Application Note

How to Select Inductor and Output Capacitor for TPS56x25x

Lucia Gao

ABSTRACT

The TPS56325x, TPS562242, TPS56425x family of devices use D-CAP3™ control mode which provides fast transient response with no external compensation components and an accurate feedback voltage. The TPS56x25x data sheet includes a table recommending LC. This application note introduces how to choose inductor and output capacitor values to accomplish specific design goals, such as transient response, loop stability, or output voltage ripple, based on an application's needs.

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Trademarks

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1 Introduction

The TPS56x25x is a simple, easy-to-use, high efficiency, high power density, synchronous buck converter with input voltage ranging from 3 V to 17 V and supports output voltages between 0.6 V and 10 V. TPS56x25x uses small SOT563 package which is 1.6 mm × 1.6 mm and uses HotRod package technology. TPS56x25x has good thermal performance and loop stability. Table 1-1 shows the comparison table for TPS56x25x family parts. These parts can be widely used in Wi-Fi™ access point, switch, router, pro-audio, TV, STB and so on.

Table 1-1. TPS56x25x Family Part Comparison Table

PN	Max load current	Mode	Frequency	Vref
TPS563252	3 A	ECO	1.2 MHz	0.6 V
TPS563257	3 A	FCCM	1.2 MHz	0.6 V
TPS564252	4 A	ECO	600 kHz	0.6 V
TPS564255	4 A	OOA	600 kHz	0.6 V
TPS564257	4 A	FCCM	600 kHz	0.6 V
TPS562242	2 A	ECO	1.4 MHz	0.8 V

2 An Overview of D-CAP3 Control Mode

D-CAP series control schemes are widely used in various electronic systems such as notebook, server, switches, Wifi-AP because of its fast transient performance, few external components for low cost and small design size.

Diagram of buck converter with D-CAP2™ control scheme is shown as Figure 2-1. The bode plot of open loop transfer function for D-CAP2 converter is shown as Figure 2-2.

