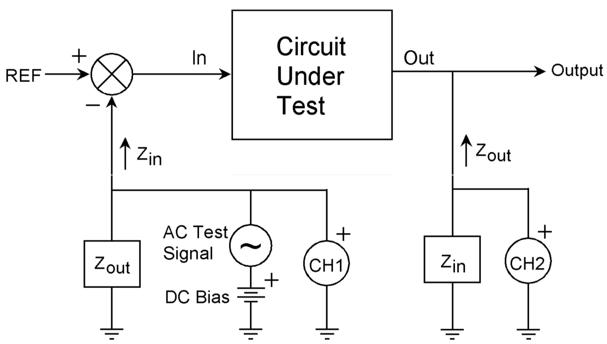
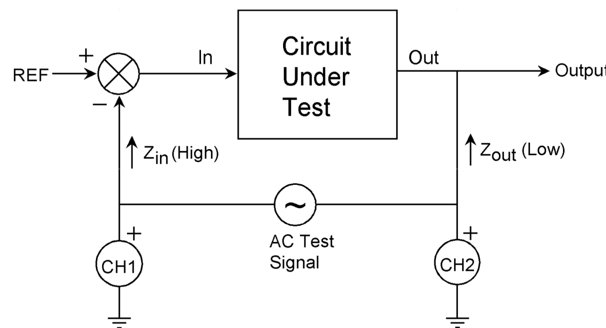
Measuring a Feedback Loop Transfer Function

The classical way to measure a feedback loop transfer function is to break the loop at some point, terminate the input with the output impedance, terminate the output with the input impedance, drive a small AC signal into the input and measure the ratio of the output to the input. In SPICE analysis, the input is frequently set at 1 volt and the output voltage is then plotted directly as gain since the denominator of the ratio has a constant value of 1. In real life, this measurement approach is virtually impossible since the loop gain is usually very high at low frequency and it is difficult to keep the input stable enough to prevent the output from swinging wildly from limit to limit.

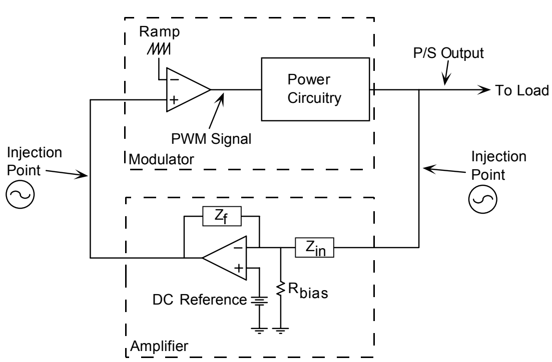


Classical Method

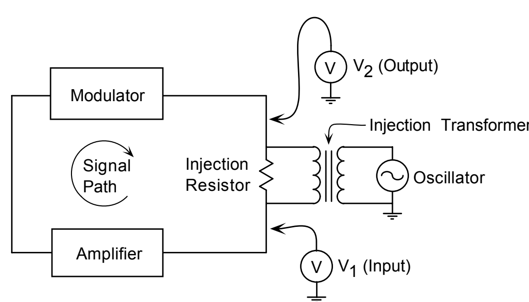


Venable Method

We avoid this difficult measurement situation by finding a place where the loop is confined to a single path (also a requirement in the classical method) and a place where the signal comes from a low-impedance point and drives a high-impedance point. This impedance condition minimizes the error caused by not properly terminating the input and output. We then insert a small resistor into the feedback loop (small compared to the input impedance of the loop). Finally, we connect a floating AC source (the output of a transformer or floating oscillator) across the new resistor and drive it with a sinusoidal voltage source. This converts the resistor into a floating sinusoidal error voltage in series with the feedback loop. This voltage modulates the operating point of the entire circuit.



