Application Report

150-V Output, Low Power Boost Solution Using Coupled Transformer

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ABSTRACT

This application note introduces a method of using a coupled transformer to extend the output voltage of a boost converter. It introduces the operating principle of the method at three operation modes. Then it uses TPS61096A as an example to design circuit and select the external components, and finally the method is proved to be reliable.

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1 Introduction

In some special application scenarios of boost converters, the output voltage required by the customer could be up to 150 V, which is much higher than the capability of a general boost converter. Taking TPS61096A as an example, its maximum output voltage is only 28 V because of the voltage limitation of the integrated power switch. This application note introduces a method of using a coupled transformer to increase the output voltage level of the boost converter.

2 Operating Principle

The Figure 2-1 shows a boost converter circuit with a coupled transformer. The turns ratio of the transformer is 1:N, the inductance value of the primary side is L1 and the inductance value of the secondary side is L2. C1 and C4 are input and output capacitor, Q1 is the N-MOS and D2 is rectifier diode integrated in the TPS61096A, D1 is rectifier diode.

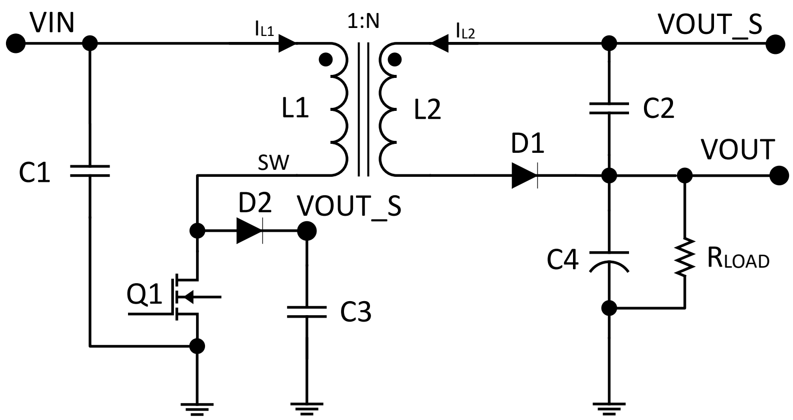

Figure 2-1. The Boost Converter Circuit with Coupled Transformer

According to the inductor current value at the end of each switching cycle, the circuit could operate at CCM(Continuous conduction mode), BCM(Boundary conduction mode) and DCM(Discontinuous conduction mode). Figure 2-2 is the ideal waveform of the converter when the boost converter operates in CCM.

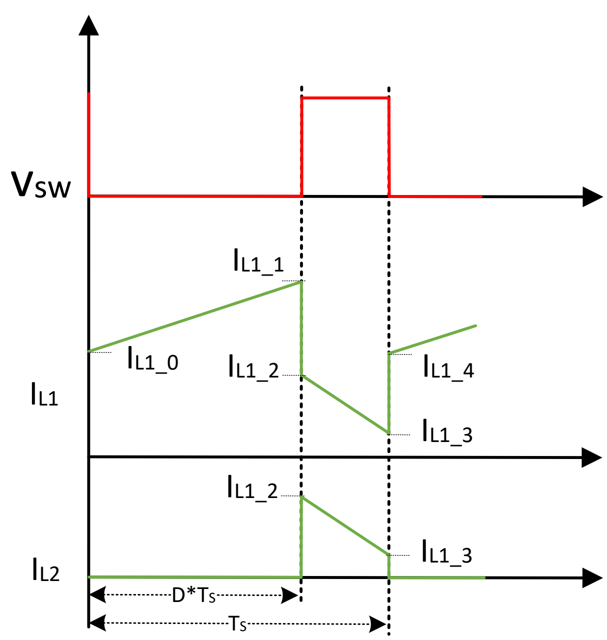

Figure 2-2. CCM Waveform

During one switching cycle T_S, the primary current and secondary current have two working status. When the MOSFET Q1 is turned on and the diode D1 is off, the inductor current rises linearly from I_{L1_0} to I_{L1_1} as shown in Equation 1.

$$\Delta I_{L\_1} = I_{L1\_1} - I_{L1\_0} = \frac{V_{IN}}{L_1} \cdot D \cdot T_S \tag{1}$$

The MOSFET Q1 is turned off and the diode D1 is on. The current through L1 suddenly decreases, and the energy in the primary inductor is transferred to the secondary. The initial current of the secondary is shown in Equation 2, where the N is the turn ratio of the coupled inductor.

$$I_{L1\_2} = \frac{I_{L1\_1}}{N+1} \tag{2}$$

For the next switching cycle, the primary inductor continues to store energy, and then transferred the energy to the secondary. If the input voltage and the output current keep stable, the I_{L1_4} is equal to I_{L1_0}. At the steady state, each winding of coupled inductor meets the voltage-second balance, as shown in Equation 3.

$$V_{IN} \cdot D \cdot T_S = \frac{V_{OUT} - V_{OUT\_S}}{N} \cdot (1-D) \cdot T_S \tag{3}$$

$$\frac{V_{OUT\_S} - V_{IN}}{L} = \frac{V_{OUT} - V_{OUT\_S}}{NL} \tag{4}$$

From Equation 3, Equation 4, the duty cycle in CCM mode is shown in Equation 5.

$$D = \frac{V_{OUT} - V_{IN}}{V_{IN} \cdot N + V_{OUT}} \tag{5}$$

Figure 2-3 shows the device operates in BCM. When the device operates in the BCM mode, the duty cycle D is the same as Equation 5.

