

Kit Nguyen

Converter stability is a primary requirement for any synchronous buck converter design. Confirming converter stability requires that you derive the small-signal transfer function and measure the Bode plot of a closed-loop system. It is possible to derive the small-signal transfer function rigorously using complicated mathematic equations; the results can be very insightful in terms of understanding the nature of the stability requirement. However, deriving the small-signal transfer function is outside of the scope of this post.

In the absence of theoretical analysis, you can use a network analyzer to measure the Bode plot and confirm the stability of your converter design. If done properly, the Bode plot result can be a very useful, quick way to help you gauge converter stability.

The D-CAP™ topology is gaining in popularity due to its ease of use. D-CAP stands for “directly across the output capacitor.” TI introduced a family of D-CAP™ switch mode power supplies that incorporates either the external RCC network ( $R_{RAMP}$ ,  $C_{RAMP1}$  and  $C_{RAMP2}$ ) or an internal ripple-injection circuit such as D-CAP3, making it easier to design with all-ceramic-output capacitor configurations (Figure 1). In this post, I will compare the D-CAP3™ Bode plot measurement results based on different setup methods, including ripple injection magnitude and small-signal injection magnitude. In order to obtain a reliable and meaningful Bode plot result, you’ll have to follow a few preliminary steps.

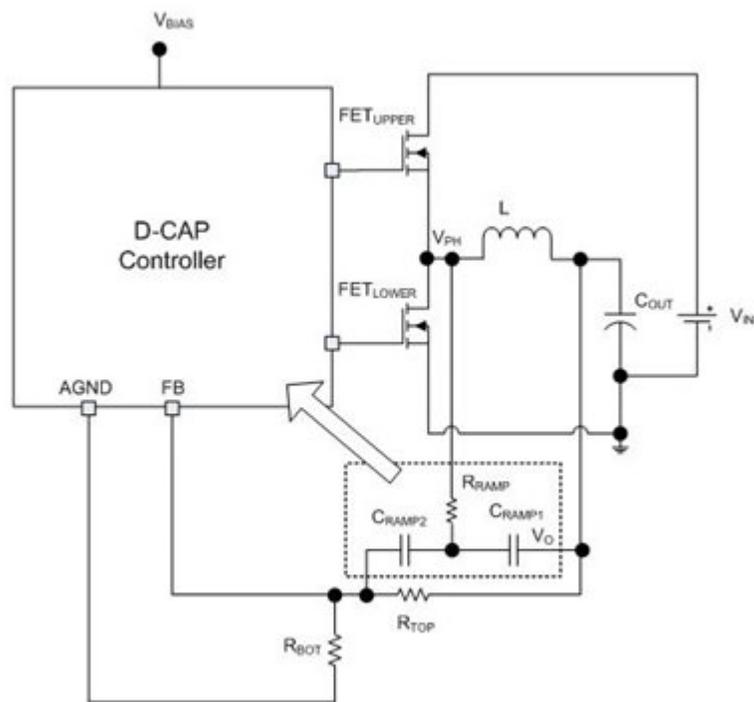


Figure 1. D-CAP IC with RCC Network Synchronous Buck Converter

Figure 2 shows two setup methods of network analyzer equipment: the VO pin at the input ( $V_A$  in Figure 2a) and output ( $V_B$  in Figure 2b) of the AC injection. This VO pin is the same signal as the  $V_O$  of the RCC network in Figure 1. From the Bode plot phase margin test theorem, the crossover frequency is defined when the frequency of the converter loop gain is at 0dB or unity. At this crossover frequency, the phase margin of the converter loop

gain must be positive, and at least higher than 45 degrees in order to reduce output voltage ringing during the load transient step.

The results in Figure 3 show the minimum difference between the two setup methods. However, by using the results from Figure 2a, you can confirm the resonant frequency location of the inductor and output capacitor values of the converter. The results are from the TPS548B22 evaluation board with  $V_{IN} = 12V$ ,  $V_{OUT} = 1V$ ,  $F_{SW} = 650kHz$ ,  $L = 330nH$ ,  $C_{OUT} = 2 \times 470\mu F + 7 \times 100\mu F$  and  $I_{LOAD} = 10A$  resistive load.

