Application Note

Measuring the Bode Plot of D-CAP™, D-CAP2™, and D-CAP3™ DC/DC Converters

TEXAS INSTRUMENTS

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ABSTRACT

The stability test is an important part of the evaluation of a DC/DC converter. If done properly, the Bode plot result can be a very quick and useful way to help you gauge the stability of the converter. In the absence of a theoretical analysis, use a network analyzer to measure the Bode plot and confirm the stability of the design. The control-loop gain, which can be plotted in a Bode plot, is a very good indicator of the stability of the DC/DC converter.

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Trademarks

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1 D-CAP Feedback Loop

DC/DC converters using D-CAP, D-CAP2, and D-CAP3 control architectures, referred to as D-CAPx in this report, became popular for their fast transient response with minimal output capacitance and their simplicity by eliminating external compensation components. The D-CAPx control architecture, a derivative of non-linear constant on-time control, poses a challenge for designers when measuring the control-loop gain. As Figure 1-1 shows, breaking the control loop is the proper technique for traditional linear control architectures, like voltage-mode control and current-mode control, where there is only one output feedback path. But when measuring the control-loop gain for D-CAPx architectures, a different approach is necessary. The D-CAPx control architecture has two direct output feedback paths as shown in Figure 1-2: one through the feedback resistor divider network R_{up} and R_{low}, and the other through the direct current resistance (DCR) injection circuit R_p, C_p, and C_{ff}. The D-CAPx control system does not have a high DC gain error amplifier like the traditional type II or type III compensator of current-mode or voltage-mode control architectures, where the FB pin is usually the negative input of the error amplifier. For D-CAPx converters, the FB pin is only one of the inputs of the PWM comparator.

By leaving out one of the feedback path outputs of the measurement, the Bode plot measured using the setup in Figure 1-1 does not directly correlate to the transient response waveforms. To properly measure the loop-gain Bode plot, the loop breaking point must include both feedback paths, as Figure 1-3 shows.
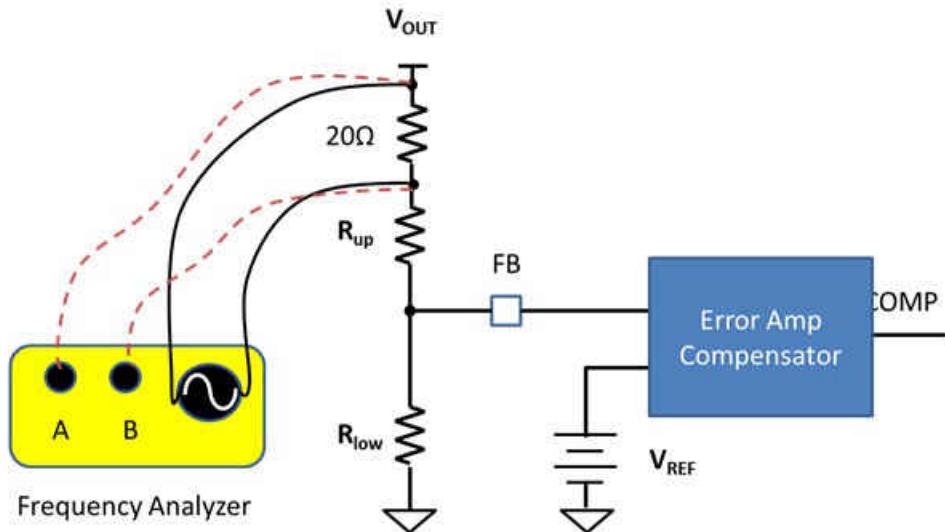

