Designing for Lowest Noise with the TPS62125

Brian Berner *Battery Power Applications*

ABSTRACT

To design a power supply for lowest noise, designers have traditionally required the power supply to operate in continuous conduction mode (CCM) at the lowest load current. By operating in CCM, the power supply is not allowed to enter its power save mode which usually has higher output noise. Designing in CCM requires either increasing the switching frequency and/or selecting a larger inductance. Both of these decrease the efficiency of the power supply, while choosing a larger inductance also worsens the transient response. The various ICs that use DCS-Control™ are designed to produce excellent efficiency at light loads in discontinuous conduction mode (DCM) while keeping the output noise low. No longer is the designer forced to design the power supply in CCM to achieve very low noise targets. In this application report, the performance results of designing the TPS62125 for CCM at light load currents are compared to the effects of re-designing the circuit with a lower inductance value that allows the TPS62125 to operate in DCM at the same load. The performance parameters of output voltage ripple, load transient response, switching frequency across load, and efficiency are compared between the CCM and DCM designs.

1 Circuit Operating Conditions

In order to design for the TPS62125 to operate in CCM, the designer first determines the typical operating conditions of the device. Table 1 lists the operating conditions used in this application report:

PARAMETER	VALUE
Input Voltage	12 V
Output Voltage	3.3 V
Minimum Load Current	50mA
Maximum Load Current	300mA
Output Voltage Ripple	0.2% (6.5mV)

Table 1. Operating Conditions of TPS62125 Circuit

Since the TPS62125's switching frequency is determined internally, only the inductance can be changed to adjust the CCM/DCM boundary. To eliminate solution size from the comparison of the two circuits, the same inductor family, Coilcraft's LPS3015, is used for both designs.

2 Choosing an Inductor to Operate in CCM

The benefits of CCM mode are a more predictable switching frequency across load and, as a result, the ability to calculate an output capacitor value that results in the desired output noise for the application. Before calculating the minimum output capacitance required though, an inductance must be calculated to ensure CCM at the minimum load current required by the application. Stability criteria must also be met, and the final inductor and output capacitors should be chosen based on the stability criteria outlined in the application report *Optimizing the TPS62125 Output Filter* (SLVA515).

In order for a buck converter to operate in CCM, the inductor current should not reach zero. To do this, first define the circuit parameters of maximum input voltage, output voltage, and minimum load current. Then, use Equations 1 and 2 to determine the minimum inductance that maintains CCM operation at the minimum load:

$$I_{L,min} = I_{out,min} - \frac{\Delta I_L}{2} \qquad (1)$$

$$L = \frac{(V_{in} - V_{out})}{\Delta I_L} \, x \, \frac{V_{out}}{V_{in}} \, x \, \frac{1}{fsw} \qquad (2)$$

For this design, the lightest load current that the circuit needs to supply is $I_{out,min} = 50mA$. From Equation 1, the ripple current should not exceed 100mA in order to keep $I_{L,min}$ above 0. By examining the graph in Figure 22 of the TPS62125 data sheet (SLVSAQ5), which is also shown in Figure 1 below, the switching frequency with $V_{in} = 12V$ and $V_{out} = 3.3V$ is approximated. In the graph, the left-hand side of the curve where the slope is steep and positive shows the region where the IC is operating in DCM. In this region, the IC outputs single “pulses” of current which then return to zero for an extended period of time. As the load increases, the pulses get closer together to supply the additional load current. Hence the drastic change in frequency versus load in this mode of operation. The “plateau” and right-hand side of the curve, where the slope is shallower and negative, is where the part is operating in CCM. Since the design requires CCM at a 12-V input voltage, in CCM (to the right of the peak frequency, where DCM ends and CCM begins) the frequency reaches its lowest point at 650 kHz. This value is used in equation 2 and slightly over-sizes the inductor since the actual switching frequency is higher at the minimum load current. Given all the necessary values, Equation 2 is solved for L. In this case, the inductance should be at least 37µH, so the next highest common value of 47µH is used.