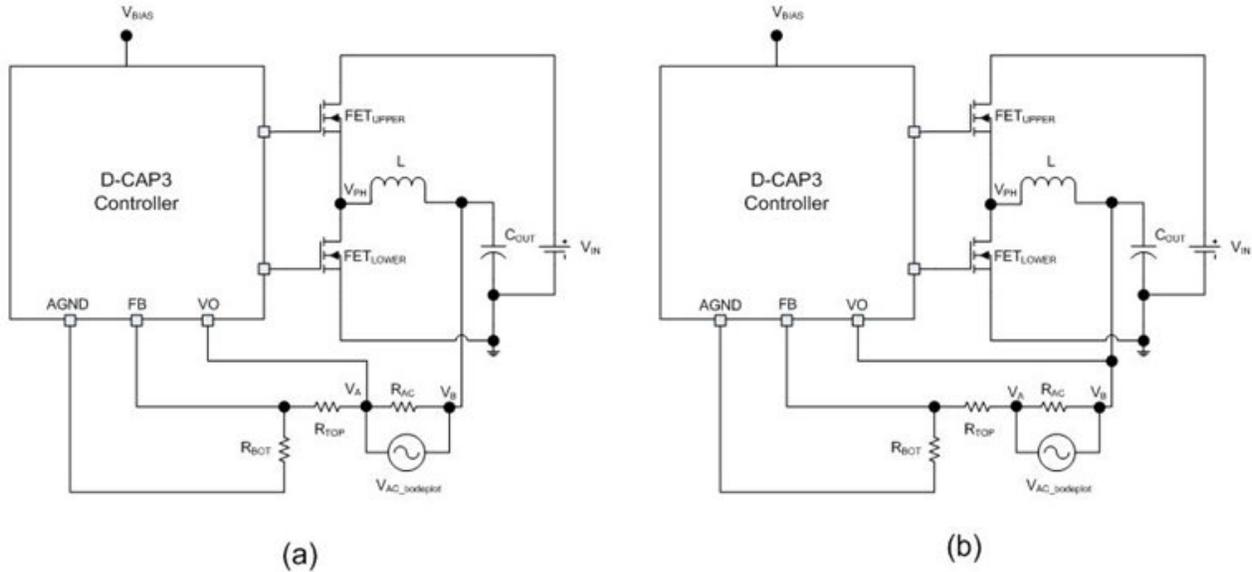


Figure 2. Bode Plot Setup of VO Pin at  $V_A$  (a) and at  $V_B$  (b) on TPS548B22 Evaluation Module EVM