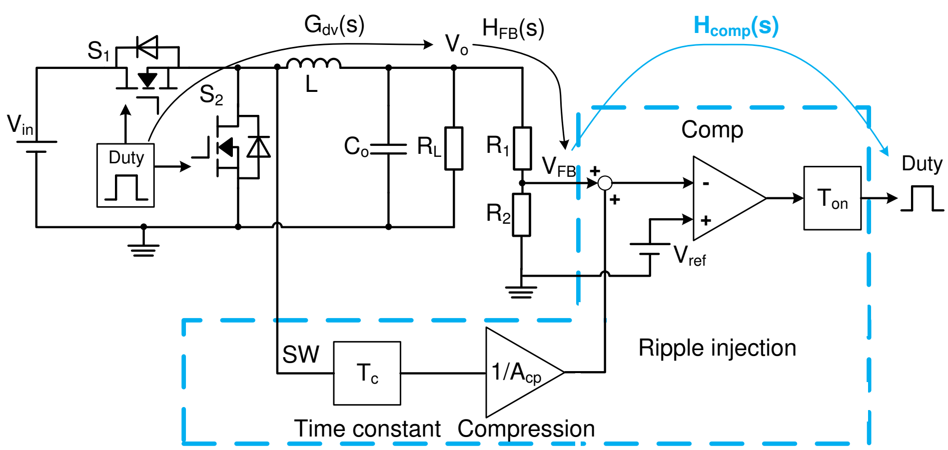

Figure 2-1. Control Diagram of D-CAP2 Converter

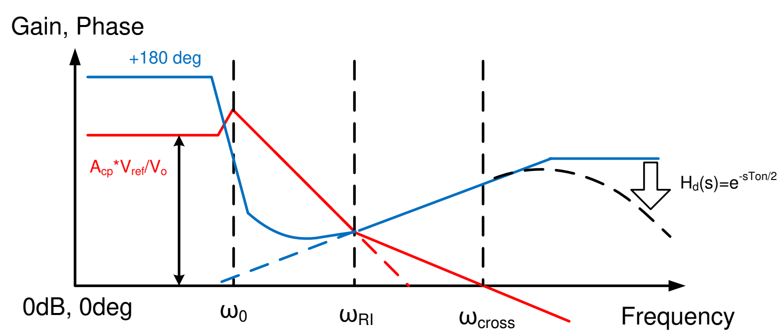

Figure 2-2. Bode Plot of D-CAP2 Converter

The D-CAP3 control mode is a variation of a constant-on-time control mode where the loop comparator monitors its inputs from the feedback voltage, reference voltage and emulated current ramp voltage to simulate ripple to generate on-pulses. To enhance DC accuracy of output voltage, D-CAP3 is proposed and widely used in TI's current products. Compared with D-CAP2, the DC error correction performance is further improved in D-CAP3. By adding additional poles and zeros at low frequency range, the gain at low frequency range is increased to achieve better ability for DC error correction. But the characteristics of gain and phase at middle frequency and high frequency are almost same as D-CAP2 converter. The bode plot of open loop transfer function is shown as Figure 2-3. *Stability Analysis and Design of D-CAP2 and D-CAP3 Converter – Part 1: How to Select Output Capacitor* application note gives stability analysis and design of D-CAP2 and D-CAP3 converter.

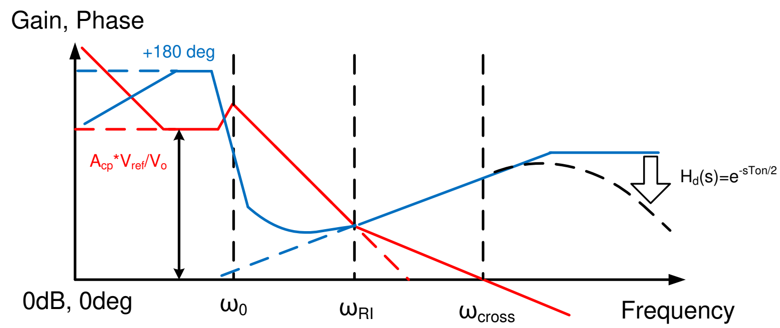

Figure 2-3. Bode Plot of D-CAP3 Converter

3 Method to Choose an LC Combination

When selecting inductor and output capacitor for Buck switching regulator, many factors need to be considered includes output ripple, loop stability and transient response. For example, in general, it is preferable to choose lower inductance in switching power supplies, because it usually corresponds to faster response, smaller DCR, and reduced size for more compact designs. Too low of an inductance can generate too large of an inductor current ripple so that the device can generate more inductor core loss. Larger inductor current ripple also implies larger output voltage ripple with the same output capacitors. For system loop stability, at the output filter pole frequency, the gain rolls off at a -40 dB per decade rate and the phase drops has a 180 degree drop. The internal ripple generation network introduces a high-frequency zero that reduces the gain roll off from -40 dB to -20 dB per decade and leads the 90 degree phase boost. Table 3-1 shows the stability of different LC combinations of TPS56325x that have been tested in the laboratory with an input voltage of 12 V and a load current of 3 A at an output voltage of 3.3 V. These combinations shown in below table can meet the requirement of loop response performance while for other performances like output voltage ripple, load transient response, it still needs to check based on real requirement.

Table 3-1. Stability and LC Combinations

	Nominal Ceramic Capacitance Value				
Nominal Inductance Value	10 uF	22 uF	22 uF * 2	22 uF *3	22 uF *4
	Effective Corner Frequencies				
1.5uH	53.1 kHz	34.2 kHz	24.2 kHz	19.8 kHz	17.1 kHz
2.2uH	43.8 kHz	28.3 kHz	20.0 kHz	16.3 kHz	14.1 kHz
3.3uH	35.8 kHz	23.1 kHz	16.3 kHz	13.3 kHz	11.5 kHz
	Recommended for TPS56325x in data sheet LC table				
	Stable with Cff (outside recommended LC table in data sheet)				

From Table 3-1, the blue cells are within the data sheet recommended LC range and are thus stable. The gray cells are outside the data sheet recommended range, but have been tested and were stable with appropriate Cff. The corner frequencies listed are based on the effective inductance and capacitance which means that the dc bias effect of ceramic capacitors are taken into account. For example, the part number of 22 uF capacitor is GRM21BR61A226ME44L. Considering the DC bias de-rating, its effective value is 14.4 uF at a 3.3-V bias.