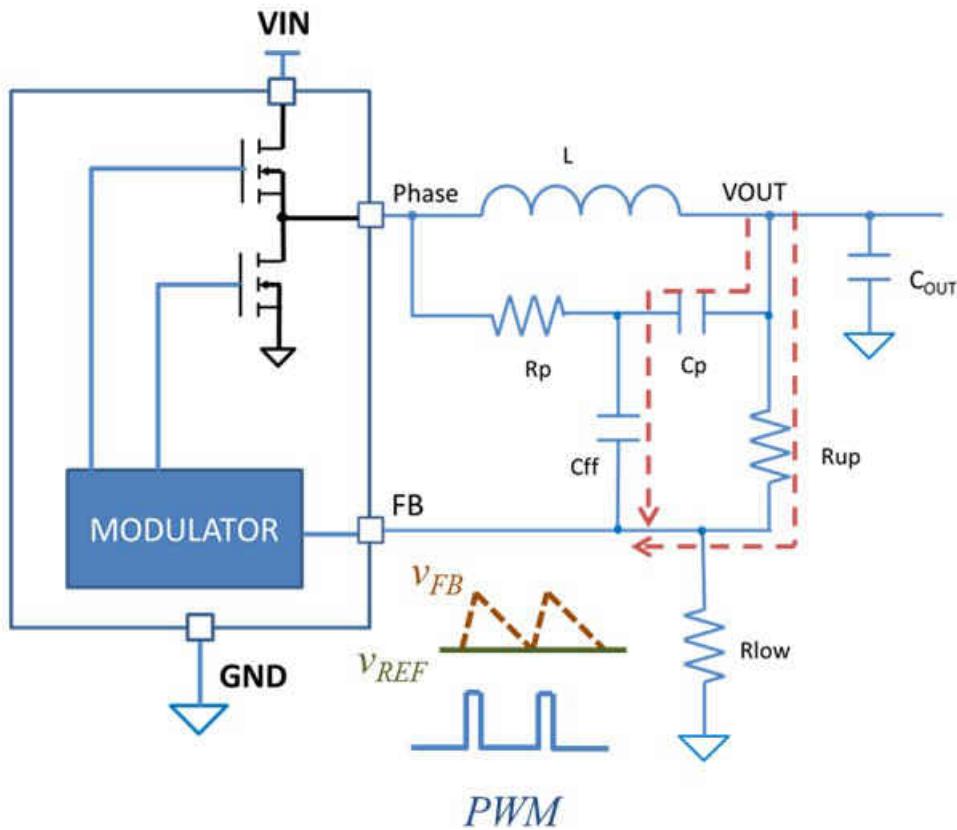**Figure 1-1. Voltage-Mode or Current-Mode Control-Loop Gain Setup**

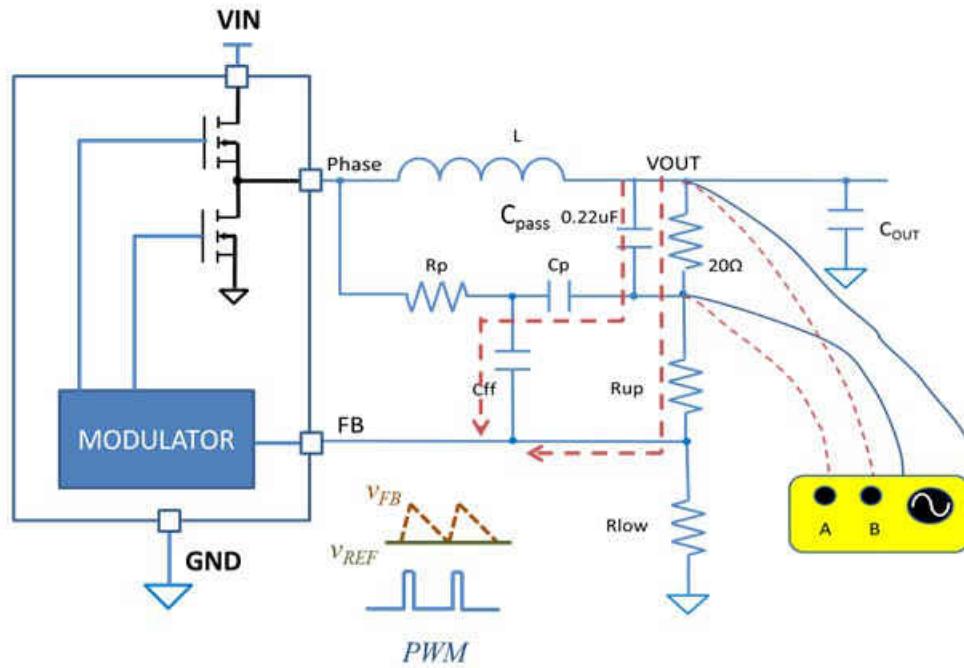**Figure 1-2. Block Diagram of a D-CAP Regulator With an External DCR Injection Circuit**

