Application Report
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Optimizing the TPS62090 Output Filter

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ABSTRACT

The TPS62090 family of devices uses a variation of the inherently stable hysteretic control topology called DCS-Control™, which allows for a wider range of inductor and output capacitor values than traditional voltage mode buck converters. The inductor and output capacitor values can be chosen to accomplish specific design goals, such as transient response or loop stability based on an application's needs. This application note discusses how to choose the output filter for the TPS62090 Vin buck converter in order to meet the specific requirements of a design.

Choosing an LC Combination

The designer must consider many factors when choosing an inductor and output capacitor combination for any switching regulator. For example, lower inductances can be physically smaller due to fewer windings which can save board space; however, the peak switch current and output voltage ripple increase. Larger voltage ripple can be offset by using a higher capacitance at the cost of larger size and slower transient response.

Stability is also a key factor that is affected by the inductor and capacitor values. The LC filter forms a double pole in the control loop which has a strong impact on the frequency response and stability of the system. Table 1 shows the stability of different LC combinations that have been tested in the laboratory with an input voltage of 4.2 V and a load current of 1.5 A at an output voltage of 1.8 V with the device running in high frequency mode (2.8-MHz switching frequency). Table 2 shows the stability of LC combinations for the same Vin of 4.2 V, load current of 1.5 A, and output voltage of 1.8 V with the device running on low frequency mode (1.4-MHz switching frequency). Although the stable combinations in the tables satisfy the requirements for control loop stability, certain combinations may not work in every system due to other measures of performance – such as output voltage ripple, load transient response or maximum output current.

Table 1. Stability vs Effective LC Corner Frequency for 2.8-MHz f_{sw}

	Capacitance			
Inductance Value	**10 µF**	**22 µF**	**47 µF**	**100 µF**
0.6 µH **Coilcraft XAL4020-601**		126.7 kHz 52.78 deg	77.71 kHz 48.22 deg	44.56 kHz 45.99 deg
1.0 µH **Coilcraft XFL4020-102**	197 kHz 53.7 deg	132.1 kHz 56.49 deg	77.37 kHz 44.71 deg	39.55 kHz 40.31 deg
2.2 µH **Coilcraft XFL4020-222**	106.4 kHz 52.85 deg	69.93 kHz 45.17 deg	50.05 kHz 35.94 deg	27.82 kHz 28.00 deg
	Recommended LC combination			
🟩	Acceptable LC combination depending on application			
🟨	Not recommended			

Table 2. Stability vs Effective LC Corner Frequency for 1.4 MHz f_{SW}

Inductance Value	Capacitance			
	10 µF	22 µF	47 µF	100 µF
1.0 µH Coilcraft XFL4020-102	222.2 kHz 53.55 deg	125.2 kHz 51.04 deg	82.09 kHz 49.06 deg	46.83 kHz 38.45 deg
2.2 µH Coilcraft XFL4020-222	116.5 kHz 57.18 deg	72.71 kHz 47.81 deg	49.07 kHz 37.61 deg	28.58 kHz 31.22 deg
⬜	Recommended LC combination			
🟩	Acceptable LC combination depending on application			
🟨	Not recommended			

Table 1 shows control loop stability versus effective corner frequency for a switching frequency of 2.8 MHz and indicates the corresponding nominal inductance and capacitance. Table 2 shows this information for a switching frequency of 1.4 MHz. The colors of the boxes indicate the stability of the system – white is recommended, yellow is acceptable, depending on the application, and red is not recommended.

Optimizing Load Transient Response

The load transient response describes the controller’s ability to recover from sudden changes in output current, such as those caused by a processor changing states. The amount of voltage deviation and the time that the controller takes to recover are the main measures of a controller’s load transient performance.

The response time of the controller is directly related to the bandwidth of the control loop. A higher bandwidth allows the controller to respond faster. Since the control loop compensation is fixed inside the IC, the bandwidth is primarily impacted by the corner frequency of the LC filter which forms a double pole in the control loop. The corner frequency of the filter is given as:

$$f_{LC} = \frac{1}{2\pi\sqrt{LC}} \tag{1}$$

Higher LC corner frequencies allow for higher control loop bandwidths. To increase the LC corner frequency, decrease the product of the inductance and capacitance.