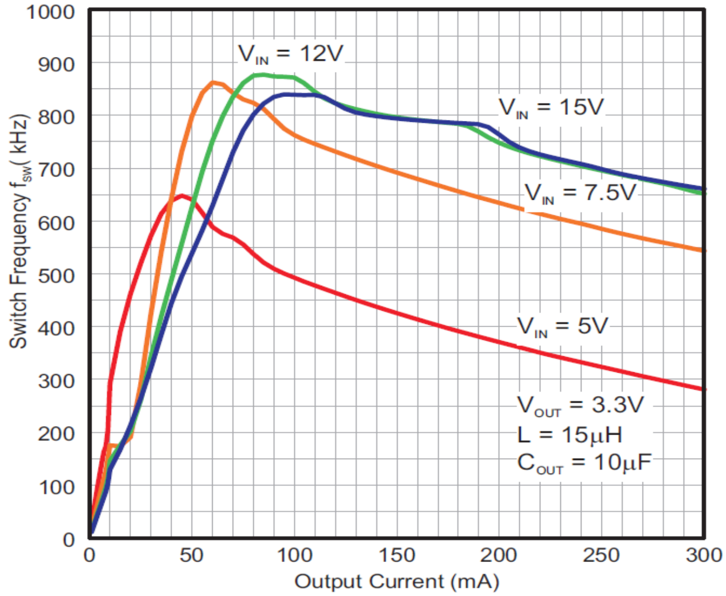

Figure 1. TPS62125 Switching Frequency vs. Output Current, V_{out} = 3.3V

3 Choosing an Output Capacitor to Meet Noise Requirements

The main concern when choosing the output capacitor is the maximum allowable voltage ripple. The capacitance required to attain a certain level of ripple in CCM is estimated using Equation 3:

$$C_{o,eff} > \frac{1}{8 \ x \ fsw} \ x \ \frac{1}{\frac{V_{o,ripple}}{\Delta I_L}} \quad (3)$$

Since the maximum ripple occurs at the minimum switching frequency (which occurs at the highest load), the same 650-kHz value is used to calculate the minimum output capacitance needed. The ripple current, $\Delta I_{L,}$ is calculated from Equation 2 using the chosen inductor value and is found to be 78.3 mA. For this example circuit, this produces a result of $C_{o,eff}$ = 2.32 µF from Equation 3, which does not account for the decrease of the capacitance due to the DC bias effect.

As the output voltage increases towards the voltage rating of the capacitor, the nominal capacitor value also needs to be increased to produce the desired effective capacitance. This can be approximated by Equation 4, which computes the nominal capacitor value needed to achieve the required effective capacitance that results from the DC bias applied to the capacitor.

$$C_{o,nominal} = \frac{(C_{o,eff} \ x \, V_{rating})}{V_{rating} - V_{out}} \quad (4)$$

Using Equation 4 with a voltage rating 6.3 V and an X5R ceramic package, the value of the capacitor is calculated to be 4.86 µF. A single capacitor with the very close value of 4.7 µF is used. The output voltage ripple at 50-mA load and at 300-mA load is shown in Figure 2 and 3, respectively.

The measured output ripple at minimum load and full load is below the target ripple of 6.5 mV, and the full load has slightly larger ripple due to the lower switching frequency. Figure 4 shows the load transient response from 50-mA to 300-mA load current.