Injection Points



Injection Technique

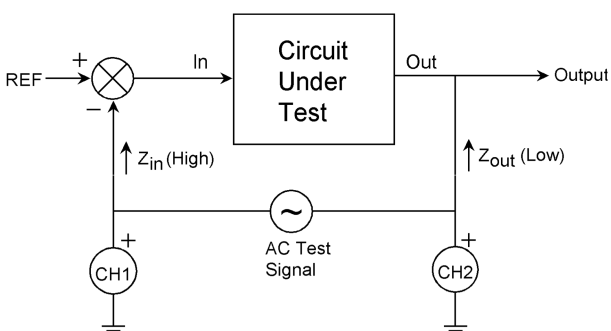
05/24/18

Once the operating point is modulated, it is easy to measure the voltage to ground from any point in the circuit. The difficult part is that the only signal that matters is the voltage at the frequency of the injected error voltage, which may be a few millivolts in the presence of volts of noise. That is where our superior Frequency Response Analyzer comes in. It uses true Fourier Integral analysis (as opposed to the less-accurate Fast Fourier Transform) to accurately measure amplitude and phase of small signals buried in large amounts of noise. Loop gain is the ratio of the voltage out of the circuit to the voltage into the circuit. The amplitude of the various voltages varies widely with frequency, but the absolute values are not important, only the ratio and relative phase angle.

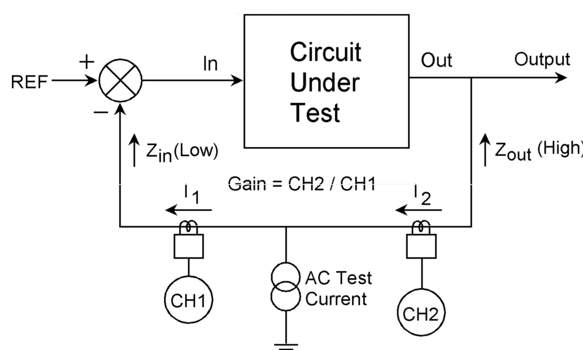
In the rare case where the impedance ratio of input to output is not sufficiently high, a correction factor can be applied to the data to correct for the impedance condition.

$$A_{actual} = \frac{A_{measured} + \frac{Z_{out}}{Z_{in}}}{1 + \frac{Z_{out}}{Z_{in}}} \qquad (1)$$

There is also a “dual” of the voltage injection method that is useful when the input impedance is much lower than the output impedance. This involves injecting a current into the loop instead of a voltage and measuring the ratio of the currents on either side of the injection point instead of the voltage. These two test techniques are shown in the figures below, and the current injection technique is used in one of the injection point examples.



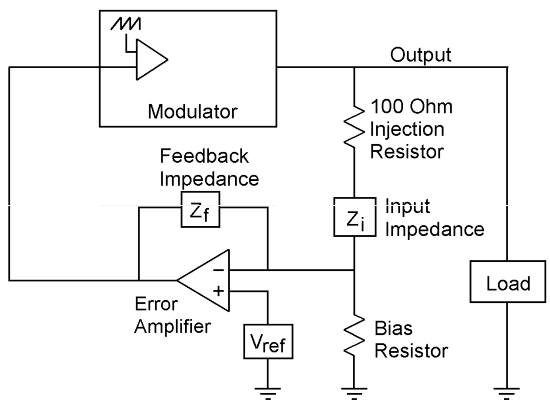
Voltage Mode Injection
Use when Zin >> Zout
Gain = CH2/CH1
This is the normal injection method



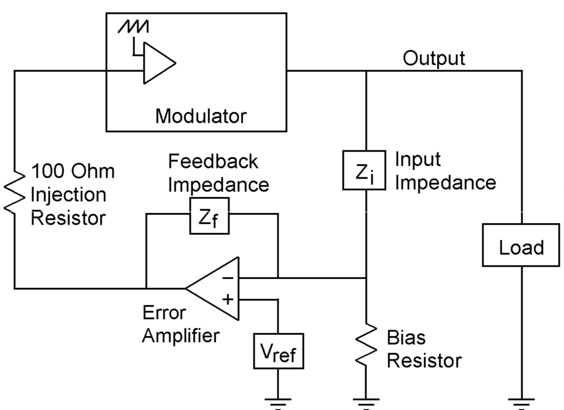
Current Mode Injection
Use when Zin << Zout
Gain = CH2/CH1
“Dual” of normal method