Secondly, the amount of voltage deviation that occurs during a change in load must be restricted to keep the power supply voltage within the requirements of the system. This can especially pose a problem for processors that may operate incorrectly at low voltages. There are two main things that determine the amount of voltage deviation: the output capacitance and control loop bandwidth.

From the equation I = C × dV/dt, the output voltage deviation in response to a load step is defined as:

$$V_{DEV} = V_{OUT}(t_2) - V_{OUT}(t_1) = \frac{1}{C}\int_{t_1}^{t_2}\left[i_L(t) - i_{Load}(t)\right]dt \tag{2}$$

Where t_1 is the time the load step begins and t2 is the time that the average inductor current equals the new load current (see Figure 1). The time between t1 and t2 is an initial time period during which the output capacitor must supply the extra load current and therefore the capacitor voltage must decrease. From Equation 2, the most obvious way to reduce this initial deviation is to use a larger capacitance. It is worth noting that a larger capacitance has a negative impact on the controller’s response time.

Figure 2 and Figure 3 show the effects of a larger output capacitor on voltage deviation and settling time, and the time it takes for the output voltage to settle within a tolerable percentage of the nominal voltage. Figure 2 shows the transient load response with a 1.0-µH inductor and 10-µF capacitor. Figure 3 shows the transient load response with the same inductor and a 100-µF capacitor. The 10-µF capacitor has a voltage deviation of about 50 mV, while the 100-µF capacitor has a deviation of about 40 mV. The downside of using the larger capacitor is that the settling time of the output voltage is about one and a half times as long as the smaller capacitance.

Figure 4 and Figure 5 show the control loop bandwidth for each circuit as measured by the method presented in SLVA465. As expected, Figure 5 has a lower bandwidth which translates to a longer response time.

At time t_2, when the average inductor current is equal to the new load current, the controller begins to supply the extra current rather than the output capacitor. At this time, the voltage has deviated by its maximum amount from the desired value and the controller begins to recharge the output capacitor. Therefore, another way to reduce the amount of voltage deviation is to decrease the amount of time that the controller takes to respond and thus reduce the time between t_1 and t_2. This is accomplished by increasing the bandwidth of the controller by decreasing the inductance.

