How to Select a Proper Inductor for Low Power Boost Converter

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1 Introduction

Traditionally, the inductor value of a boost converter is selected through the inductor current ripple. The average input current $I_{L(DC\_MAX)}$ of the inductor is calculated using Equation 1. Then the inductance can be calculated using Equation 2. It is suggested that the $\Delta_{IL(P-P)}$ should be 20%~40% of $I_{L(DC\_MAX)}$ [1-2].

$$I_{L(DC\_MAX)} = \frac{V_{OUT}\ x\ I_{OUT(MAX)}}{V_{IN(TYP)}\ x\ \eta} \quad (1)$$

Where:

- V_{OUT}: output voltage of the boost converter.
- $I_{OUT(MAX)}$: the maximum output current.
- $V_{IN(TYP)}$): typical input voltage.
- η: the efficiency of the boost converter.

$$L = \frac{V_{IN}\ x\ (V_{OUT} + V_D - V_{IN})}{\Delta I_{L(P-P)}\ x\ f_{SW}\ x\ (V_{OUT} + V_D)} \quad (2)$$

Where:

- f_{SW}: the switching frequency of the boost converter.
- V_D: Forward voltage of the rectify diode or the synchronous MOSFET in on-state.

However, the suggestion of the 20%~40% current ripple ratio does not take in account the package size of inductor. At the small output current condition, following the suggestion may result in large inductor that is not applicable in a real circuit. Actually, the suggestion is only the start-point or reference for an inductor selection. It is not the only factor, or even not an important factor to determine the inductance in the low power application of a boost converter.

Taking TPS61046 as an example, this application note proposes a process to select an inductor in the low power application. The process compromises the inductor package, efficiency, stability and current limit of the boost converter.

2 Inductance Calculation

2.1 Inductance calculation through Inductor Current Ripple

The TPS61046 is a highly integrated boost converter designed for applications requiring high voltage and tiny solution size such as PMOLED panel used in wearable device. The power for the display is approximately 12 V and 20 mA for most conditions. The input voltage is a lithium-ion battery. The electrical specification for this boost converter application is summarized in Table 1.

Table 1. Electrical Specification Summary

SPECIFICATION	MIN	TYPICAL	MAX	UNIT
Input Voltage	3	3.8	4.2	V
Output Voltage		12		V
Output Current	0		20	mA
Switching Frequency		1.05		MHz

With the parameter in Table 1, the average inductor current can be calculated using Equation 3.

$$I_{L(DC\_MAX)} = \frac{V_{OUT}\ x\ I_{OUT(MAX)}}{V_{IN}\ x\ \eta} = \frac{12\ x\ 0.02}{3.8\ x\ 0.8} = 79\ mA \tag{3}$$

If setting the inductor ripple $\Delta I_{L(P\text{-}P)}$ to 30% of the $I_{L(DC\_MAX)}$, the inductor value can be calculated using Equation 4

$$L = \frac{V_{IN}\ x\ (V_{OUT} + V_D - V_{IN})}{\Delta I_{L(P-P)}\ x\ f_{SW}\ x\ (V_{OUT} + V_D)} = \frac{3.8\ x\ (12 + 0.8 - 3.8)}{0.3 \times 0.079\ x\ 1.05 \times 10^6\ x\ (12 + 0.8)} = 107\ \mu H \tag{4}$$

The typical values of an inductor provided by most vendors are shown in Table 2. The unit could be nH, µH and mH.

Table 2. Typical Value of an Inductor

1	1.5	2.2	3.3	4.7	6.8
10	15	22	33	47	68
100	150	220	330	470	680

Equation 4 and Table 2 provide a typical 100 µH inductance for reference. However, if the inductor size is limited, this large inductance means high DCR and small saturation current. So the large inductance may decrease the conversion efficiency.

2.2 Limitation by the Datasheet

The second limitation on the inductance is the stability. The TPS61046 datasheet provides the recommended external component value range as shown in Table 3. The inductor value is limited at 1 µH to 22 µH. The performance of the TPS61046 has been verified by simulation and bench test using the inductance within this range. So it is suggested to follow Table 3.