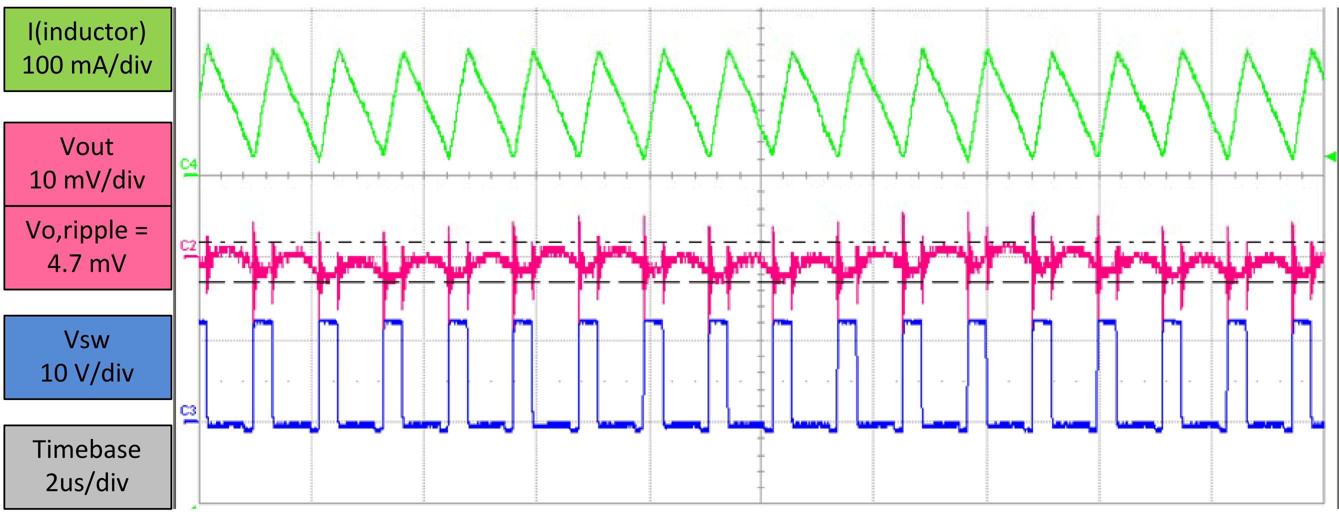

Figure 2. TPS62125 output voltage ripple at 50-mA (minimum) load using a 47-µH inductor and a 4.7-µF output capacitor

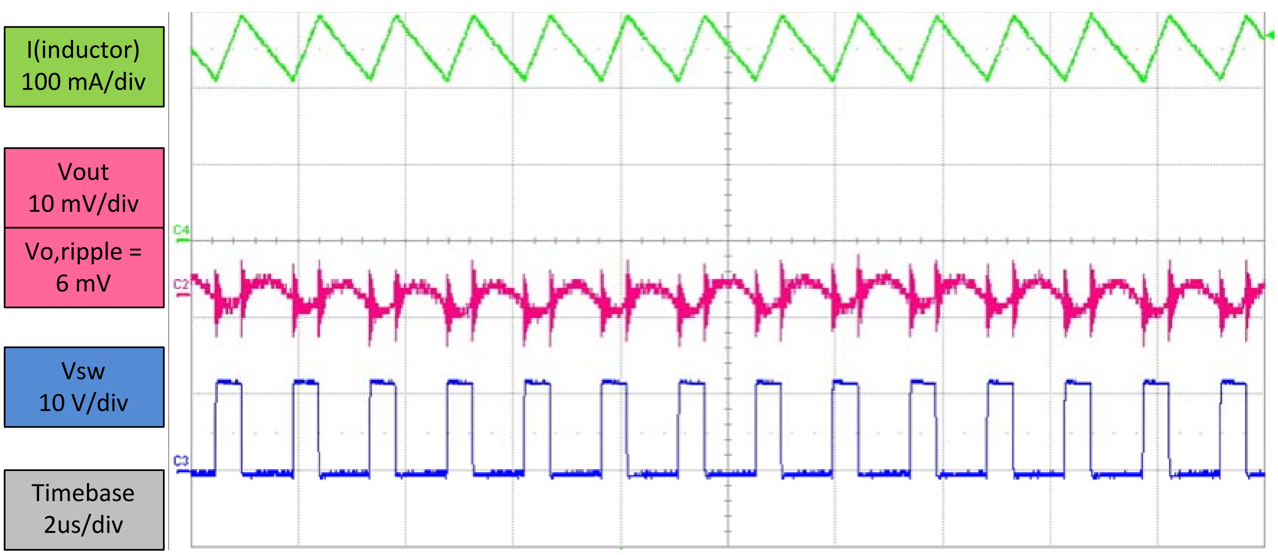

Figure 3. TPS62125 output voltage ripple at 300-mA (full) load using a 47-µH inductor and a 4.7-µF output capacitor