Figure 1-3. Proper D-CAP Regulator Control-Loop Bode Plot Measurement Setup

2 D-CAP Bode Plot Measurement Setup

For D-CAPx regulators, the PWM modulation gain is determined by the falling slope of the triangular waveform formed at the FB pin by the DCR injection network and output-capacitor equivalent series resistance (ESR). The parasitic inductance and resistance along the injection cable and noise coupled into the wires distorts the triangular waveform at the FB pin, which renders a different PWM modulation gain than the regulator with an improper test setup. To preserve accuracy, a bypass capacitor, C_{pass}, is added in parallel to a 20-Ω resistor by forming a high-pass filter. The corner frequency is set lower than one-half of the switching frequency of the converter so that the triangular waveform at the FB pin during the testing remains similar to that during normal operation. A 0.22 μF capacitor is used for a converter switching at 500 Hz in this example. For most applications, the proper C_{pass} value would be from 0.1 μF to 0.47 μF. To minimize the effect on the system, the DCR injection capacitor, C_p, should be less than one-tenth of C_{pass}, as Figure 1-3 shows.

3 Bode Plot Measurements

Figure 3-1 shows the Bode plot measurement results using the test setup shown in Figure 1-3 using the TPS53319 using an external DCR injection circuit and programmed to 1.2-V output. A capacitor value of 0.22 µF is chosen for C_{pass} and 22 nF for C_p. By adjusting R_p and C_{ff}, the crossover frequency is set at one-sixth of the switching frequency with a phase margin of 66 degrees.
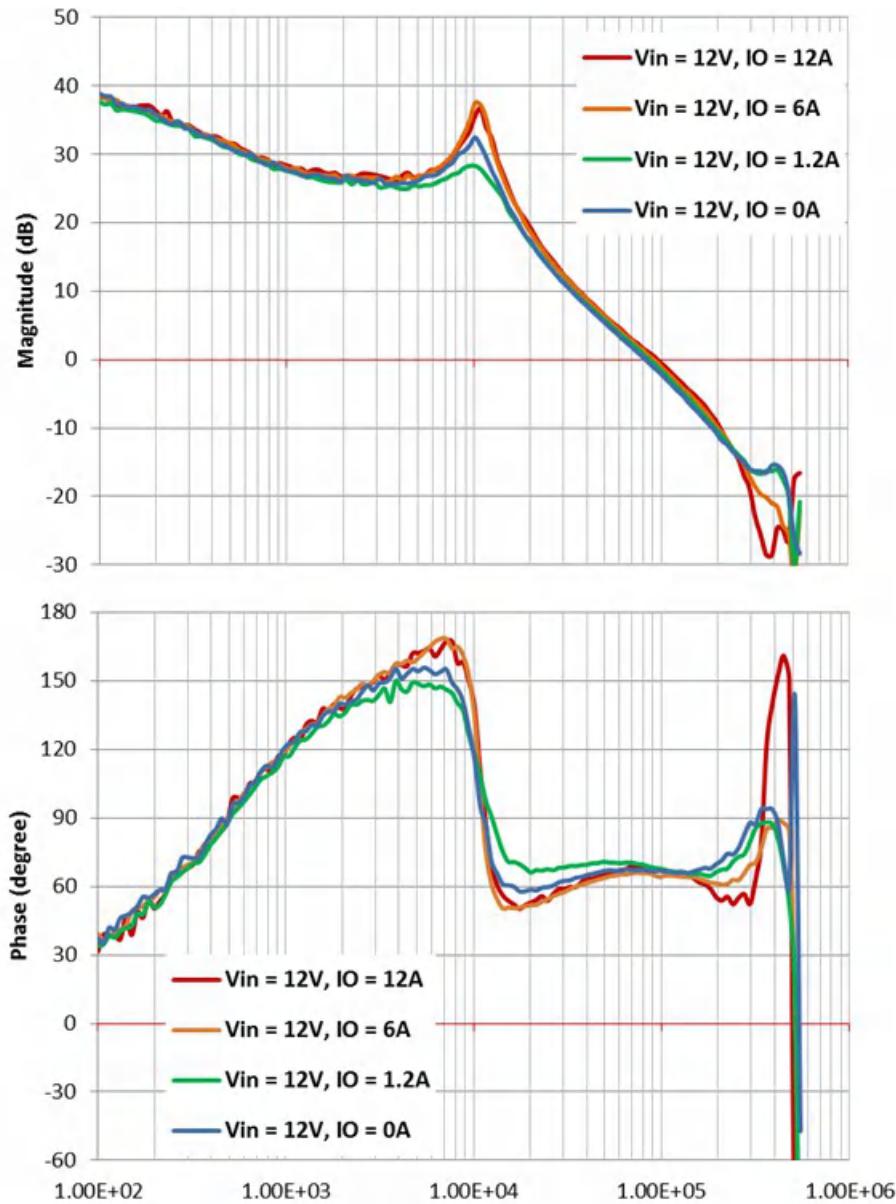

