

Measure power-supply-loop transfer

USING A FUNCTION GENERATOR AND AN OSCILLOSCOPE, YOU CAN MEASURE GAIN AND PHASE SHIFT VERSUS FREQUENCY IN A POWER SUPPLY'S CONTROL LOOP.

Power supplies use control-loop circuits to produce constant voltage or current. The transfer function—gain and phase as a function of frequency—provides valuable information about a control loop's speed and stability. Knowing a control loop's transfer function, as well as the poles and zeros of the transfer circuit, can help you select the right compensation and power-stage components.

You can measure gain and phase shifts and plot them with a network analyzer that sweeps the frequency of an injected signal and automatically computes the control loop's phase difference and gain. Such an instrument is nice to have and convenient—but is also expensive. If you don't have one available, you can make the measurements with an oscilloscope, a signal generator, and a standard transformer.

To perform the measurements, you inject a small ac signal into the power supply's control-loop circuit and measure the loop's gain and phase shift. By measuring the gain and phase, you can plot them with a Bode plot. The gain and phase differences between the injected signal and the control loop's output are the transfer function.

PREPARE THE CIRCUIT

Figure 1 shows a typical step-down switch-mode regulator with the required measurement setup. Start by breaking the loop of the power supply's regulator circuit (highlighted area in Figure 1) so you'll have a point at which to inject the small signal and measure the loop's response. You can break the loop at the low-impedance output node above the high-side feedback resistor, R_1 , in the feedback path.

You must electrically isolate the measurement points, A and B, by placing a small resistance, such as 20Ω , in the control loop's feedback path. A 20Ω resistor in the control loop has a negligible effect on the power supply's output voltage, V_{OUT} .

To inject the signal into the control loop and make the measurements, you need a sound measurement structure. The online version of this article contains a sidebar, "Good connections," that explains how to modify a regulator-IC evaluation board for these measurements (www.edn.com/ms4284).

The injected signal must be small in relation to the output voltage so that it won't change the way the power supply handles large signals. Yet, the injected signal must be large enough that you can recognize it in the control loop. The injected signal must not trigger a voltage-protection threshold at a regulator IC's feedback pin, FB.

You should inject a sine wave with an amplitude of 30 to 100 mV across the 20Ω resistor. The exact signal amplitude

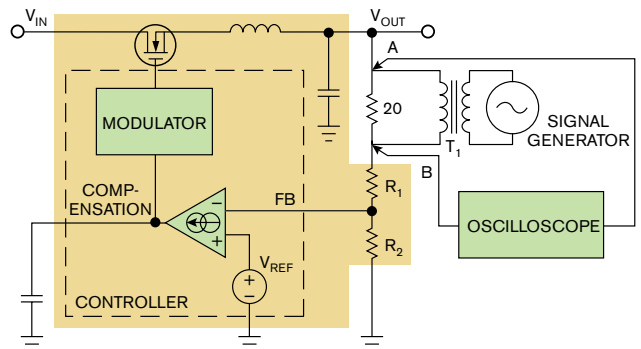


Figure 1 This measurement setup lets you compare an injected sine wave with the signal as it rides on a power supply's output, V_{OUT} .

you need may change depending on the control loop's gain, and the amplitude will vary with frequency. Start by injecting a small signal and then increase its amplitude as needed until you can see it on an oscilloscope screen. This step ensures that the signal is still small relative to the loop's dc output.

The injection transformer, T_1 , prevents dc from entering the control loop. Look for a transformer that offers a flat voltage transmission over a wide frequency band. If you don't have such a transformer, you can compensate for frequency variations in your transformer's flatness by adjusting the signal generator's output amplitude.