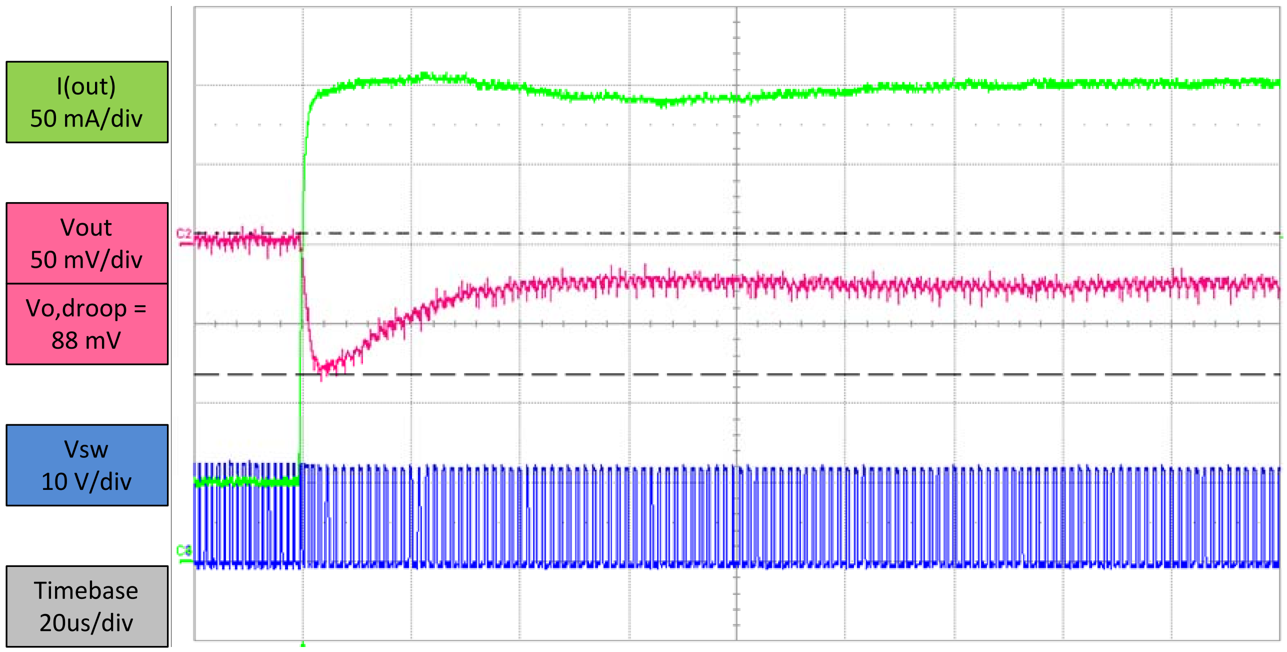

Figure 4. TPS62125 load transient response from 50-mA to 300-mA load current with a 47-µH inductor and a 4.7-µF output capacitor

4 Operating in DCM to Achieve Lowest Output Noise

DCS-Control™ is designed, not only for a seamless transition into power save mode, but also for a low output voltage ripple and noise in power save mode. Because of this, applications that with previous generations of converters would have required operating in CCM to achieve the required noise performance can now, with DCS-Control™, operate in power save mode and maintain the same output voltage performance while obtaining the benefit of increased efficiency at light loads. By reducing the inductance to 10µH, higher efficiency at both light and heavy loads is obtained. Figure 5 shows the very low output voltage ripple at 50-mA load with the same 4.7-µF output capacitor.