4 Reducing Output Voltage Ripple

The output ripple is essentially composed of two parts. One part is caused by the inductor current ripple going though the Equivalent Series Resistance (ESR) of the output capacitors. And the other part is caused by the inductor current ripple charging and discharging the output capacitors. The two components in the voltage ripple are not in phase, so the actual peak-to-peak ripple is smaller than the sum of the two peaks. If the lower output ripple is desired, there are mainly three ways. One way is to reduce the amount of the ripple current through the inductor. The second way is to reduce the magnitude of the impedance of the capacitor. For a ceramic capacitor with very low ESR, the most effective way is to use a larger capacitance. Due to the effect of ESR, the effect of increasing the capacitance can have a negligible effect when the capacitance becomes larger. The third way is to choose higher switching frequency. For TPS56325x, the switching frequency is 1.2 MHz which is high frequency part compared with last generation devices. The high-switching frequency allows smaller inductors and output capacitors with the same output ripple requirement.

Figure 4-1 shows the output voltage ripple of TPS563257 when using 2.2 uH inductor with a 10 uF output capacitor. Figure 4-2 shows the output voltage ripple of TPS563257 when using 2.2 uH inductor with 22 uF *3 output capacitor. Using a larger ceramic capacitor is an effective way to reduce the ripple.

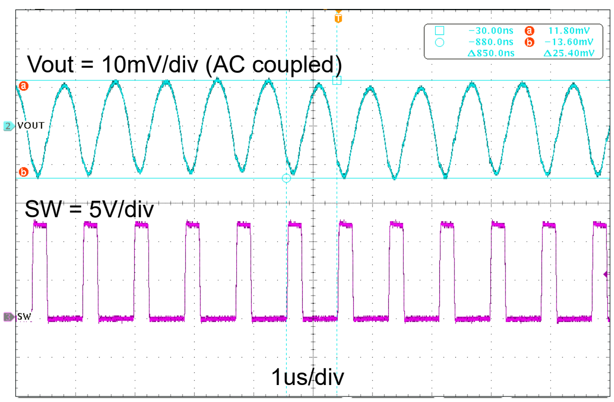

Figure 4-1. Output Voltage Ripple with 2.2 uH Inductor and 10 uF Capacitor

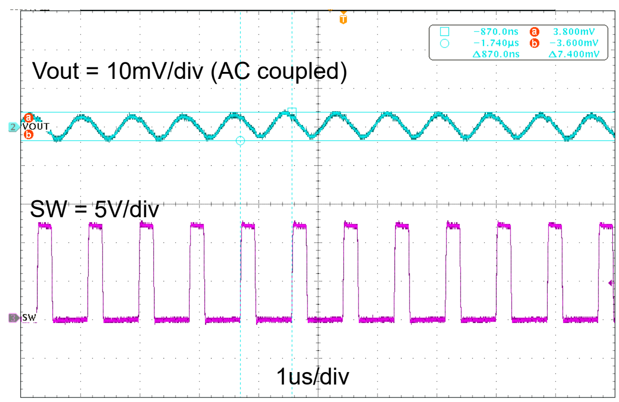

Figure 4-2. Output Voltage Ripple with 2.2 uH Inductor and 22 uF *3 Capacitors

5 Optimizing Load Transient Response

Virtually all electronic devices require a supply voltage that is held within a specific tolerance range, even when the load current varies. The voltage regulator must be able to hold it's output voltage constant as the load current demand varies anywhere from zero up to full load, even if the change occurs in a relatively short time. How much the output voltage changes will be dependent on the speed of the regulator, amount and type of output capacitor and the di/dt of the load current change. The di/dt of the load current is related with the application, thus the amount and type of the capacitor and the speed of the regulator are the two main things to improve how much the output voltage changes.

