ISSUE: June 2025

Measuring Loop Response Of Regulators With Inaccessible Feedback Resistor

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For a power supply to be stable, a certain gain and phase margin is needed. Typically, a phase margin target of at least 45° and a gain margin target of at least 10 dB is required for a power supply to be considered stable. These values are usually measured by inserting a small resistor between the V_{OUT} node and the top feedback resistor. A perturbation signal is applied across this added resistor and the loop response is measured across the desired frequency range. This conventional approach of making Bode plot measurements is preferred for its simplicity, assuming the user has access to the top feedback resistor.

But how can the loop response be measured when the top feedback resistor is inaccessible within a molded module? And how is the loop response measured when a device does not require a top feedback resistor and instead uses an output voltage sense pin?

Previously, when confronted with these situations, engineers either skipped Bode plot measurements, relied on load step response, or possibly just ran simulations. In more recent years, engineers have used impedance measurements to determine phase margin, a technique known as the non-invasive stability measurement (NISM).[1] However, this approach requires use of certain instruments with specialized software installed.

In this article, we present variations on the conventional loop response measurement method, which use the same instrument but with some changes in the connection to the regulator and (in one case) some simple additional circuitry. Results obtained with the two new methods will be compared against those obtained using the conventional measurement approach.

Where Is The Top Feedback Resistor?

As shown in Fig. 1, the conventional method for measuring loop response is to insert a small value resistor between the V_{OUT} node and the top feedback resistor. This method can only be used if the top feedback resistor is accessible.

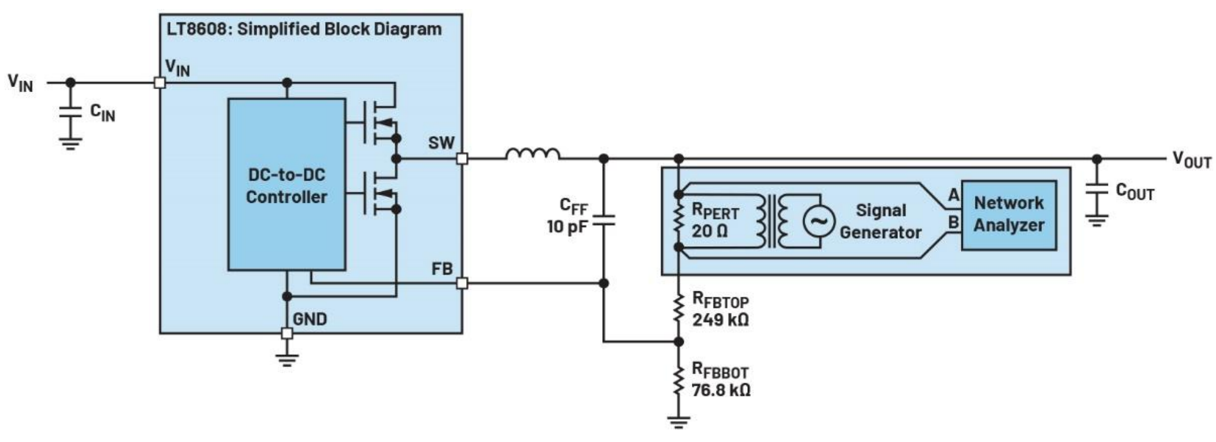

Fig. 1. Schematic showing the added resistor required to measure the loop response with the LT8608.[2]

There are many power supply modules whose top feedback resistor is inaccessible within the power supply package. With a top feedback resistor hardwired to the V_{OUT} node, the output voltage should never increase above the voltage set by the feedback resistor divider. If the top feedback resistor is not hardwired, then the V_{OUT} node could increase as high as the input voltage for a buck regulator if the top feedback resistor is not connected properly or if it breaks.

Many of Analog Devices' line of µModule devices have the top feedback resistor molded inside the module for this added protection. But now the loop response cannot be measured using the conventional method. Fig. 2 shows the LTM8074 with its inaccessible top feedback resistor.