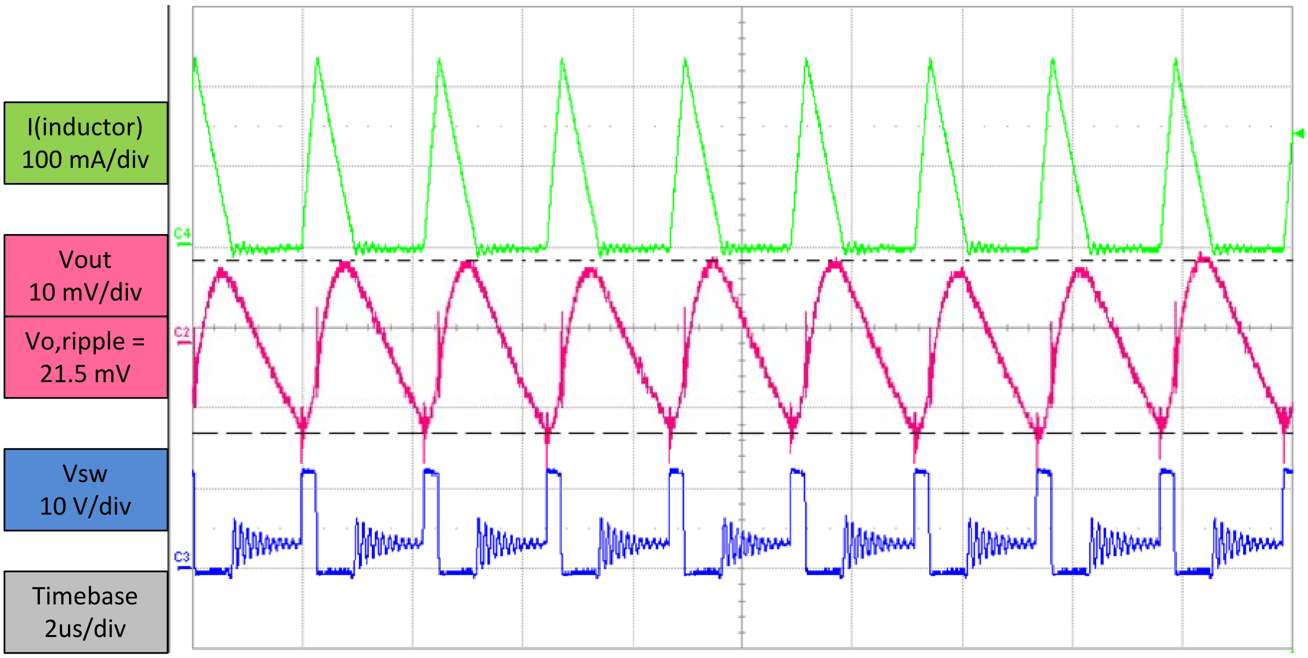

Figure 5. TPS62125 output voltage ripple using a 10-µH inductor and a 4.7-µF output capacitor

The amount of output ripple voltage increased to about 20 mV, which is 0.6% of 3.3 V. For some applications, this would be more than sufficient noise performance. For those applications requiring the reduction of the already low ripple in power save mode, more output capacitance can be used to further reduce the power save mode ripple.

5 Increasing the Output Capacitance to Meet the Output Noise Requirement

When the TPS62125 is in power save mode (DCM), then the magnitude of the ripple current is technically indeterminate because it cannot be negative. When the current should be negative, it is 0 instead as power save mode does not allow negative current. The exact calculation of ripple voltage in CCM can be seen in Equations 5 and 6.

$$\Delta V_{out} = \Delta I_L \; x \; Z_C \qquad (5)$$

$$|Z_C| = \sqrt{R_{ESR}^2 + (2\pi \; x \; fsw \; x \; L_{ESL} - \frac{1}{2\pi \; x \; fsw \; x \; C})^2} \qquad (6)$$

Although these equations do not directly apply to DCM, since ΔI_L cannot be easily calculated, they aid in determining how to reduce output voltage ripple. Increasing the output capacitance, C, reduces the resulting value of the fraction in Equation 6 and, in turn, reduces the impedance of the capacitor and the output voltage ripple. The easiest way to achieve the desired output voltage ripple is to choose a reasonably large capacitance and empirically determine that the output voltage ripple is below the desired amount. The smallest capacitance that results in under 6.5-mV voltage ripple is 47µF and the voltage ripple graph at minimum load is shown in Figure 6. The ripple at full load in this case is less than the ripple at minimum load due to the higher switching frequency in CCM. The load transient graph is displayed in Figure 7. A desired side effect of adding output capacitance to reduce ripple voltage is the positive benefit of a reduction in the voltage droop during the load transient.