Here is a step-by-step description of how to measure a feedback loop transfer function:

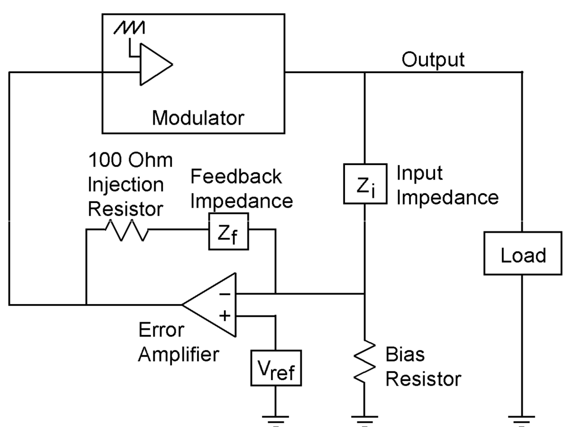
1. Find a place in your circuit where the loop is confined to a single path, comes from a low impedance, and drives a high impedance. In a power supply, the most reliable place that meets these criteria is the point where the resistor or network (labeled Z_i in the figure below) connects to the output of the power supply, typically a large-value electrolytic capacitor.



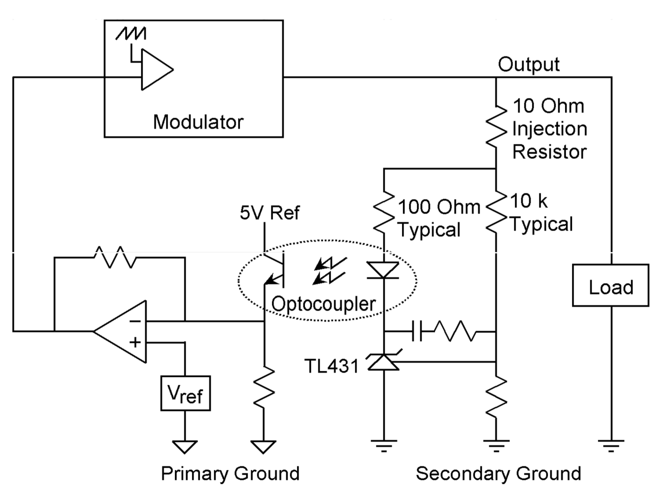
Injection in top of feedback string.



Injection between amplifier and modulator.