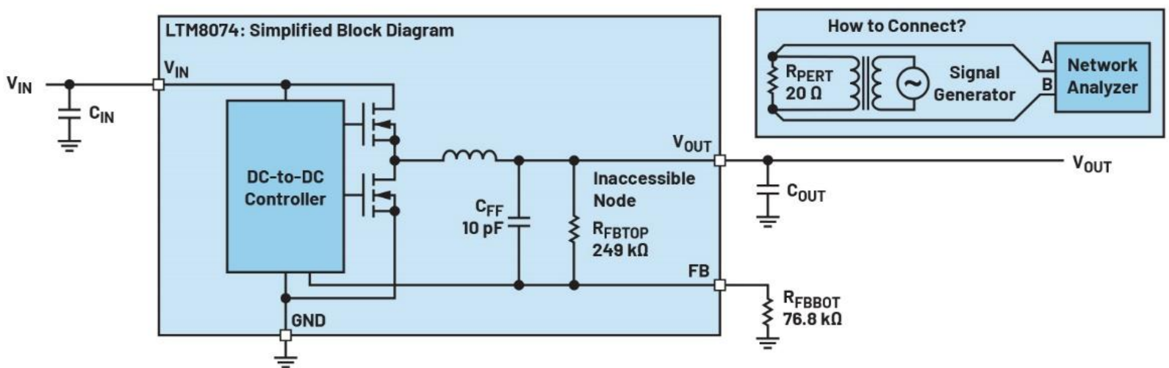

Fig. 2. Example circuit showing an inaccessible top feedback resistor.

Another unique situation occurs when a module uses an output voltage sense pin (V_{OSNS}) to regulate the V_{OUT} voltage. As the simplified block diagram shows in Fig. 3, there is no top feedback resistor due to this setup using a current reference instead of the typical voltage reference. The LTM4702 uses this current reference circuit to regulate its output voltage.

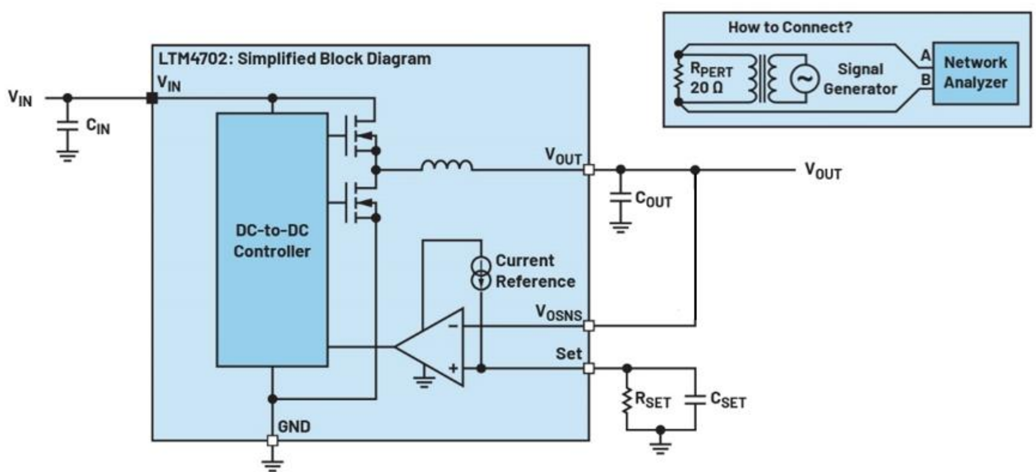

Fig. 3 Simplified block diagram showing V_{OSNS} circuitry.

Load Transient Response Or Bode Plot?

Without a way to measure the loop response of a power supply, one must rely solely on the transient response of the system to determine stability or apply the NISM as mentioned previously.[1] The transient response test looks at the voltage response of V_{OUT} when a load step is applied to the V_{OUT} node.

An example transient response is shown in Fig. 4. From the waveform, the bandwidth (f_{BW}) can be estimated by measuring the time from when the load step is applied to when the output voltage starts to recover. The bandwidth of the control loop is the inverse of this recovery time (t_r) multiplied by π. In this example, the recovery time is approximately 4 µs and the bandwidth is 80 kHz.

Also, the stability can be estimated by looking at the shape of the waveform. The system has an underdamped response when ringing is seen in the waveform (green response). This means the system can be unstable and have a lower phase margin. But how low is the phase margin?

If the recovery time of the waveform takes a significant amount of time, then the response can be considered overdamped (blue response). The system can take much longer for the output voltage to recover than desired. Downstream circuitry may be impacted due to the voltage drooping for a longer duration than preferred.