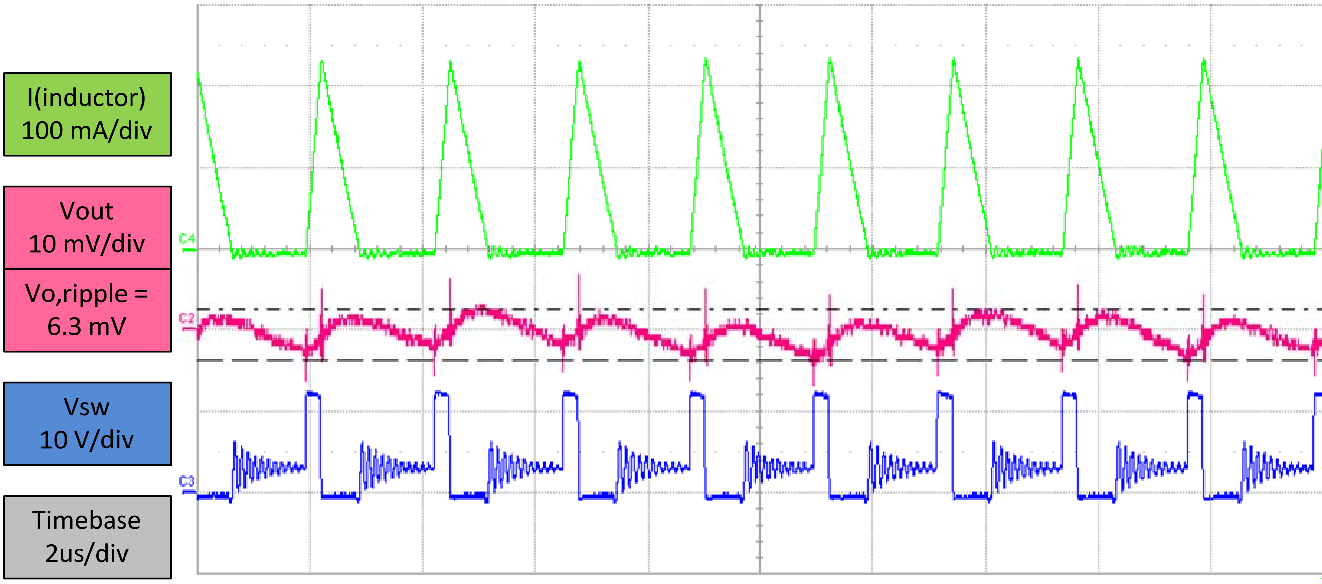

Figure 6. TPS62125 output voltage ripple using a 10-µH inductor and a 47-µF output capacitor

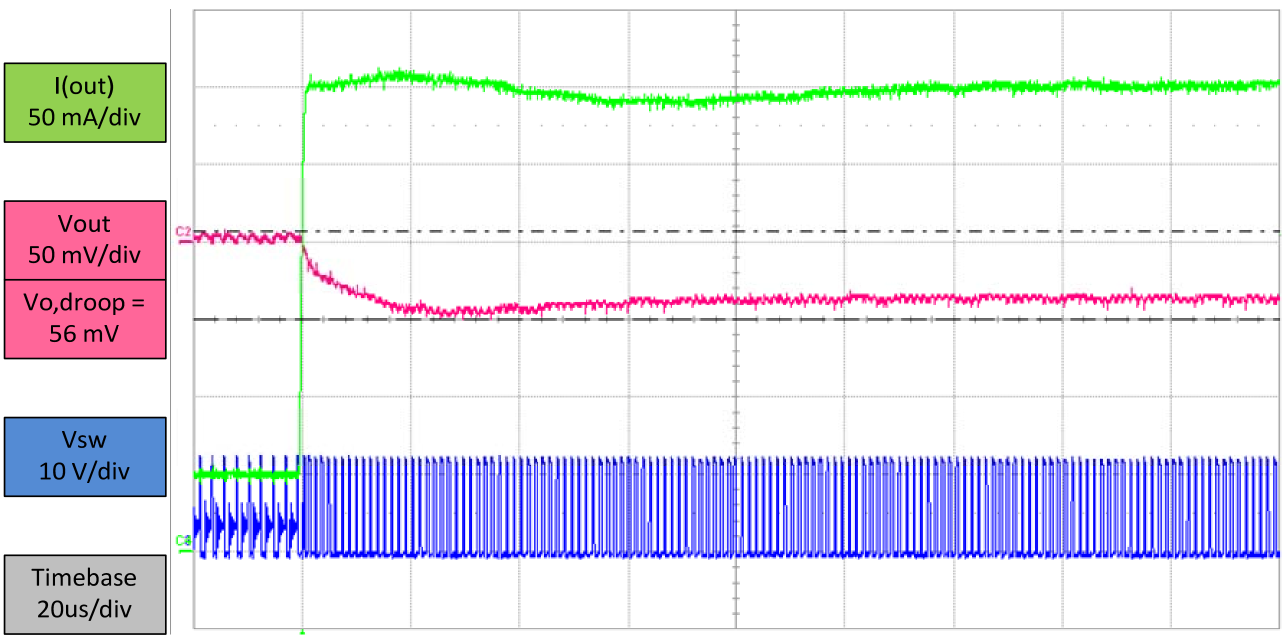

Figure 7. TPS62125 load transient response from 50-mA to 300-mA load current with a 10-µH inductor and a 47-µF output capacitor

6 Overall Performance Comparison of the Two Circuit Designs

As stated previously, the major benefit of using the TPS62125 in power-save mode is the increased efficiency. Figure 8 shows that the efficiency of the design using the 10-µH inductor is about 5% higher than the 47-µH inductor design.