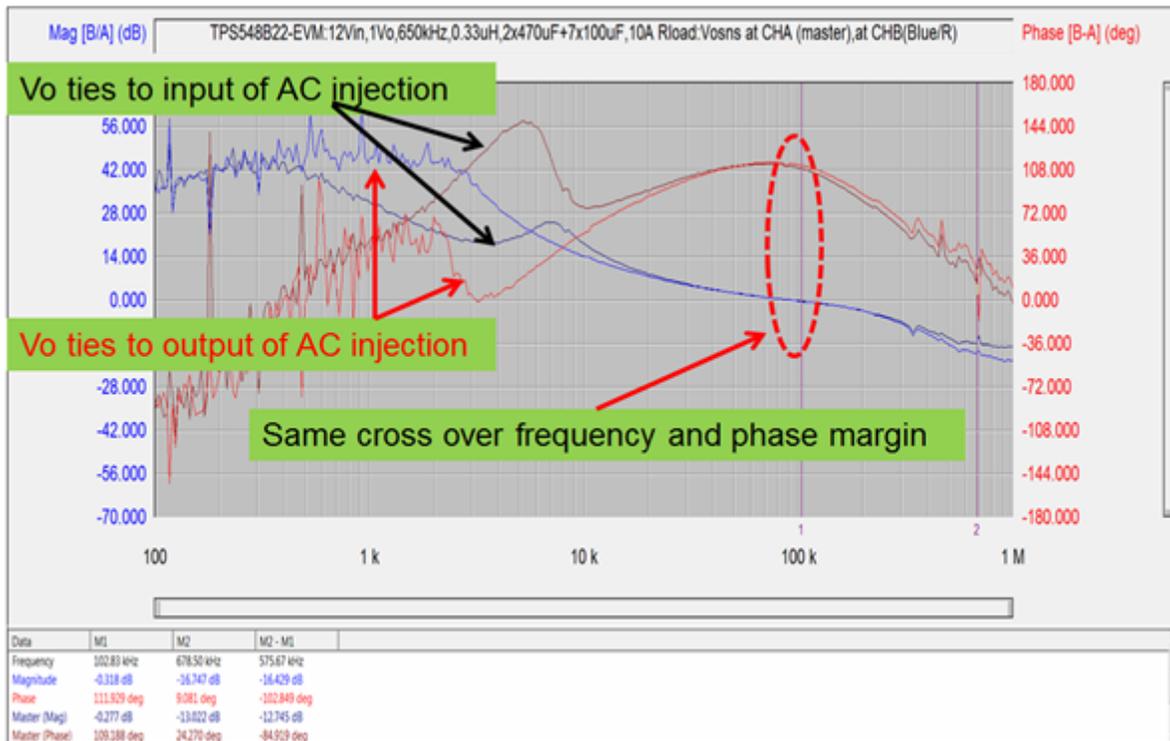
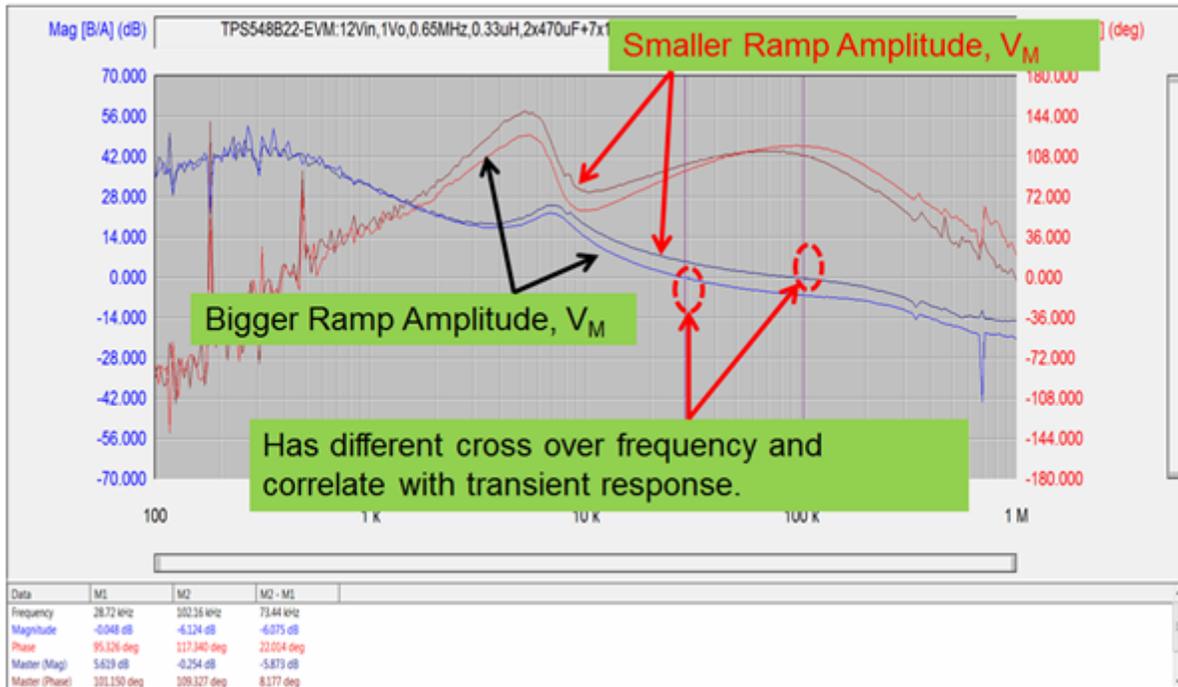