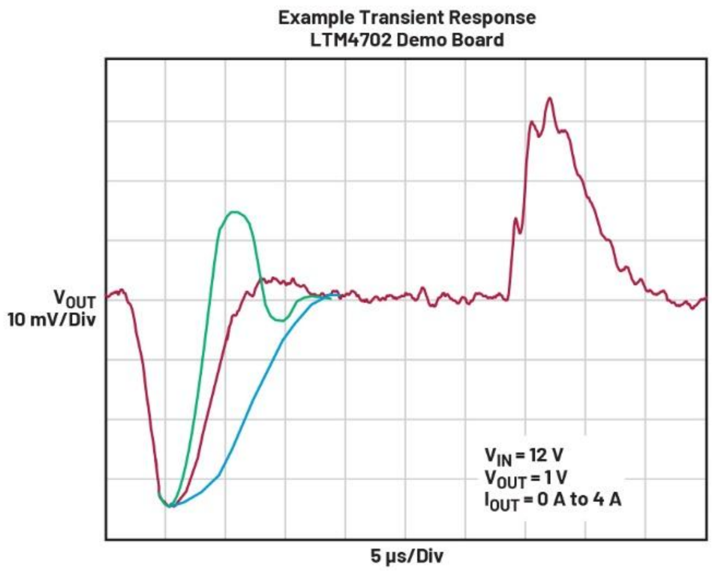

Fig. 4. Example transient response of a switching regulator.

Although the transient response can give clues to the system's loop response, the exact phase margin and gain margin can only be determined by measurement.

Novel Methods To Measure Loop Stability

For the scenario where an output voltage sense pin is used, the loop response measurement is similar to the conventional measurement approach. Simply place a small value resistor between the V_{OUT} node and the V_{OSNS} pin. The perturbation signal is applied across this resistor as shown in Fig. 5 and the loop response is measured.

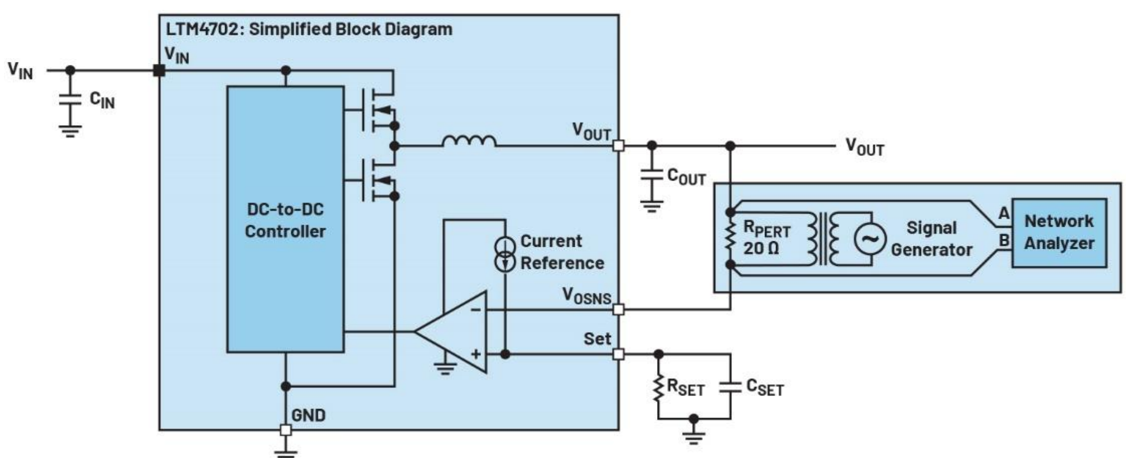

Fig. 5. Simplified block diagram showing V_{OSNS} circuitry between V_{OUT} and V_{OSNS} .

For the scenario where the top feedback resistor is inaccessible inside a module, the novel loop measurement technique requires a bit more care. As shown in Fig. 6, a parallel resistor divider network must be installed, and the perturbation signal is now placed across a resistor inserted between the bottom feedback resistor and ground. Care must be taken to keep the parallel resistor divider network as close as possible to the feedback resistor network to minimize errors.