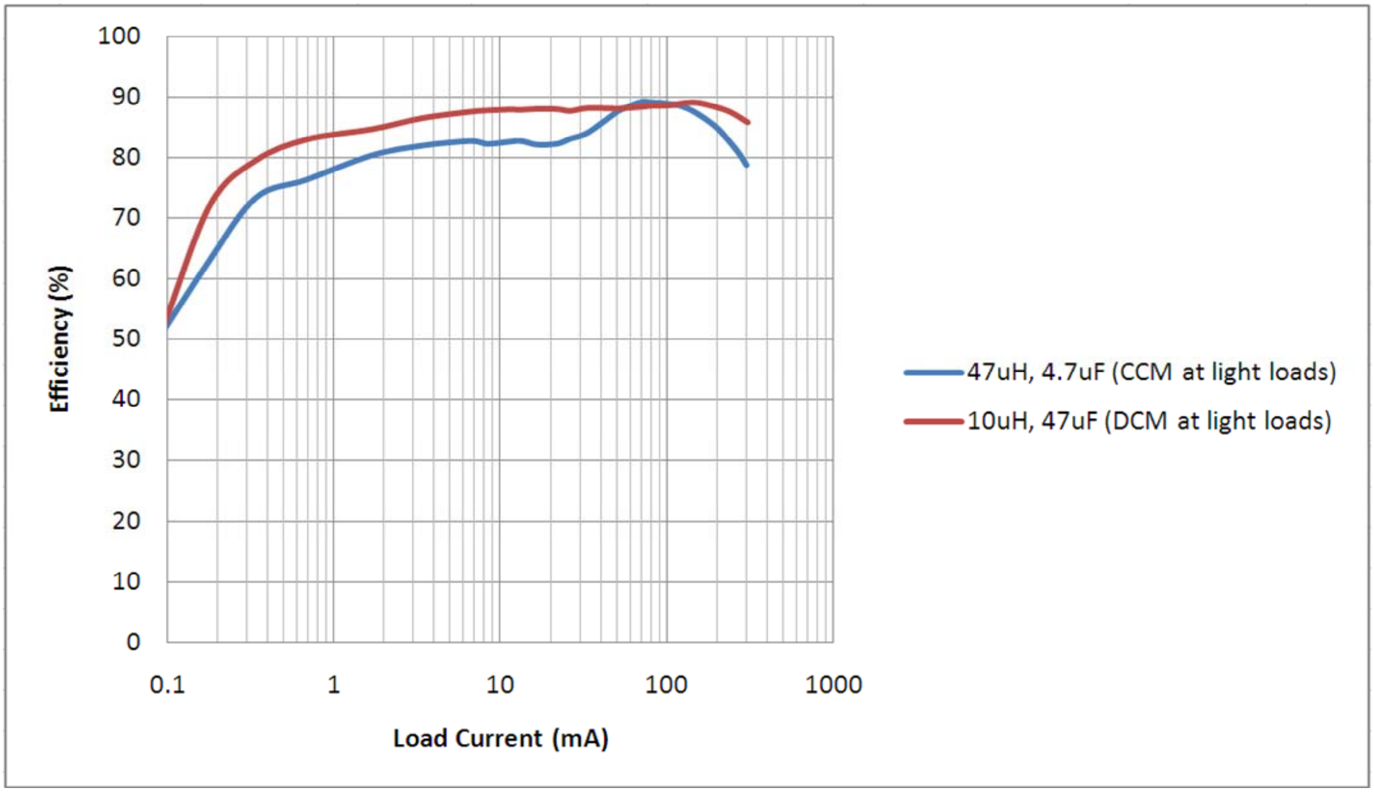

Figure 8. TPS62125 Efficiency vs. load current graph of the two designs

On the other hand, the larger inductance of the CCM design produces less switching frequency variation across load current in CCM. When compared to the 10-µH inductor results and the 15-µH inductor graph from Figure 1, it can be seen that increasing the inductor value also creates a steeper slope in DCM, transitions to CCM at lighter loads, and decreases the maximum switching frequency at the peak of the graph where the DCM-CCM transition occurs. Figure 9 shows these results and that the original design with the 47-µH inductor and 4.7-µF capacitor has less frequency variation across load current in CCM.