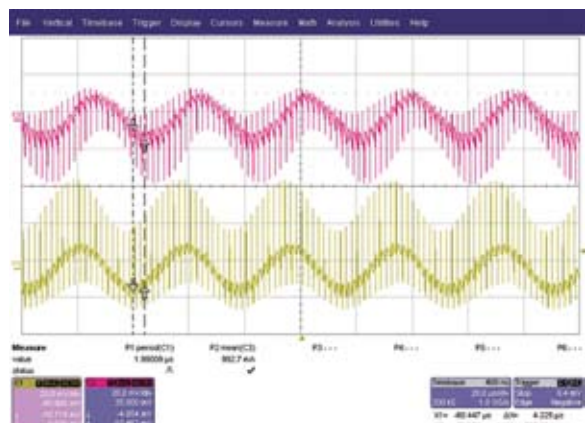


Figure 2 When control-loop gain is 1 (0 dB), the amplitude of the injected signal (upper trace) will equal the amplitude of the output signal (lower trace).

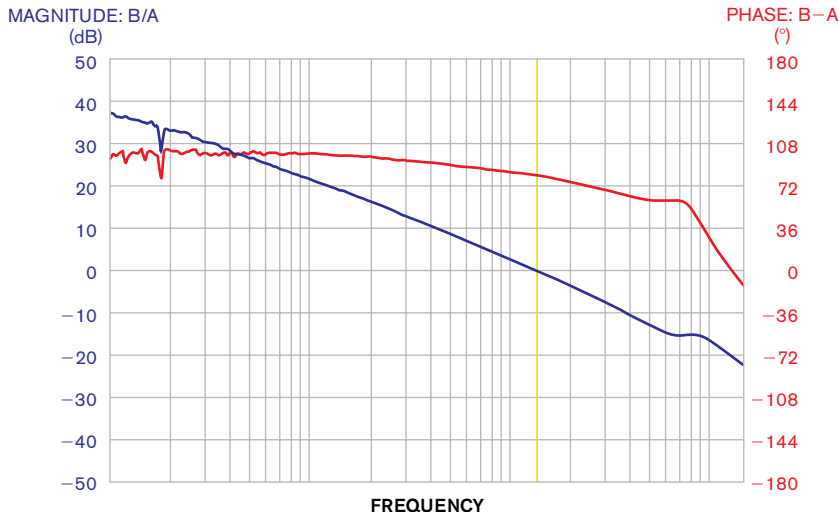


Figure 3 A Bode plot shows the point at which the gain (blue trace) is 0 dB and shows the corresponding phase offset (red trace).

Connect the signal generator to the transformer's primary side, and then turn on the generator. Measure the injected signal across the 20Ω resistor using two calibrated oscilloscope probes. (Attach the ground leads of both probes to a common ground point on the power supply under test.) To make the measurement, you'll need to view the difference between the signals on Channel A and Channel B.

Adjust the signal generator's amplitude so that the transformer's output voltage won't drive the control-loop circuit into nonlinear operation. Set the dc offset of the signal generator's output to 0V because only ac is transferred through the transformer anyway.

To prevent switching noise from filling the oscilloscope's screen and covering the waveform of interest, set the oscilloscope for bandwidth limiting. You can ensure a well-triggered waveform by connecting a third oscilloscope channel to the signal generator's output and triggering on the output signal.

POWER SUPPLY

Next, you should power up the control-loop circuit and make a loop-transfer-function measurement as described above. Repeat this measurement under different load and line conditions.

At low output loads, most power supplies will go into discontinuous current-conduction mode, which will change the control loop's characteristics. In voltage-mode control, a power supply's loop characteristics will change with input voltage.

After setting up the equipment and powering the control loop, you should see a line on the channel connected to the output voltage (Probe A in Figure 1) and a noisy sine wave on the other channel. If you don't see a sine wave, then set the oscilloscope to the highest-amplitude resolution—typically, 20 mV/division—or increase the amplitude of the signal generator's output.