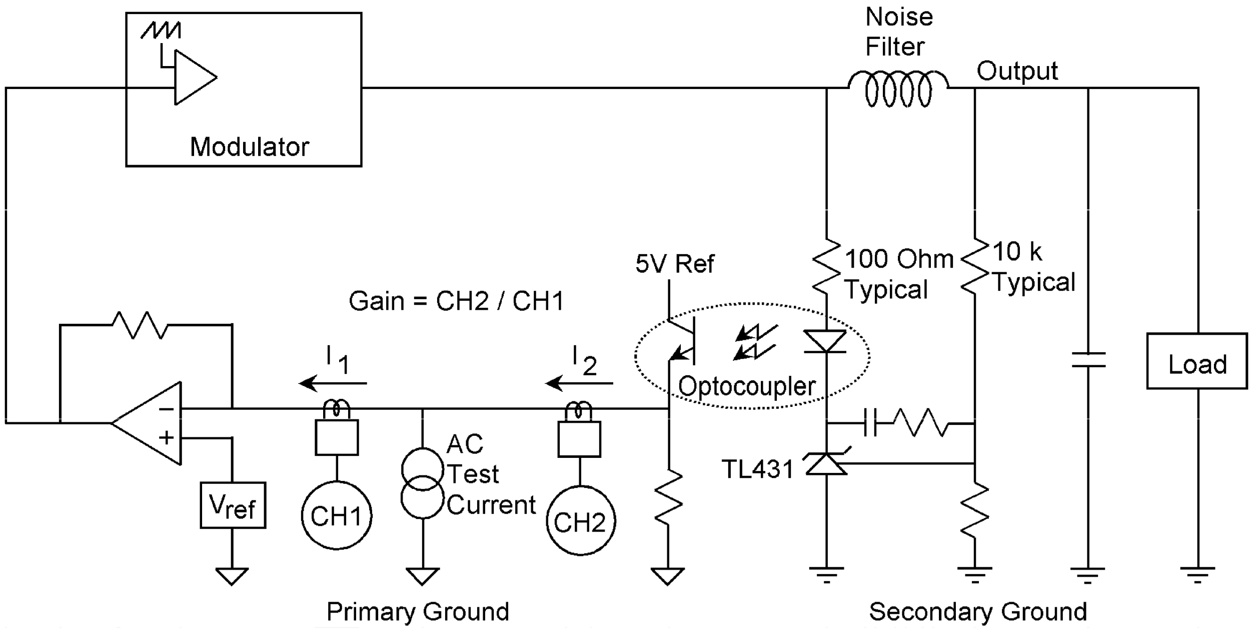


Inject in feedback of error amplifier. Always available but usually noise sensitive. Also works on circuits with TL431's and optocouplers.



Injection in circuits using TL431.
Make sure injection includes both the "fast loop" through the diode and the "slow loop" through the resistive divider string.

05/24/18



Current injection works in many difficult measurement situations. This method requires two current loops and two current probes but no resistor inserted in the circuit. Gain is determined by the ratio of two currents instead of the ratio of two voltages. A high-value resistor (typically 10k) is used to couple the oscillator output to the test point between the two current probes. Use the DC offset capability of the oscillator to bias the DC level to match the common mode voltage of the error amplifier, usually 2.5 volts, so the DC operating point of the circuit is not disturbed.

2. At the injection point, lift the resistor or network off the printed circuit board and insert a low-value resistor between the network and the output bus. The preferred value of this injection resistor is 100 ohms. Lower resistance values can be used, even down to 1 ohm, but the signal levels and the bandwidth of the injection transformer may suffer. You can judge the effect for yourself by noting the quality of the data, especially the data at frequencies far below or above the loop crossover frequency. On future designs, think about designing the injection resistor in as a permanent part of the circuit. The cost is negligible and it allows you to perform a loop frequency response test any time you want to.

3. Three points are necessary to measure loop gain: the two sides of the injection resistor and signal ground. The connection used to measure signal ground should preferably be very near the ground of the DC reference voltage, typically the ground pin of the PWM control chip. If these three points are not all accessible with Mini-grabber clips, solder test points to the circuit as required.

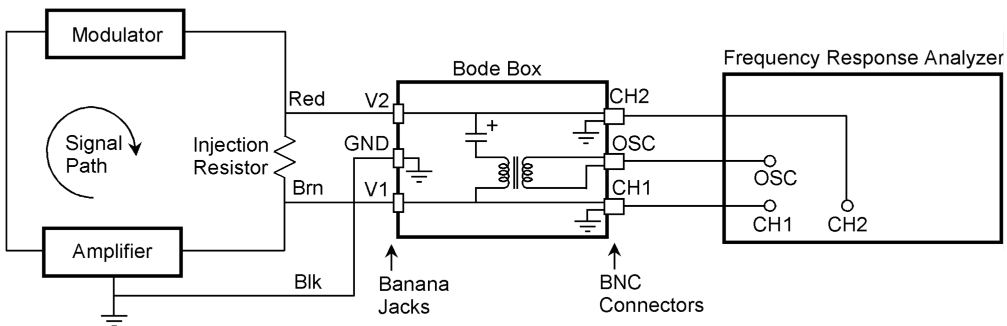
4. Using three of the BNC-BNC cables provided, connect the Oscillator, Channel 1, and Channel 2 of the Frequency Response Analyzer to the corresponding three BNC connectors on a Bode Box injection transformer.