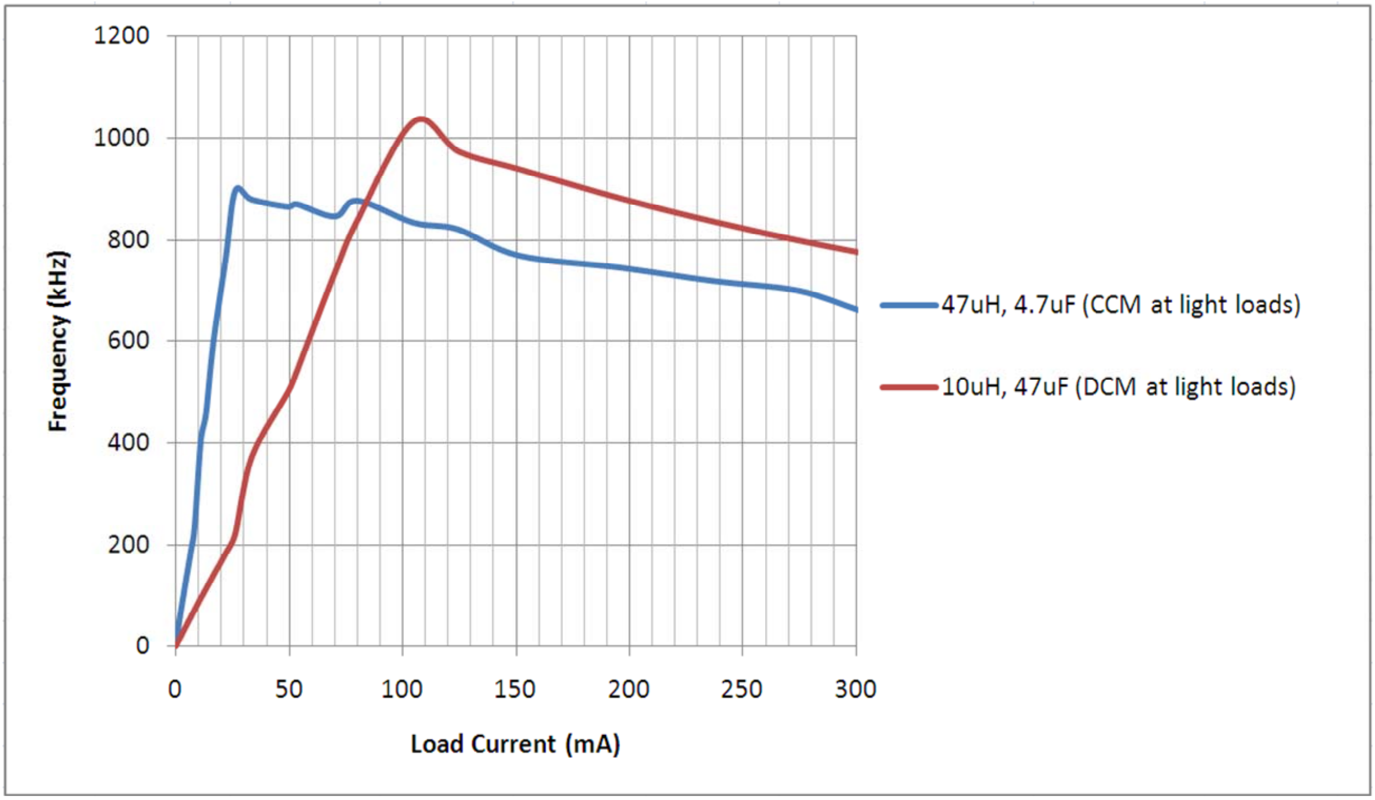

Figure 9. TPS62125 Frequency vs. load current graph of the two designs

Additionally, the DCS-Control™ topology is advantageous for audio applications because it minimizes interference with other noise-sensitive components in the system by keeping the switching frequency out of the audible range. While the switching frequency decreases with load, the transition below 30 kHz and into the audible range occurs at a load current of about 1µA for the 47-µH inductor, 4.7-µF capacitor circuit and at a load current of about 3.4µA for the 10-µH inductor, 47-µF capacitor circuit. Although the larger inductor circuit results in a steeper frequency slope and a transition out of the audible range at a lighter load, both circuits are only in the audible range for very light loads and interference is not a concern for most applications.

7 Conclusion

This application report has presented design considerations to create a low noise power supply with the TPS62125 operating in either CCM or DCM at light loads. The traditional CCM design uses a larger inductance which produces lower efficiency and poorer transient response though achieving smaller switching frequency variation. With DCS-Control™, a DCM design maintains the same magnitude of output voltage ripple and stays above the audible range, while keeping high efficiency and excellent transient response.

References

1. *Optimizing the TPS62125 Output Filter* (SLVA515)
2. *TPS62125, 3V-17V, 300mA Buck Converter With Adjustable Enable Threshold And Hysteresis* (SLVSAQ5)

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