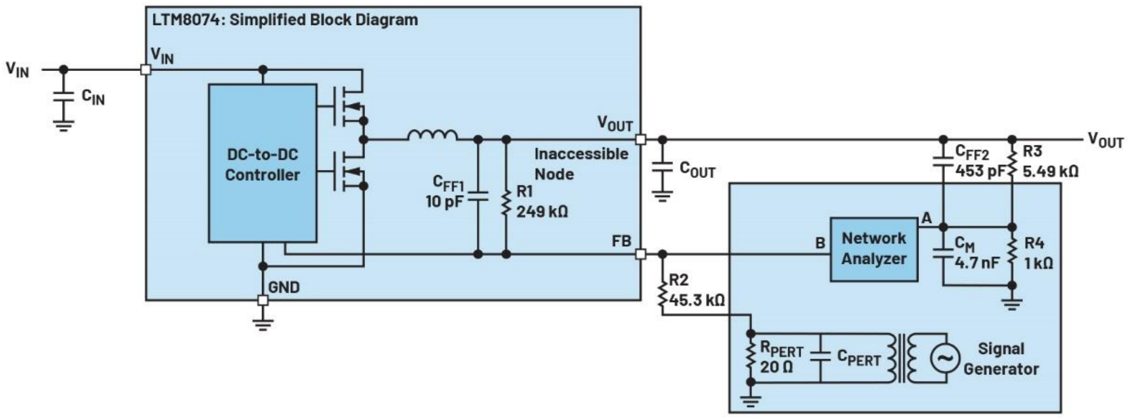

Fig. 6. Novel loop response measurement method.

The following procedure is used to determine the component values in the test circuit.

Step 1. Insert the 20-Ω R_{PERT} resistor between R2 and ground. The perturbation signal is applied across R_{PERT}.

Step 2. Choose R4 to be in the range of 500 Ω to 1 kΩ. (See Note 1.)

Step 3. Calculate the parallel resistor divider network ratio n = R2/R4.

Step 4. Calculate R3 and C_{FF2} using the ratio, n, from step 3. R3 = R1/n and C_{FF2} = n × C_{FF1}.

Step 5. Reconstruct the parallel resistor divider network including the feedforward capacitor C_{FF2} and the capacitor (C_M) where C_M = n × C_{PERT} to negate the effects of the added capacitance from the perturbation signal. (See Note 2.)

Note 1: Choose R4 so that R2 is 40 to 100 times greater than R4. This will allow the R2 and R3 resistor network to dominate the feedback loop measurement.

Note 2: If the perturbation signal's parasitic capacitance cannot be reliably measured, then the C_M capacitance can be determined empirically through iteration.

This novel measurement approach yields the same loop response as the conventional approach as shown in Fig. 7.

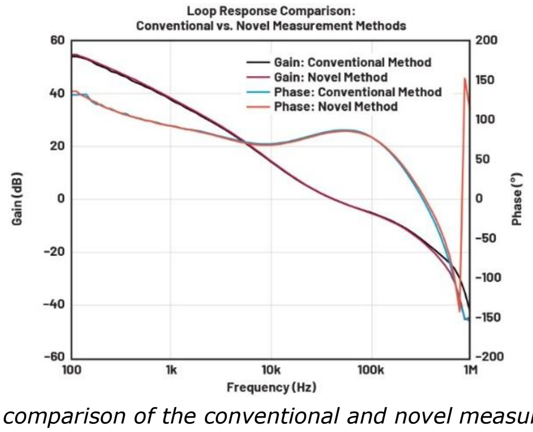

Fig. 7. Bode plot comparison of the conventional and novel measurement methods.

Conclusion

With the novel measurement approaches, the user can now determine the loop response without access to the top feedback resistor and for the case where an output voltage sense pin is used. The user is no longer mandated to use a compromised approach with limited bandwidth and significant error. And the user does not have to estimate the loop stability from only looking at the load transient response.

References

1. Non-Invasive Stability Measurement.
2. LT8608 product page.
3. "Application Note 149: Modeling and Loop Compensation Design of Switching Mode Power Supplies" by Henry Zhang, Linear Technology, January 2015.

About The Authors

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For more on power supply stability measurements, see the How2Power Design Guide, locate the Design Area category and select "Stability".