Figure 3-1. Bode Plots Measured With the Proposed Test Setup

4 Transient Response Waveforms

Figure 4-1 and Figure 4-2 show the corresponding transient response waveforms during step-up and step-down load transients using the TPS53319 configured with a 1.2-V output. The transient waveform behavior correlates to the Bode blot in Figure 3-1.
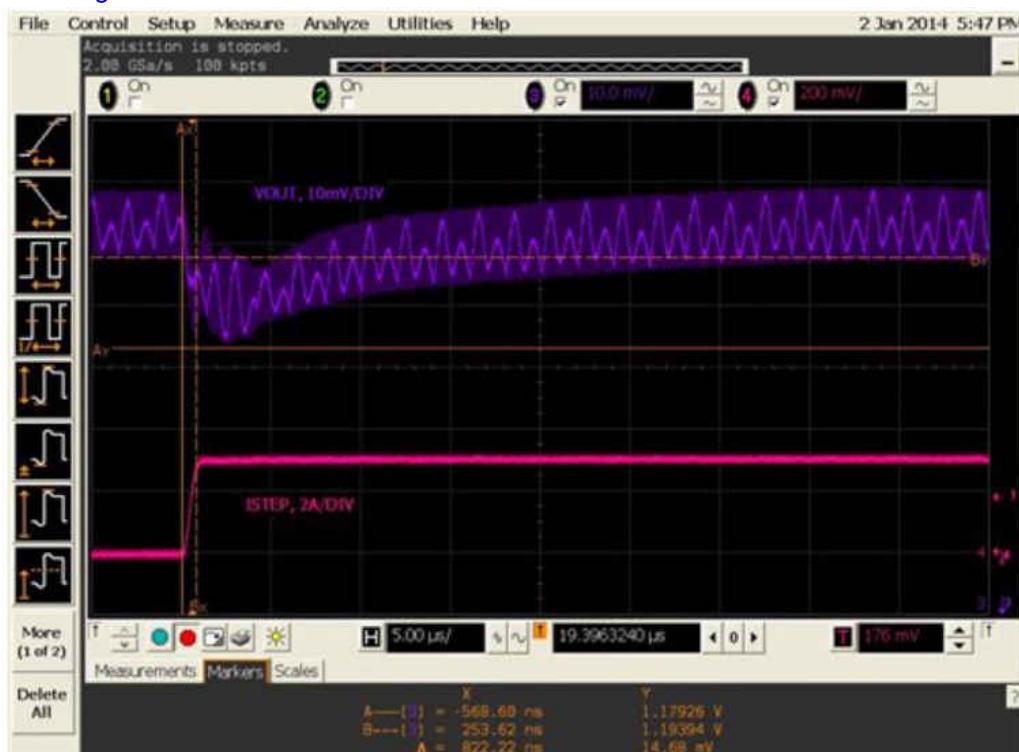

