TECHNICAL ARTICLE

Design a Second-stage Filter for Sensitive Applications

Certain applications, such as test and measurement (http://www.ti.com/applications/industrial/test-measurement/overview.html), are sensitive to voltage ripple and routinely require very low output voltage ripple. For example, 10µV/V of ripple ratio translates to 100dB of attenuation.

Since it's impractical to attain this level of attenuation using a buck regulator with a single-stage filter, a powerful design technique to reduce output voltage ripple is to use a second-stage inductor-capacitor (LC) filter, as shown in Figure 1. Proper configuration of the second-stage filter is essential for optimal performance.

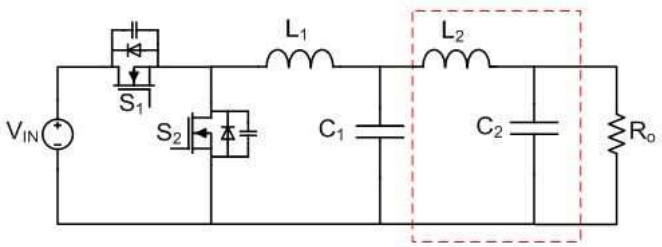

Figure 1 Buck with a Second-stage LC Filter

In order to obtain a total of 100dB attenuation at the switching frequency, the first and second LC filter are designed to give an attenuation A_1 (60dB) and A_2 (40dB), respectively. For the first-stage filter, inductor L_1 is designed to give a chosen ripple ratio based on the load current. In power modules, this L_1 inductor is integrated inside the package.

Equation 1 expresses the impedance of inductor L_1 at the switching frequency as:

$$X_{L1} = 2\pi * f_{SW} * L_1 \qquad (1)$$

Therefore, Equation 2 expresses the impedance of C_1 at the switching frequency as:

$$X_{C1} = \frac{X_{L1}}{10^{\frac{A_1}{20}} - 1} \qquad (2)$$

Equation 3 translates the required impedance X_{C1} to the value of capacitor C_1:

$$C_1 = \frac{1}{2\pi * f_{SW} * X_{C1}} \qquad (3)$$

The impedance of the filter should be sufficiently low at the output so that it does not significantly affect the loop gain of the converter. Low output impedance also helps with better regulation over long trace lengths. This is particularly true in systems where you can't maintain the load that the regulator is driving in close proximity to the regulator. As we can see from Figure 2, the ratio of first-stage capacitance (C_1) to second-stage capacitance (C_2) is critical to the impedance of the converter.

To ensure low impedance and make sure that the filter doesn't substantially affect the loop, I set the ratio of C_1 to C_2 as 1 to10.