Table 3. TPS61046 Recommended Operating Conditions

		MIN	TYP	MAX	UNIT
V_{IN}	Input voltage range	1.8		5.5	V
V_{OUT}	Output voltage range	4.5		28	V
L	Effective inductance range	1 x 0.7	10	22 x 1.3	µH
C_{IN}	Effective input capacitance range	0.22	1		µF
C_{OUT}	Effective output capacitance range	0.22	1	10	µF
T_J	Operating junction temperature	–40		125	°C

2.3 Limitation by Package Size

The third limitation is the inductor package size. For the application in wearable device, the accepted inductor package size would be 1.6 mm × 0.8 mm × 1 mm or 2.0 mm × 1.6 mm × 1 mm. the inductance provided by the inductor vendors is limited in these two packages, as shown in Table 4.

Table 4. Inductors From Different Vendors

VENDOR	SERIES NUMBER	MAXIMUM INDUCTANCE / I_{SAT}
1.6 mm × 0.8 mm × 1 mm		
Murata	LQM18PNR	4.7 µH / 0.62 A
Taiyo Yuden	MBKK1608T	4.7 µH / 0.37 A
Taiyo Yuden	BRL1608T	10 µH / 0.17 A
2.0 mm × 1.6 mm × 1 mm		
TDK	VLS201610HBX	10 µH / 0.65 A
TOKO	DFE201610E	10 µH / 1 A
Taiyo Yuden	MAKK2016T	4.7 µH / 1.3 A
Cyntec	HTEX20161T	10 µH / 0.8 A

The inductors with these two packages are not higher than 10 µH.

3 Saturation Current Calculation

Using a 10-µH inductor and assuming the TPS61046 is at CCM (Continuous Conduction Mode), the $\Delta I_{L(P\text{-}P)}$ would reach 0.25 A, as calculated using Equation 5. This current ripple is higher than 200% of the inductor average current $I_{L(DC\_MAX)}$.

$$\Delta I_{L(P-P)} = \frac{V_{IN(TYP)}\ x\ \left(V_{OUT} + V_D - V_{IN(TYP)}\right)}{L\ x\ f_{SW}\ x\ \left(V_{OUT} + V_D\right)} = \frac{3.8\ x\ (12 + 0.8 - 3.8)}{10\ \mu \times 1.05\ M\ x\ (12 + 0.8)} = 0.25\ A \tag{5}$$

As the inductor current of TPS61046 cannot be negative, the device must operate at DCM (Discontinuous Conduction Mode). The inductor current decreases to zero for a period in the DCM, as shown in Figure 1.

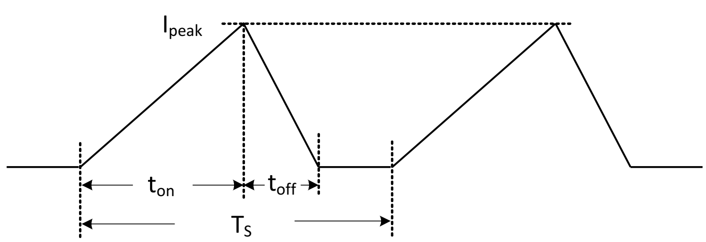

Figure 1. Inductor Current Waveform in DCM

In the DCM, the peak current of the inductor need to be calculate with formula (6), Where $V_{IN(MIN)}$ is the minimum input voltage.

$$I_{L(PEAK)} = \sqrt{\frac{2I_{OUT}\ x\ \left(V_{OUT} + V_D - V_{IN(MIN)}\right)}{L\ x\ f_{SW}}} \tag{6}$$

The maximum peak current of inductor is 193mA for 10-µH inductor and 280mA for 4.7-µH.

Make sure the peak current is lower than both the saturation current of the inductor and the current limiting value of the TPS61046. For example, the peak current would reaches 610mA if using 1-µH inductor, higher than current limiting value 600 mA. So a 1-µH inductor can’t be used in this application. The BRL1608T series inductor in the Table 4 cannot be selected because its saturation current is lower than the required peak current.

4 Power Loss Calculation

The inductor between 1.5-µH and 10-µH can be used in the application. The efficiency or the power loss of the boost converter is one important factor that determines which one is the best. For the same package, smaller inductor will have the smaller DCR, which mean smaller DC conducting loss. However, the current ripple becomes larger which causes larger AC loss or core loss [3], and larger conducting loss in the TPS61046.

