage of the open loop.

These two steps are both inconvenient and time consuming. A new method, utilizing a Hewlett-Packard Model 302 or 310 Wave Analyzer and a  1110A Clip-On Current Probe, allows loop gain to be measured without breaking the loop. Consequently, the measurement can be made in a very small fraction of the time previously needed.

The loop gain measurement is made in four simple steps (see Figure 1):

1. The probe, which is attached to the BFO output of the Wave Analyzer, is clipped around a lead in the feedback circuit where the signal is confined to a single path.
2. The narrow-band, tuned voltmeter of the Wave Analyzer is connected to one side of the clip-on probe.
3. The BFO Output Amplitude control is adjusted to set a convenient reference level, such as 0 db, on the Wave Analyzer voltmeter.
4. A voltage reading is taken on the other side of the probe.

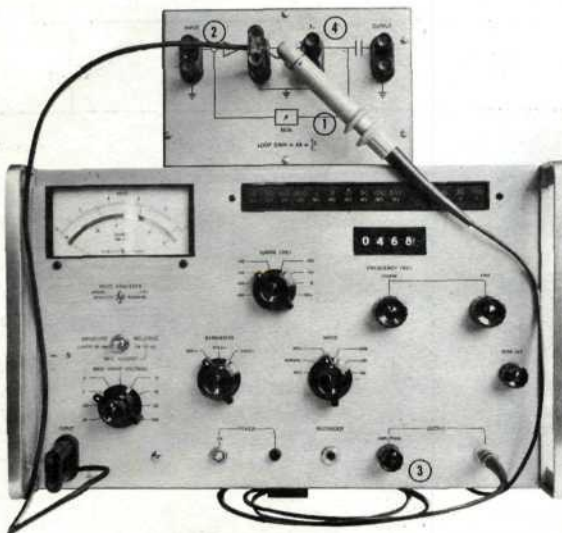


Figure 1

This reading will be the loop gain of the feedback circuit, expressed directly in db, at the particular BFO frequency.

Accurate measurements are made with this method, especially when the loop gain is small, because the Wave Analyzer's narrow-band, selectively-tuned voltmeter avoids the spurious measurement of hum and noise that are usually present at low signal levels. Also, the BFO output is automatically adjusted to coincide with the frequency to which the input is sensitive. Since signal levels are necessarily small to avoid saturating the circuit, the narrow bandwidth and high sensitivity of the Wave Analyzer are essential requirements for measurements of this type.

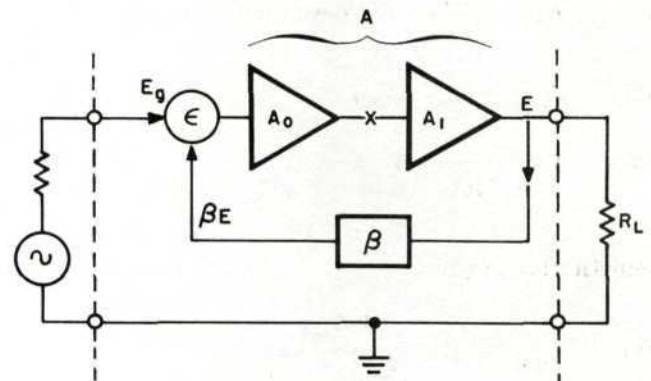


Figure 2

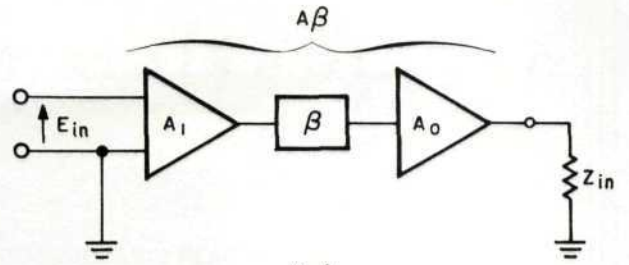
## MEASUREMENT OF FEEDBACK

In a typical feedback amplifier, such as shown in Figure 2, the gain around the feedback loop,  $A\beta$ , can be measured in the conventional way. To do this, however, means breaking the feedback circuit at some point, such as at "X", applying a signal to amplifier  $A_1$ , and measuring the output of amplifier  $A_0$ . But for this measurement to be valid,  $A_0$  must be terminated in the load that  $A_0$  would normally see when the loop is not broken. Besides the inconvenience of breaking the circuit, it may be difficult to design a load that will equal the input impedance of  $A_1$  over the frequency range for which  $A\beta$  is to be measured. With the new technique the loop need not be broken and, consequently, the difficulty of designing the proper termination is completely avoided.