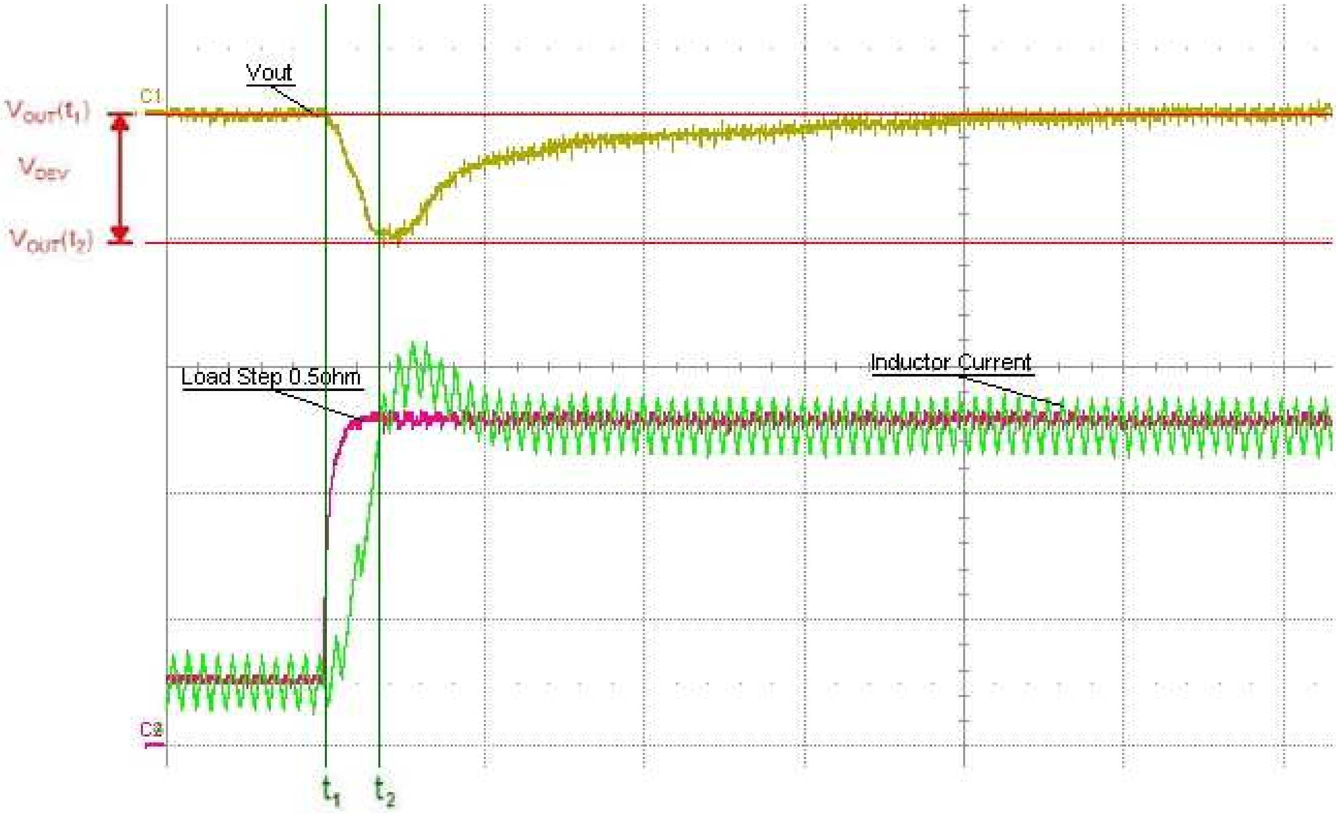

Figure 1. Load Transient Response of the TPS62090

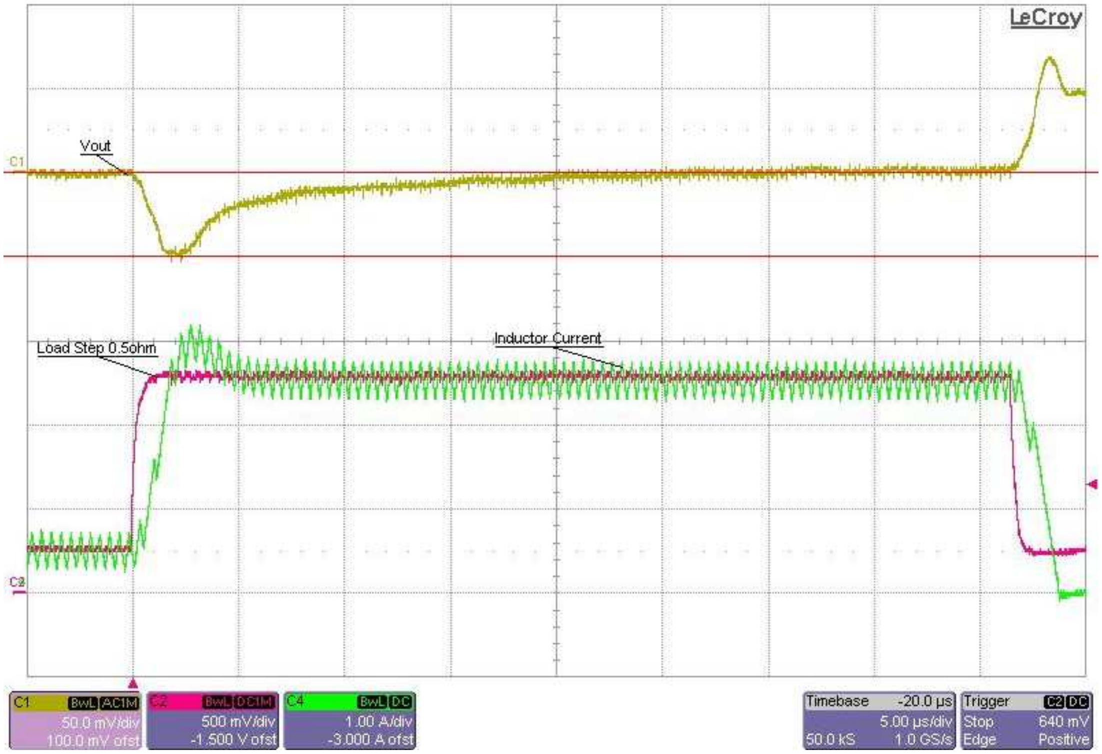

Figure 2. Load Transient with 1.0-µH Inductor and 10-µF Capacitor (f_{sw} = 2.8 MHz)