Figure 4-1. Step-Up Load Transient Response

Figure 4-2. Step-Down Load Transient Response

5 D-CAP2 and D-CAP3 Bode Plot Measurement Setup

For D-CAP2 and D-CAP3 control systems, the DCR injection circuit is integrated inside the integrated circuit. However, the same technique is applicable. Figure 5-1 shows the loop Bode plot test setup for both D-CAP2 and D-CAP3 converters.
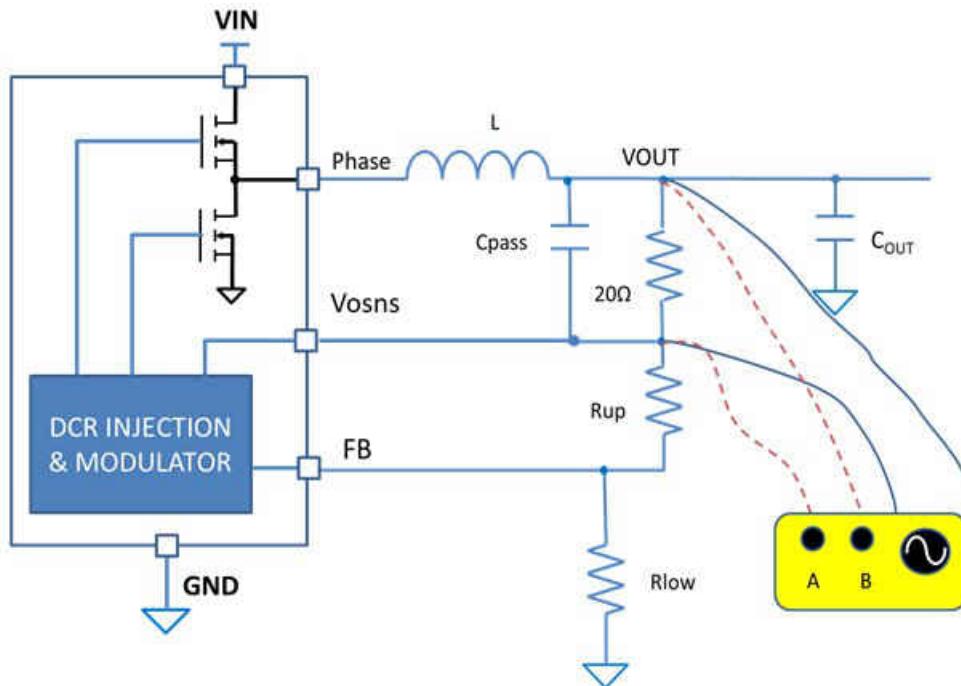
Figure 5-1. Proper D-CAP2 and D-CAP3 Control-Loop Bode Plot Measurement Setup

6 Measurement Tips

To obtain a good Bode plot measurement, it is important to pay attention to the setup and take precautionary steps to reduce measurement errors. Some basic recommendations are:

- Before taking the measurement, calibrate the network analyzer or do a 0-dB measurement to ensure flat gain and zero phase across the frequency range of interest.
- Use the analog ground of the controller or converter as the reference for the Bode plot probes.
- Keep the probes far away from the inductor to avoid coupling the inductor magnetic-field signal onto the AC injection magnitude.
- If possible, use the resistive power dissipation at the load connection instead of the electronic current source mode.

7 Summary

Bode plots are measurable for DCAP, D-CAP2, and D-CAP3 converters. With the technique provided, Bode plots can be measured to make sure of the system stability and to serve as a guideline to optimize load transient performance. To obtain a trustworthy Bode plot result that provides confidence about your system, take some precautionary setup steps to minimize errors.

The author of this application note shares thanks to Manjing Xie for her work in measuring Bode plots.

8 References

- Texas Instruments, *Power Tips: How connection wires affect Bode plot measurements*, Manjing Xie.
- Texas Instruments, *D-CAP3 – A sequel better thLAan the original*, George Lakkas.
- Texas Instruments, *Design advantage of D-CAP control topology*, Xiao Xu.

9 Revision History

Changes from Revision * (May 2021) to Revision A (April 2023) **Page**

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