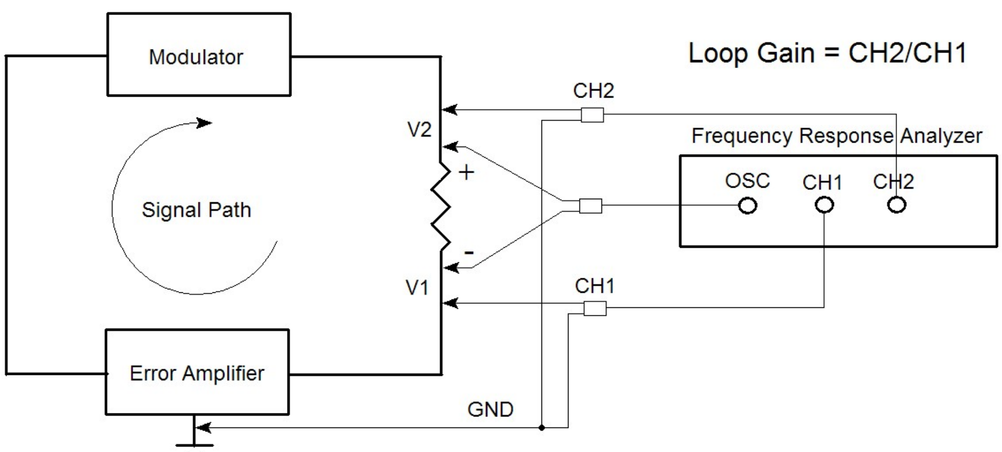
5. Using the black, brown, and red Banana-Mini-grabber cables provided, connect each banana plug end to the correspondingly colored banana jack on the same Bode Box injection transformer.

6. Connect the black Mini-grabber to signal ground near the ground of the reference voltage. This point must be within rated signal ground to chassis ground voltage of your particular analyzer.

7. Connect the brown Mini-grabber to the point where the injection resistor ties to the error amplifier input resistor or network. This voltage must be within rated input to signal ground voltage of your particular analyzer.

8. Connect the red Mini-grabber to the point where the injection resistor ties to the power supply output bus (or equivalent point in your circuit). This voltage must be within rated input to signal ground voltage of your particular analyzer.

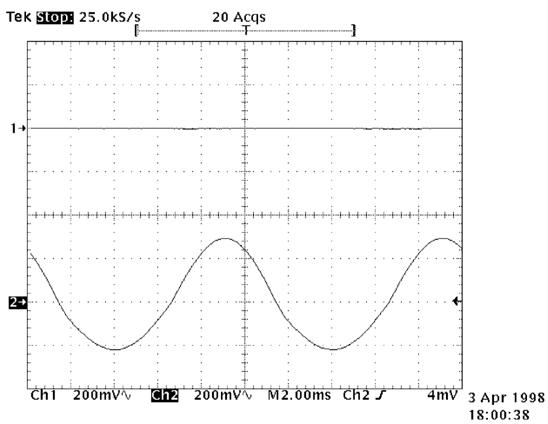




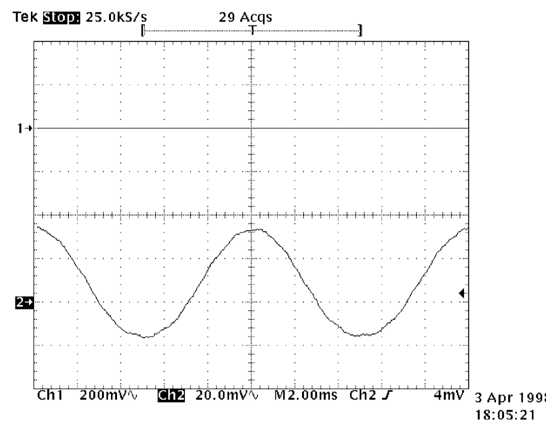
Loop gain measurement setup using a Venable analyzer with a floating oscillator. No transformer is required in this case. Separate BNC-Minigrabber cables are used to inject and measure the loop gain input and output voltages