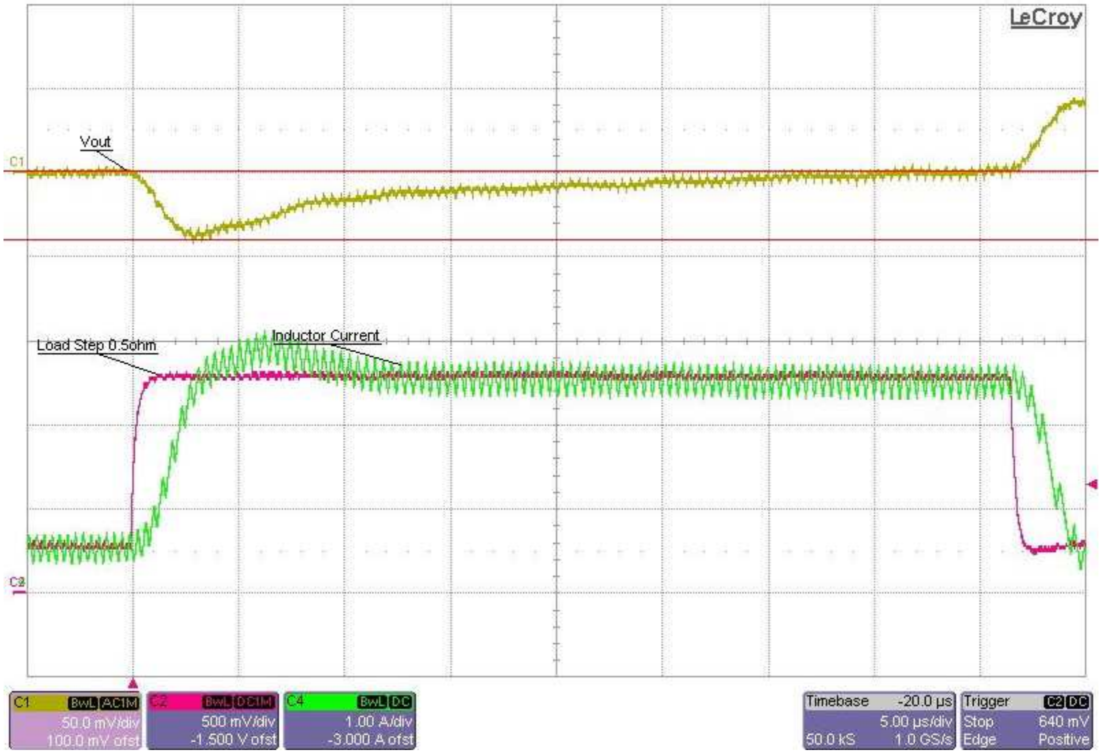

Figure 3. Load Transient with 1.0-µH Inductor and 100-µF Capacitor (f_{sw} = 2.8 MHz)

