How to Measure the Control Loop of DCS-Control™ Devices

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ABSTRACT

The DCS-Control™ topology, although not inherently stable, is stable for a wide range of output filter values and its stability can be measured through a load transient or bode plot. The converter's response to a load transient is measured in the same fashion as other integrated circuits, whereas taking a bode plot requires a slightly different setup for the DCS-Control™ topology. This application report reviews the basics of measuring control loops, discusses the changes for this family of DCS-Control™ devices, and gives an example of a measured bode plot for the TPS62130.

1 Review of Measuring Control Loop Gain and Phase

Measuring the loop gain of a control system provides much insight into the performance of a system. For instance, the bandwidth of the control loop indicates the response time of the system to changes. In terms of a switching regulator, the bandwidth gives an indication of the time it takes the output voltage to recover from quick changes in load, such as a processor transition from a sleep state to an active state. In addition, the control loop phase margin is a sign of the stability of the system and the dc gain provides information about the steady-state error of the dc output voltage.

The preferred method of measuring the control loop is called voltage injection as presented by Erickson and Maksimovic in *Fundamentals of Power Electronics*. The measurement is performed by breaking the whole loop in a single place, injecting a signal into the loop, and measuring the relative amplitudes and phase of the input signal and output signal versus frequency. Voltage injection requires breaking the loop by placing a resistor between a relatively low Thevenin equivalent source impedance and a high load impedance. The actual loop gain, $T_v(s)$, in terms of the measured gain, T(s), is related by Equation 1. The error between the actual loop gain and the measured gain is minimal when $|Z_1(s)| << |Z_2(s)|$, where $Z_1(s)$ is the source impedance and $Z_2(s)$ is the load impedance. Therefore, the measured gain, T(s), is approximately equal to the actual gain, $T_v(s)$, when the loop is properly broken.

$$T_v(s) = T(s)\left(1 + \frac{Z_1(s)}{Z_2(s)}\right) + \frac{Z_1(s)}{Z_2(s)} \tag{1}$$

For traditional voltage-controlled switching regulators, the resistor is added between the output and the high-side feedback resistor. This ensures the condition previously stated because the output impedance of the regulator is low and the high-side feedback resistor is relatively high. A signal is then injected by a transformer placed across the resistor and the measurements are taken on each side of the resistor. Theoretically, the value of the added resistor does not effect the measurement, but in practice a 10-Ω to 50-Ω resistor is used to avoid affecting the output voltage set point of the controller. Figure 1 shows the control loop test setup for a generic buck converter where Rs is the added resistor, Vsig is the injected signal, and the measurements are taken at points C1 and C2. Because the measurement requires breaking the entire loop, any feedforward capacitance also needs to be separated from Vout as shown in Figure 1.

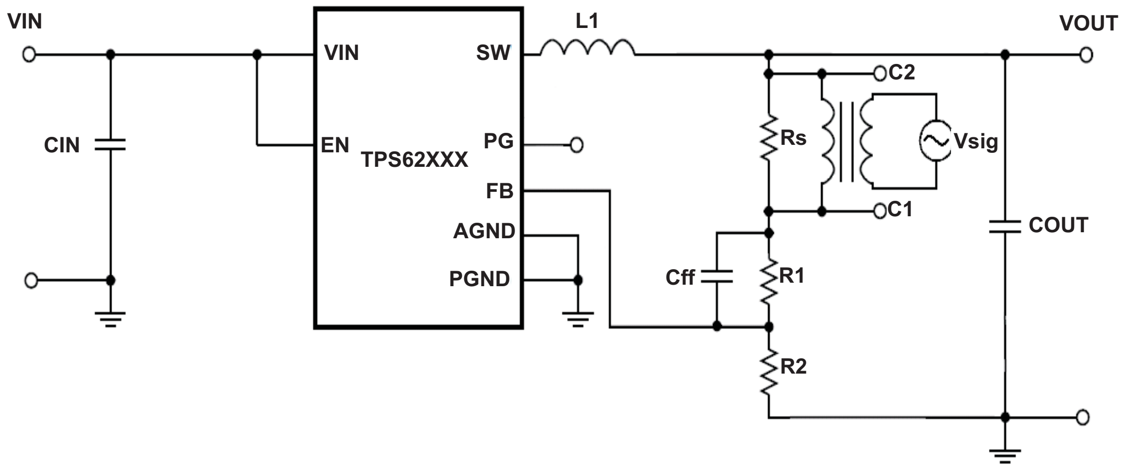

Figure 1. Control Loop Measurement Setup for a Generic Buck Converter

2 Measuring the Control Loop of the TPS62130

Although the voltage injection method is still used for DCS-Control™ devices, Figure 2 shows a few changes in the implementation with the TPS62130 used as an example. For one, the DCS-Control™ architecture has two control loops, which includes a direct connection to Vout (VOS) as well as a connection to the FB pin. In order to measure the entire control loop, both loops must be broken by placing the added resistor, Rs, between Vout and the VOS pin. The VOS pin, which is normally connected to Vout, is then connected to the top of the high-side resistor, R1, in the feedback loop. If an external feedforward capacitor is used, it is placed across R1, just as the TPS62130's internal 25-pF feedforward capacitor is, as shown in Figure 2. With this configuration, the voltage is still injected across Rs through a transformer and the measurements are still taken at the points C1 and C2.