Once you see a sine wave, change its frequency by adjusting the signal generator. You will see a change in amplitude on Channel A. Look for a frequency in which the sine waves of Channel A and Channel B have equal amplitude; at

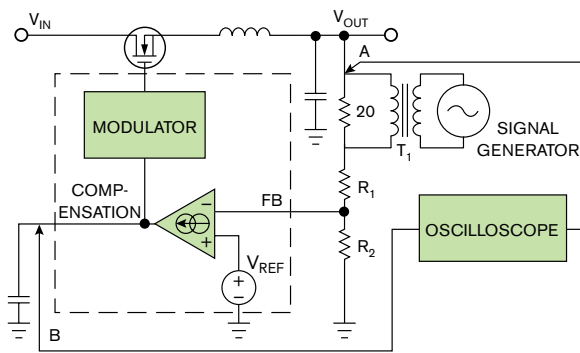


Figure 4 This measurement setup lets you measure the compensation signal of the voltage-regulator IC (Probe B).

this point, the gain of the control loop is 1 (0 dB). This frequency is the loop's 0-dB crossover frequency (**Figure 2**).

Typically, the two sine waves will be phase-shifted relative to each other. The amount of phase difference at the 0-dB crossover frequency is the phase margin of the control loop. Besides measuring the injected and output sine waves at the 0-dB crossover point, you should also measure the sine wave riding on the output voltage at lower frequencies. The amplitude difference between Channel A and Channel B gives the gain at a given frequency. **Table 1** lists the voltage ratio between the injected sine wave and the sine wave riding on the output voltage and the corresponding values in decibels.

You can successfully make these loop measurements on a control loop that doesn't oscillate or is in some sort of hysteretic overvoltage-protection mode. If the error amplifier is a transconductance amplifier, you can achieve a stable loop design by placing a capacitor from the regulator IC's compensation pin to ground. If the error amplifier is a standard voltage-to-voltage error amplifier, then place a capacitor from the compensation pin to the FB pin. A 1- μ F capacitor typically works well. It sets a pole at very low frequencies and forces the gain to drop quickly so that the 0-dB crossover is at a very low frequency. In current-mode-control designs, the phase margin at very low frequencies is usually enough to yield a stable circuit.

THE BODE PLOT

To generate a Bode plot, you must sweep the signal generator's frequency across the frequency range of interest and measure the gain and the phase shift between the input signal (Probe B in **Figure 1**) and the output signal (Probe A). For large and small gains, you might have a difficult time seeing results on the oscilloscope screen. At 30-dB gain, for example, it's difficult to see a voltage relationship between Channel A and Channel B.

For typical designs, you can easily and

TABLE 1 COMMON DECIBEL VALUES FOR VOLTAGE RATIOS

| Voltage ratio (A/B) (V) | Decibel level ($20 \times \log[A/B]$) (dB) |
|-------------------------|--|
| 0.03162 | -30 |
| 0.1 | -20 |
| 0.3162 | -10 |
| 0.7071 | -3 |
| 1 | 0 |
| 1.414 | 3 |
| 3.162 | 10 |
| 10 | 20 |
| 31.62 | 30 |

accurately measure the most important points, such as the 0-dB crossover point of a Bode plot. At high gain frequencies, you might have a difficult time viewing the exact decibel value, but you can make a quantitative observation, such as that the gain is probably higher than 30 dB. **Figure 3** shows the control loop's 0-dB-gain crossover frequency, where the blue trace crosses 0 dB.


You can consider loop bandwidth as a combination of the level of dc gain and the frequency of the 0-dB crossover. The control loop's phase-margin measurement can indicate the control loop's stability margin. Depending on the design, you need a minimum phase margin of 45 to 50°. More is better.

Besides using the measurement setup in **Figure 1**, you can connect the oscilloscope channel that was measuring the injected signal (Probe B) to the compensation pin of a power-supply-regulator IC (**Figure 4**). In this setup, you can measure the transfer function of the control loop without the influence of the compensation network (the capacitor that connects to the regulator's compensation pin). With the information you obtain about the power stage with this measurement, you can easily select optimized compensation components for a desired control-loop bandwidth and phase margin. **EDN**

AUTHOR'S BIOGRAPHY

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A version of this article appeared in the September 2008 issue of *Test & Measurement World*.

 The online version of this article contains a link to a seven-minute video that describes the test procedure. Go to www.edn.com/ms4284.