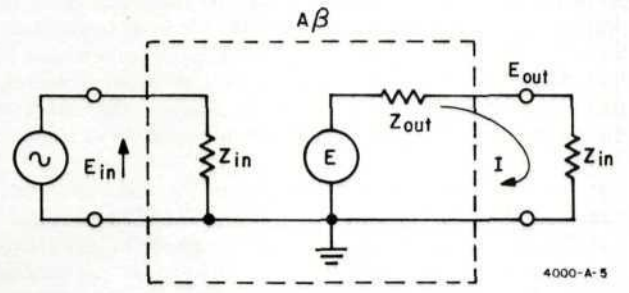


The new method for measuring loop gain utilizes the magnetic coupling capability of the current probe to insert a signal into the feedback loop - without breaking it - by simply clipping it around a circuit lead. The current probe does not alter the feedback loop since it has very low output impedance (0.01 ohm). The  $\phi$  Models 302 or 310 Wave Analyzers can be very conveniently used for both the signal source and voltage measurement device when used in the BFO mode. The advantage of the Wave Analyzer is that both the source and the measurement circuits are tuned simultaneously so that only the gain at the frequency of interest is being measured. The narrow bandwidths of the Wave Analyzers also ensure a high degree of noise and spurious signal rejection.

The signal from the BFO output of the Wave Analyzer, which is coupled into the feedback loop by the current probe, establishes voltages in the loop which allow  $A\beta$  to be measured directly. To understand how  $A\beta$  can be measured in this matter, consider first the feedback loop of Figure 2 as an open loop amplifier with a gain of  $A\beta$ . The amplifier is opened at "X", terminated with the input impedance of  $A_1$  ( $Z_{in}$ ), and a signal  $E_{in}$  is applied to  $A_1$ .



(a)



(b)

EQUIVALENT CIRCUIT OF (a)

Figure 3

From Figure 3(b)

(1)  $A\beta = \frac{E_{out}}{E_{in}}$  definition of loop gain

(2)  $E_{out} = E - IZ_{out}$

(3)  $I = \frac{E}{Z_{out} + Z_{in}}$

Substituting in (2)

(4)  $E_{out} = E - \frac{EZ_{out}}{Z_{out} + Z_{in}}$

$$E_{out} = \frac{EZ_{in}}{Z_{in} + Z_{out}}$$

Substituting in (1)

(5)  $A\beta = \frac{E}{E_{in}} \left( \frac{Z_{in}}{Z_{in} + Z_{out}} \right) = \frac{E/E_{in}}{1 + \frac{Z_{out}}{Z_{in}}}$

Now consider the situation in Figure 4 where the feedback loop is closed and a voltage source is connected in series with it by the probe. The clip-on probe can be inserted at any point in the feedback loop where the signal is confined to a single path.

From Figure 4

(6)  $E_{out} = E - IZ_{out}$

(7) But,  $I = \frac{E_{in}}{Z_{in}}$

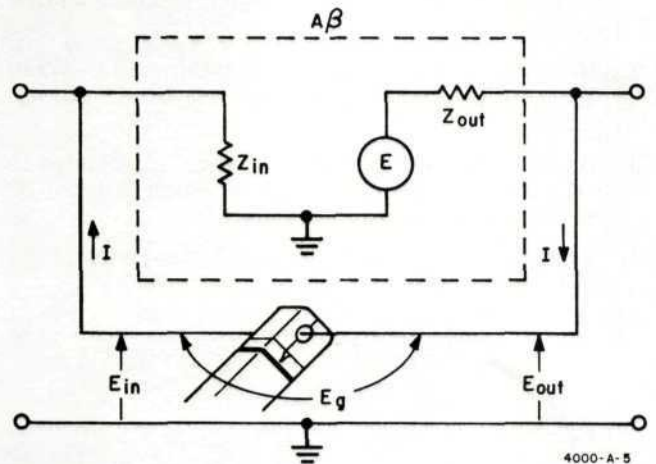


Figure 4

Substituting in (6)