Figure 3. Bode Plot Results from the Setup Shown in Figure 2

You might ask how the magnitude of the RCC network affects the Bode plot result. Due to the noise sensitivity of this topology, the controller requires a minimum ramp magnitude to ensure that the converter operates correctly

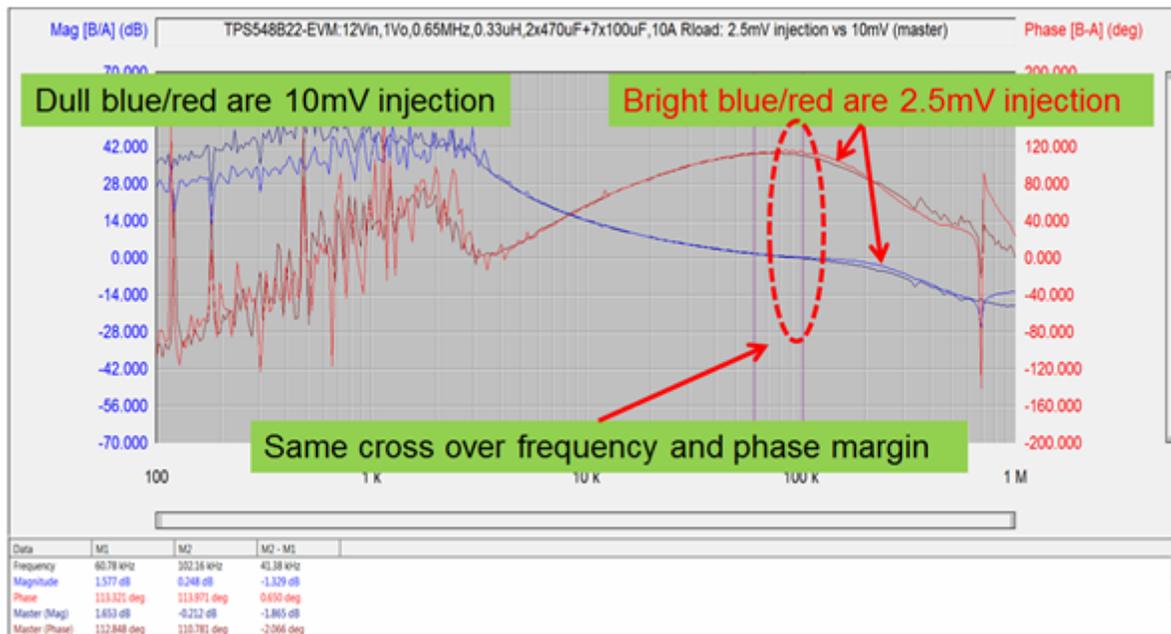
in steady state while providing the best load-transient response. Figure 4 shows the comparison results between a 6mV and 12mV ramp magnitude of the RCC network. The crossover frequency of the 12mV ramp is around 29kHz, with a 95-degree phase margin. The crossover frequency of the 6mV ramp is about 102kHz, with a 117-degree phase margin.



**Figure 4. Bode Plot Comparison with Different Ramp Values on the TPS548B22 EVM**

As you can see from Figure 4, the RCC ramp magnitude affects the crossover frequency and phase margin.