During the time interval while the regulator's control loop is adjusting for the change in load, the only thing supplying the difference in load current between the former steady-state value and the new load current value is the output capacitor. So the output capacitors will significantly affect transient response. The most obvious way to improve the output voltage deviation is to use a larger capacitance. Figure 5-1 shows the load transient of TPS563257 with 2.2 uH inductor and 10 uF capacitor. Figure 5-2 shows the load transient of TPS563257 with 2.2 uH inductor and 22 uF *3 capacitor.

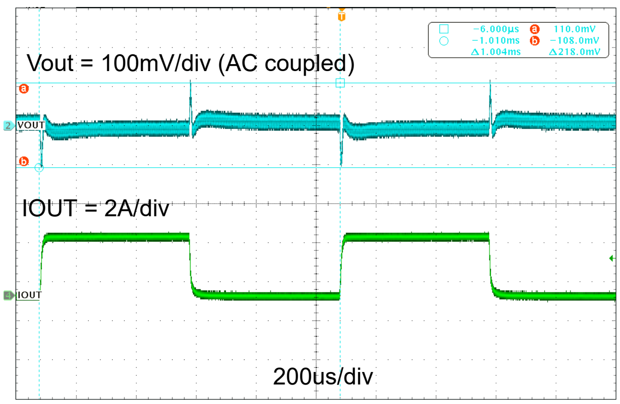

Figure 5-1. Load Transient with 2.2 uH Inductor and 10 uF Capacitor

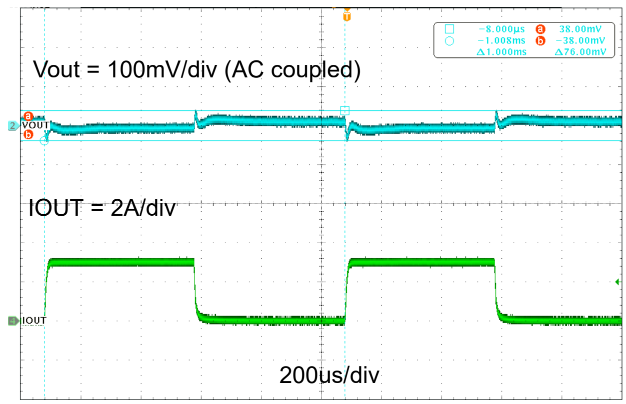

Figure 5-2. Load Transient with 2.2 uH Inductor and 22 uF *3 Capacitors

The faster the regulator's control loop can respond, the less the output capacitor's voltage will change before the loop corrects to the new value of the load current. 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 for TPS56x25x family, it is internal compensated and the bandwidth is primarily affected by the corner frequency of the LC filter, which forms a double pole in the contrl loop. As shown in Table 3-1, higher LC corner frequencies allow for higher control loop bandwidths. To increase the LC corner frequency, decrease the product of the inductance and capacitance or choose appropriate feedforward capacitor.

6 Summary

The method to select inductor and output capacitor of TPS56x25x family is proposed in this application note. The selection considers specific design goals, such as transient response, loop stability, and output voltage ripple, based on an application's needs. The methods to improve output voltage ripple and optimize load transient are also analyzed and verified with experiments. This selection guide shows the feasibility of a wide variety of external components and can help with the design of TPS56x25x family.

7 References

- Texas Instruments, *TPS56325x 3-V to 17-V Input, 3-A Synchronous Buck Converters in SOT-563 Package* data sheet.
- Texas Instruments, *Stability Analysis and Design of D-CAP2 and D-CAP3 Converter - Part 1: How to Select Output Capacitor* application note.
- Texas Instruments, *Stability Analysis and Design of D-CAP2 and D-CAP3 Converter - Part 2: How to Select Feedforward Capacitor* application note.
- Texas Instruments, *AN-1733 Load Transient Testing Simplified* application note.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265