When the boost converter operates at DCM as in Figure 1, the DC loss of the inductor is related to its RMS (Root Mean Square) value defined by Equation 7.

$$I_{RMS(IND)} = \sqrt{\frac{1}{T_S}\int_0^{t_{on}}\left(\frac{I_{peak}}{t_{on}}t\right)^2 dt + \frac{1}{T_S}\int_0^{t_{off}}\left(I_{peak} - \frac{I_{peak}}{t_{off}}t\right)^2 dt} = \sqrt{\frac{I_{peak}{}^2\,(t_{on} + t_{off})}{3 \text{ x } T_S}}$$

$$P_{L(IND)} = I_{RMS(IND)}{}^2 \text{ x } DCR \tag{7}$$

The power loss of the low side MOSFET is defined by Equation 8, where R_{LOW} is on resistance of the LSM (Low Side MOSFET).

$$I_{RMS(LOW)} = \sqrt{\frac{1}{T_S}\int_0^{t_{on}}\left(\frac{I_{peak}}{t_{on}}t\right)^2 dt} = \sqrt{\frac{I_{peak}{}^2 \text{ x } t_{on}}{3 \text{ x } T_S}}$$

$$P_{L(LOW)} = I_{RMS(LOW)}{}^2 \text{ x } R_{LOW} \tag{8}$$

The power loss of the isolated MOSFET is defined by Equation 9, where R_{LOW} is the on resistor of the IM (isolated MOSFET).

$$I_{RMS(HIGH)} = \sqrt{\frac{1}{T_S}\int_0^{t_{off}}\left(I_{peak} - \frac{I_{peak}}{t_{off}}t\right)^2 dt} = \sqrt{\frac{I_{peak}{}^2 \text{ x } t_{off}}{3 \text{ x } T_S}}$$

$$P_{L(HIGH)} = I_{RMS(HIGH)}{}^2 \text{ x } R_{HIGH} \tag{9}$$

Taking the VLS201610HBX series as example in the 2.0 mm × 1.6 mm × 1 mm package, the conducting power loss with 6.8-µH and 10-µH inductors is shown in Table 5. The conducting loss of the rectifier diode mainly relates to the average output current, and slightly impacted by inductor value, so it is not included in the Table 5. The inductor AC loss is not included either because it is not available from the inductor datasheet. The 10-µH inductor should be selected because of smaller total power loss from Table 5.

Table 5. Power Loss Calculation at 6.8 µH and 10 µH

PART NUMBER	INDUCTOR DC LOSS	LSM LOSS	IM LOSS	TOTAL LOSS
VLS201610HBX-6R8	4.8 mW	3.2 mW	2.5 mW	10.4 mW
VLS201610HBX-10R	5.3 mW	2.6 mW	2.1 mW	10 mW

Taking the MBKK1608T series as the example in the 1.6 mm × 0.8 mm × 1 mm package, the power loss data is shown in Table 6. The calculated power losses with 4.7-µH and 3.3-µH are almost the same. But it is no doubt that 4.7-µH inductor should be selected because of its smaller AC loss.

Table 6. Power Loss Calculation at 6.8 µH and 10 µH

PART NUMBER	INDUCTOR DC LOSS	LSM LOSS	IM LOSS	TOTAL LOSS
MBKK1608T3R3M	9.8 mW	6.6 mW	3.8 mW	20.2 mW
MBKK1608T4R7M	11.7 mW	5.5 mW	3.2 mW	20.4 mW

Considering that the AC power loss of some inductors is not available in the datasheet, it is necessary to compare the inductors with the same inductance from different vendors in real circuit when wanting to find the best component.

5 Summary

The steps to select a proper inductor for low power boost converter are summarized following:

1. Calculating the reference inductance based on the current ripple.
2. Inductance should be within the recommend range in the datasheet
3. Selecting the inductor package based on the real application.
4. The operating peak current should be both lower than the IC current limit and the saturation current of the inductor.
5. Calculating the inductor loss and the boost IC conducting loss, and then choosing an inductor with less power loss.
6. Efficiency measurement in the real circuit when want to find the best inductor for different vendors.

6 References

1. Texas Instruments. *How to Design a Boost Converter With the TPS61170* (SLVA319)
2. Texas Instruments. *Basic Calculation of a Boost Converter's Power Stage* (SLVA372)
3. Coilcraft. *Inductor Performance in High Frequency DC-DC Converters*

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