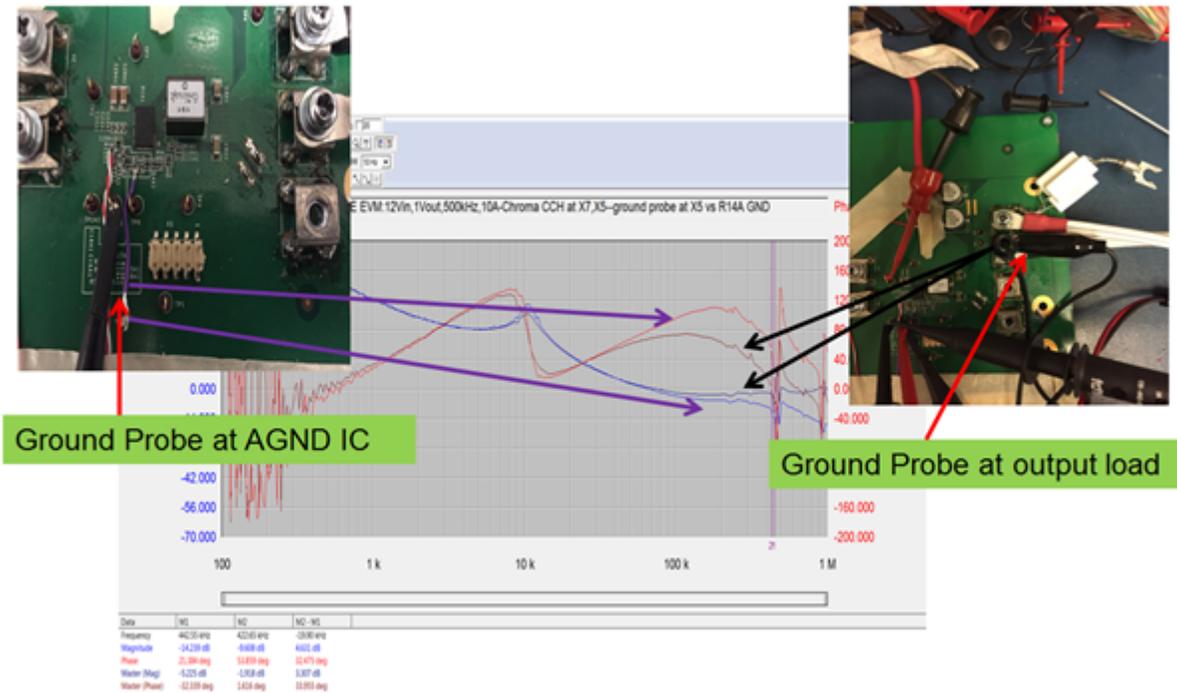
Another question that you may have when taking Bode plot measurements in D-CAP 3 control mode is what the AC injection magnitude range needs to be when measuring – and it must be a range that won't affect the converter loop-gain result. Figure 5 shows the comparison results with a 2.5mV and 10mV AC injection signal. A good recommendation value is to keep this AC injection magnitude to 10mV or less.



**Figure 5. Bode Plot Comparison with Different AC Injection Magnitude**

To obtain a good Bode plot result, it is critical that you pay attention to the setup and take some precautionary steps to reduce errors in the measurement. Some basic recommendations are:

- Before taking the measurement, calibrate the network analyzer or do a 0dB measurement to ensure flat gain and zero phase across the frequency range of interest.
- Use the analog ground of the controller as the reference for the Bode plot probes. See the example comparison in [Figure 6](#).
- Keep the probes far away from the inductor in order 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.



**Figure 6. Bode Plot Comparison on Customer Board with Different Ground Probe Connection Location**

A Bode plot measurement result enables you to quickly gauge converter stability rather than deriving the converter’s small-signal transfer function. The phase margin test theorem gives the same results whether the VO pin is at the input or output location of the AC injection in D-CAP3 control mode setups. To obtain a trustworthy Bode plot result that gives you confidence about your system, take some precautionary setup steps to minimize errors. Read the blog posts [“D-CAP3 – A sequel better than the original”](#) and [“Design advantage of D-CAP control topology”](#) for more information on TI’s D-CAP control architecture.

## IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATA SHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES "AS IS" AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, regulatory or other requirements.

These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI's products are provided subject to [TI's Terms of Sale](#) or other applicable terms available either on [ti.com](https://www.ti.com) or provided in conjunction with such TI products. TI's provision of these resources does not expand or otherwise alter TI's applicable warranties or warranty disclaimers for TI products.

TI objects to and rejects any additional or different terms you may have proposed.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2023, Texas Instruments Incorporated