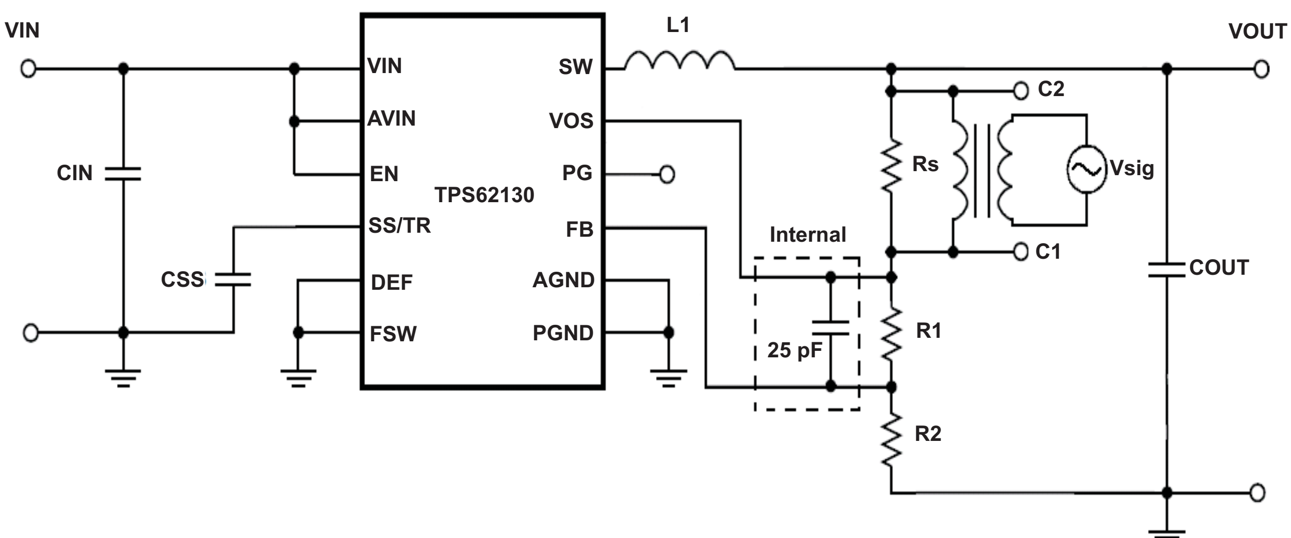

Figure 2. Control Loop Measurement Setup for the TPS62130

Figure 3 is an example plot taken of the TPS62130 with the recommended output filter of a 2.2-µH inductor and 22-µF capacitor taken with 12 Vin and 3.3 Vout at 1 A. Rs is a 10-Ω resistor and the feedback resistors R1 and R2 are 43.2 kΩ and 13.7 kΩ, respectively. No external feedforward capacitor was used. The plot shows the gain peak around 30 kHz due to the output filter and a gain crossover frequency of 291.2 kHz.