9. Turn your circuit on and make sure it is operating properly.

10. A highly recommended step is to connect a two-channel oscilloscope to the same signals that Channel 1 and Channel 2 are connected to. This will allow you to monitor the amount of signal injected into the loop and determine if there is any clipping or distortion of the sinusoidal injection signal. The theory behind this measurement requires that the output be continuously and linearly proportional to the input. If this is not true, the results will not be valid.



Distorted sine wave indicates overdrive.



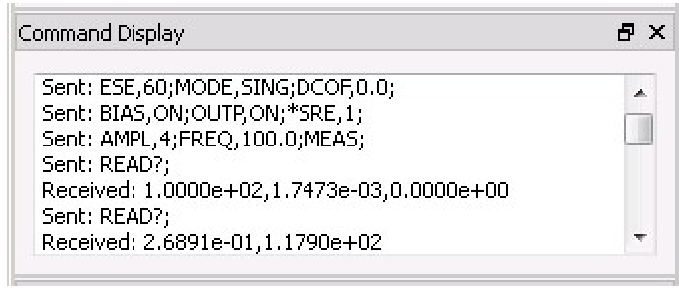
Undistorted sine wave is desired.

11. Open the Venable software. Set the variables in the Analyzer Control window as desired.

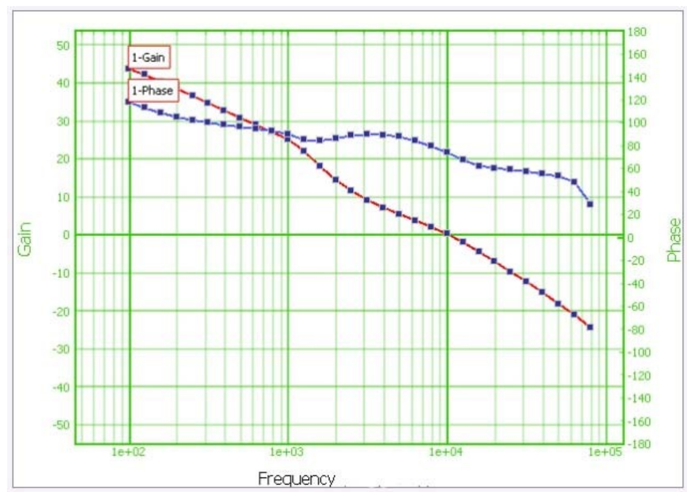
Typical values are for 100 kHz switching frequency:

Start Frequency	10 Hz
Stop Frequency	90 kHz (10-20% less than your switching frequency)
Log Sweep	10 Steps/Decade
AC Volts Out	1 V with Bode box or 100 mV with a floating oscillator
DC Volts Out	0
Waveform	Sine
Output Impedance	50 Ohm
Integration	Time
Integration Time	1 Sec
Delay Time	0 Sec
Input Impedance	1 Mohm
Servo	Off
AC Out Step Size	10 dB
Max AC Volts Out	10 Volts peak
Max Gain Change	Off (unchecked)
Max Phase Change	Off (unchecked)
Channel Ratio	CH2/CH1

12. Click on the “Take Data at Start Freq” button. There should be communication with the analyzer, with the data showing up in the Command Display text box. The “Gain” and “Phase” boxes in the Readings window should read reasonable values.



13. If everything looks OK, click the “Run Sweep” button. The system will automatically sweep from the start frequency to the stop frequency at the specified number of steps per decade. You can see the data being presented in real time.



14. The data just taken will automatically be “selected” and each data point will show as a black dot. Below the graph are the data set properties for the selected graph. You can change the ratio of output node number to input node number, scale factor, line type, line thickness or color of either curve. You can also edit the Data Text Description.

05/24/18