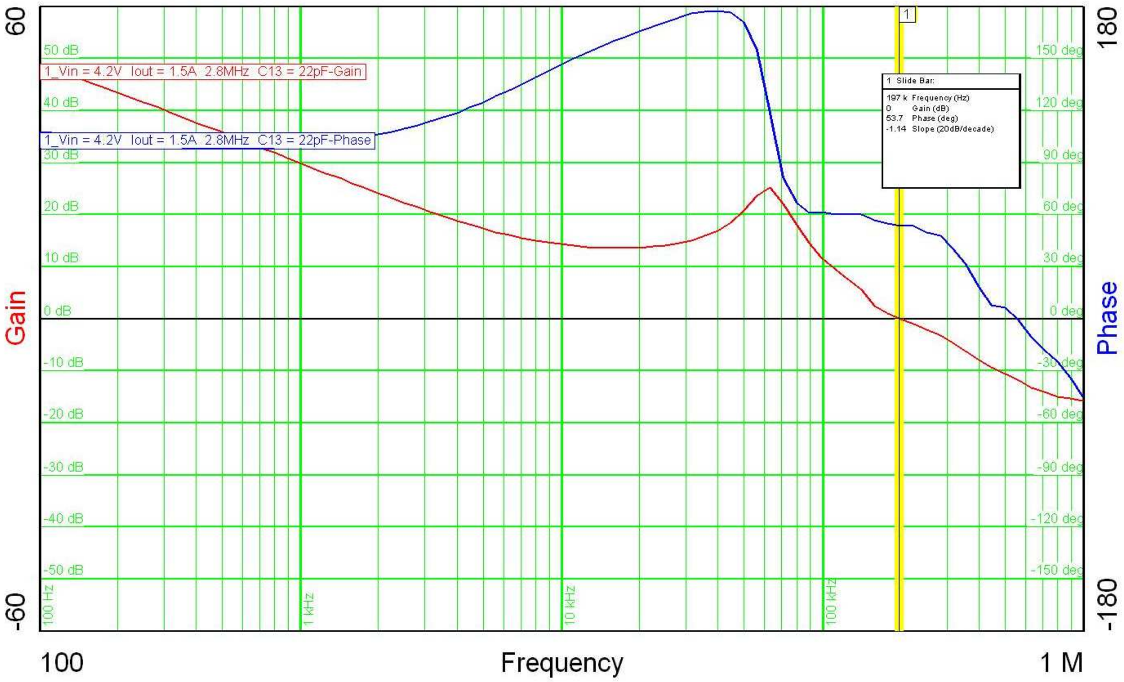

Figure 4. Control Loop Gain with 1.0-µH Inductor and 10-µF Capacitor (f_{sw} = 2.8 MHz)

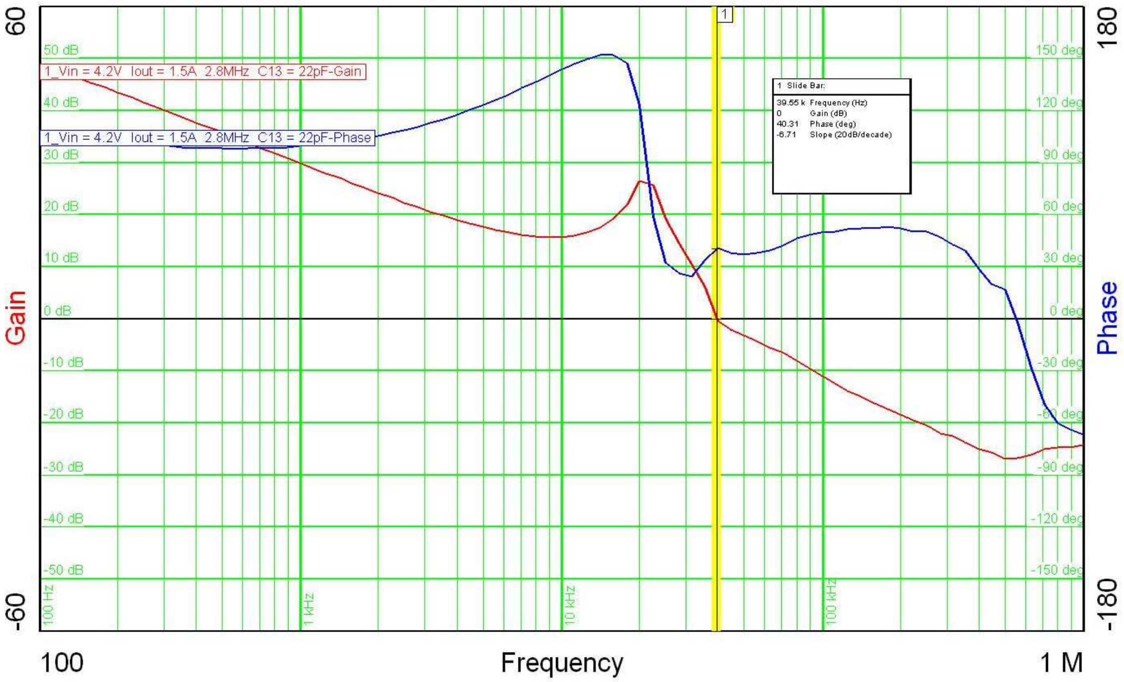

Figure 5. Control Loop Gain with 1.0-µH Inductor and 100-µF Capacitor (f_{sw} = 2.8 MHz)

Conclusion

This application note has presented methods to ensure stability and improve the load transient response with the TPS62090 device. The methods presented in this application note, as well as in the references, allow for a wide variety of external components to be used to achieve the desired power supply performance. The benefits and tradeoffs associated with designing the output filter, as discussed here, aid with the design of a TPS62090 power supply.

References

1. Measuring the Control Loop Gain of a DCS-Control Device™ (SLVA465)
2. TPS62090 Datasheet (SLVSAW2A)

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