(8)  $E_{out} = E - E_{in} \frac{Z_{out}}{Z_{in}}$

$$E = E_{out} + E_{in} \frac{Z_{out}}{Z_{in}}$$

Substituting in (5)

(9)  $A\beta = \frac{\frac{E_{out}}{E_{in}} + \frac{Z_{out}}{Z_{in}}}{1 + \frac{Z_{out}}{Z_{in}}} \approx \frac{E_{out}}{E_{in}}$  for  $Z_{out} \ll Z_{in}$

As can be seen from equation (9), if a signal is coupled into the loop at a point where the output impedance is much less than the input impedance, then the loop gain reduces to the simple ratio of  $E_{out}/E_{in}$ .

To read the ratio of  $E_{out}$  to  $E_{in}$  directly in db, set  $E_{out}$  to the 0 db level on the Wave Analyzer meter by adjusting the level of the signal to the feedback loop with the BFO Amplitude control.  $E_{in}$  will now be read directly in db units and will represent the loop gain directly in db. If the loop gain is less than one,  $E_{in}$  is set to the 0 db reference level and then the db reading of  $E_{out}$  represents  $A\beta$ .

A dual of the above method exists and may be used when it is not possible to find a point where  $Z_{out}$  is much less than  $Z_{in}$ . If  $Z_{out}$  is much greater than  $Z_{in}$ , then  $A\beta$  can be determined from the ratio of currents flowing into the feedback loop when the source of excitation is a current source. This is shown in Figure 5.  $A\beta$  equals  $I_2/I_1$  for  $Z_{out}$  much greater than  $Z_{in}$ . The current source can be simulated by connecting a resistor (much larger than  $Z_{in}$ ) in series with the Wave Analyzer's BFO output.

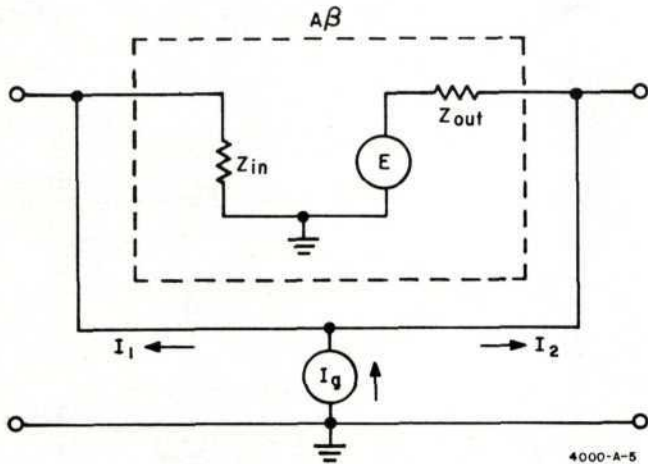


Figure 5

MEASUREMENT OF PHASE ANGLE OF  $A\beta$

It is also important to know the phase angle of  $A\beta$ , or  $E_{out}/E_{in}$ , since when the voltages are in phase, oscillations can result. From Figure 4 it is clear that  $E_{out} = E_g + E_{in}$ . If the amplitudes of these three quantities are known then, by trigonometry, the phase angles between each quantity can be determined. This is easily done by constructing a vector diagram of the amplitudes of each voltage as shown in Figure 6. From the above relationship between these voltages, the graphical construction must form a closed triangle. The phase angle between  $E_{out}$  and  $E_{in}$  can then be measured directly from the diagram.

Determining  $E_g$ , the voltage induced in the feedback loop by the clip-on probe, is easily done with the Wave Analyzer. Without changing the BFO Amplitude Output control, attach the current probe to a loop of wire attached to the Wave Analyzer input terminals.  $E_g$  will then be read directly in volts on the Wave Analyzer.  $I_{out}$ ,  $I_{in}$ , and  $I_g$  can also be used to determine the phase angle of  $A\beta$ .