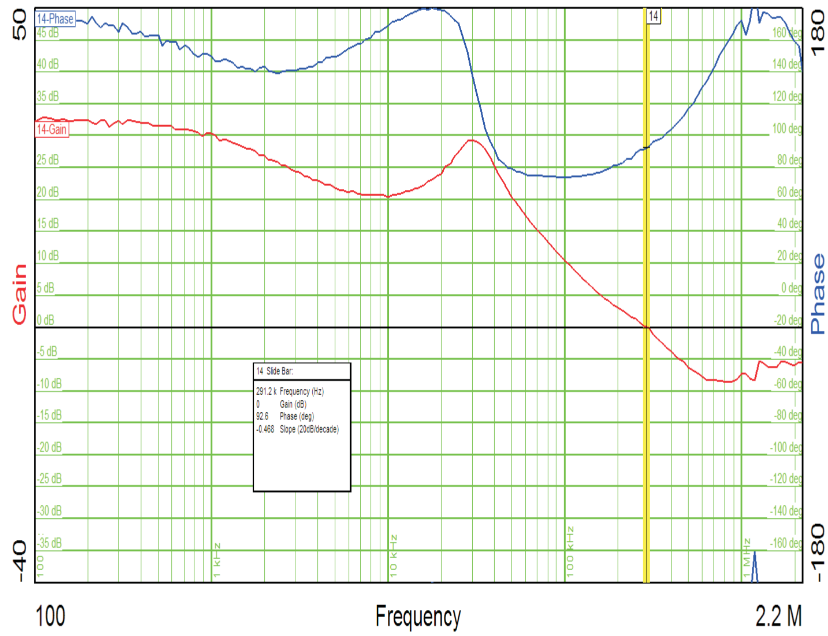

Figure 3. Example Control Loop Gain and Phase of the TPS62130

Because the DCS-Control™ architecture is fundamentally hysteretic and thus regulates based on output voltage ripple, the magnitude of the injected signal needs to be low. For Figure 3, the maximum signal voltage at either C1 or C2 was 2 mV_{RMS}. Additionally, for the control loop measurement to be valid, the converter needs to be stable and in PWM mode. To check for instability, look at the switch node on an oscilloscope and look for a large amount of jitter or a nonperiodic waveform. For the PWM mode, the device needs to have a large enough output current to prevent the inductor current from reaching zero. Because these devices respond like voltage-mode controllers, the load current does not affect the loop gain much. Thus, the measurement at 1 A is nearly the same as at 3 A.

3 Measuring the Control Loop of a Fixed Output Voltage DCS-Control™ Device

The fixed output voltage versions of the TPS62130 have internal feedback resistors that regulate the output voltage at a fixed level. Although the resistors are fixed, the inductor and output capacitor can be changed and thus may necessitate measuring the control loop to verify desired performance. Similar to the adjustable version, the control loop is broken by placing Rs between Vout and the VOS pin as shown in Figure 4. A signal is injected in the same way as before through a transformer placed across Rs and the measurements are taken at points C1 and C2. For the fixed output voltage devices, the FB pin does not provide access to the internal feedback node and should be grounded for proper operation.

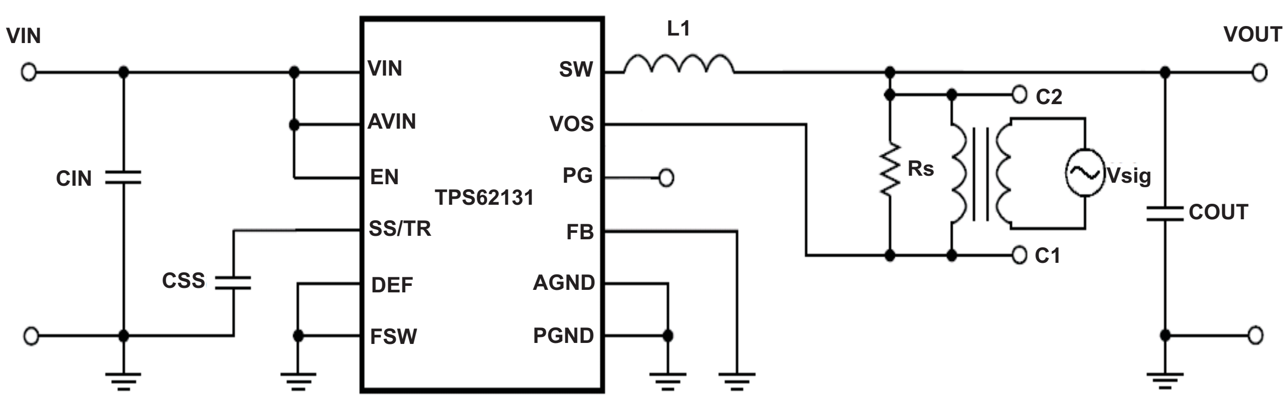

Figure 4. Control Loop Measurement Schematic for Fixed Output Voltage DCS-Control™ Devices

4 Conclusion

This application report reviews the voltage injection method of measuring a control loop and provides a method to measure the control loop of a DCS-Control™ device, such as the TPS62130. The differences between measuring the control loop for these devices versus other switching regulators are highlighted through test setups and descriptions and an example was given of measuring the control loop of a TPS62130 design. The method outlined in this application report works for both adjustable and fixed output voltage versions of the DCS-Control™ family of devices.

5 References

1. *TPS62130, 3-17V 3A Step-Down Converter in 3x3 QFN Package* data sheet (SLVSAG7)
2. Erickson, Robert, and Dragan Maksimovic. *Fundamentals of Power Electronics*. 2nd ed. Norwell, MA: Kluwer Academic Publishers, 2001. 362-67.
3. *Using a Feedforward Capacitor to Improve Stability and Bandwidth of TPS62130/40/50/60/70* application report (SLVA466)

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