Using the method of loop gain measurement explained in this article, Figure 7 shows the measurement of  $A\beta$  versus frequency for the circuit shown in Figure 8. The probe was clipped around point A and the voltage ratio on each side of the probe was measured to determine the loop gain at the desired frequencies. The time to take this data was only a matter of minutes. The convenience and simplicity of this method should make it popular with anyone who has had to measure loop gain in the old, conventional way.

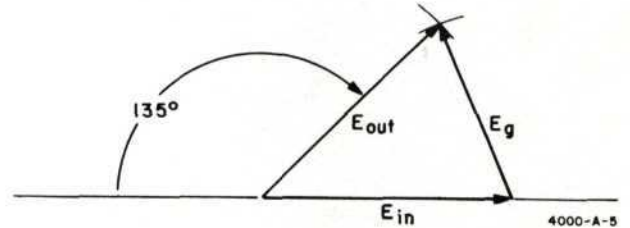


Figure 6

DETERMINING POINT OF SIGNAL INSERTION

To determine whether the output impedance is much less than the input impedance, one would normally have to make an approximate calculation based on the particular feedback circuit. However, either of the above techniques lends itself very easily to measuring the ratio of  $Z_{out}$  to  $Z_{in}$ . These impedances are the output and input impedances without feedback so that it is necessary to connect a large capacitor from a convenient point in the feedback loop to ground to short out the feedback path. Then with a signal applied with the clip-on probe as in Figure 4, the ratio of  $E_{out}$  to  $E_{in}$  is the ratio of  $Z_{out}$  to  $Z_{in}$  since the same current flows through both impedances. Alternatively, a current could be applied and the ratio of  $I_{out}$  to  $I_{in}$  would be the ratio of  $Z_{in}$  to  $Z_{out}$ .

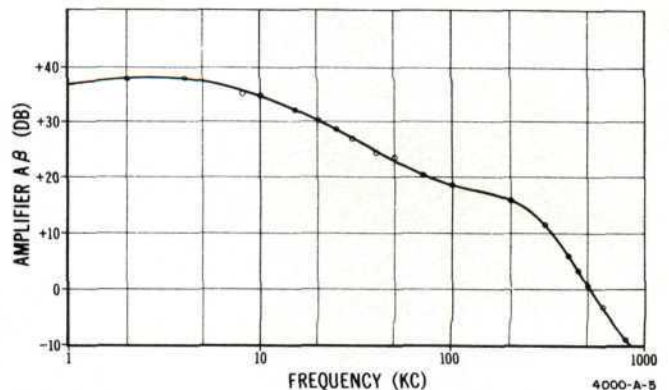


Figure 7



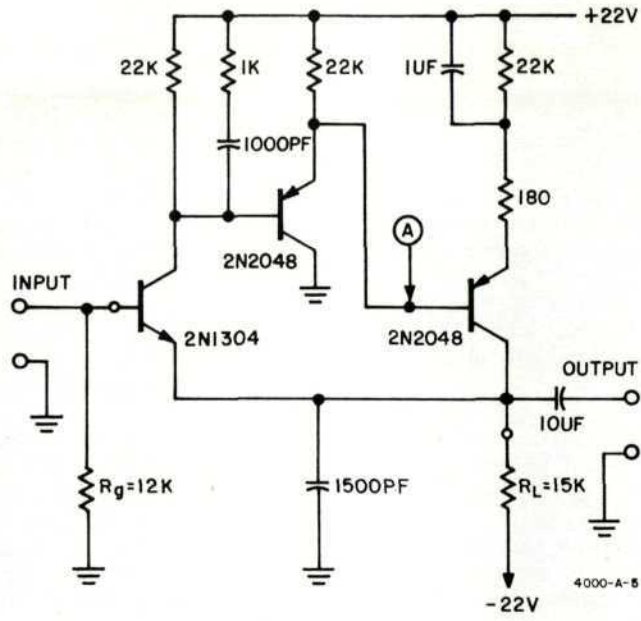


Figure 8