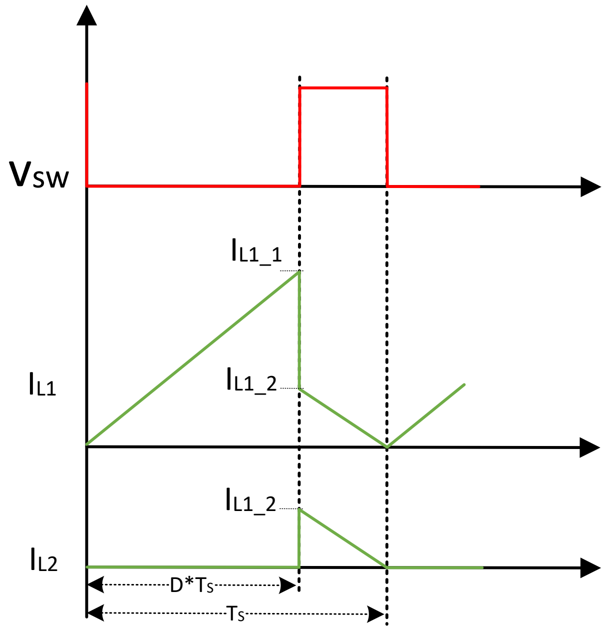

Figure 2-3. BCM Waveform

Figure 2-4 shows the device operates in DCM. When the device operates in the DCM mode.

- Within D_1*T_S, the N-MOS is on and the inductor current increases linearly from zero.
- Within D_2*T_S, the N-MOS is off and the inductor current decreases to zero.
- In the rest of a switching cycle, both the N-MOS and D1 is off. The V_{SW} is equal to V_{IN} ideally.

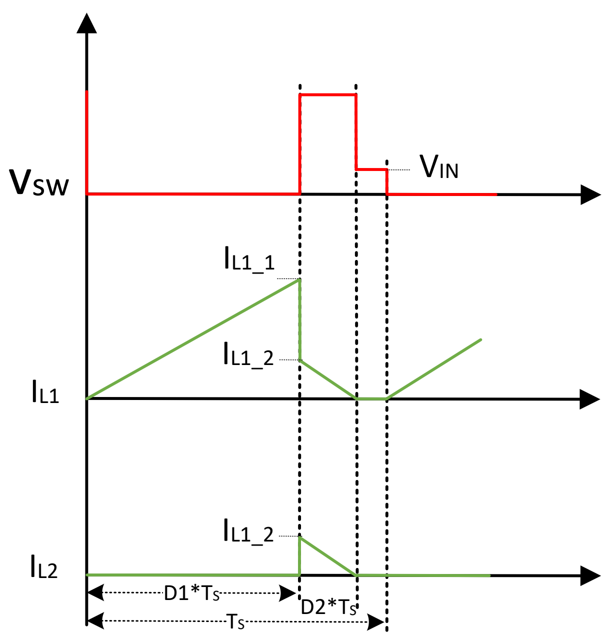

Figure 2-4. DCM Waveform

3 Example using TPS61096A

This chapter uses the TPS61096A as a design example to complete the circuit design with 3 V input voltage and 150 V output voltage. Figure 3-1 shows the schematic of TPS61096A with coupled transformer. VIN_S is control input signal and VIN_P is power input signal. R1 is the short circuit resistance. When R1 is short, the VIN_S and

VIN_P can use the same power supply. When R1 is disconnected, the VIN_S and VIN_P can use a different power supply.

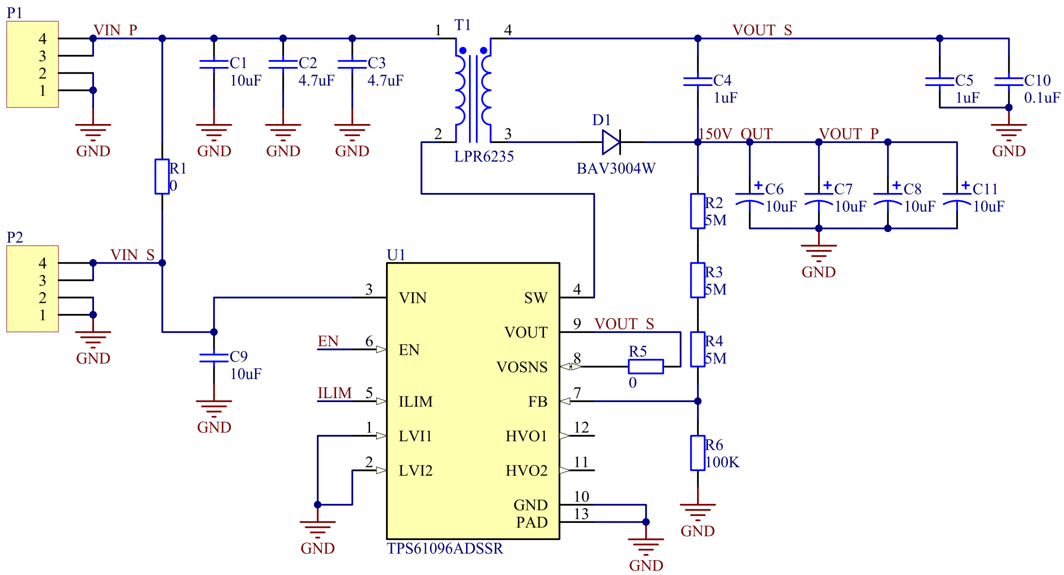

Figure 3-1. Schematic of TPS61096A with Coupled Inductor

The maximum SW pin voltage of TPS61096A is 32 V. Considering the voltage spikes caused by the leakage inductance of coupled inductor and parasitic inductance, it is recommended to limit the DC voltage below 30 V. According to Equation 6, the minimum turn ratio can be calculated. V_{IN}=3 V, V_{OUT_P}=150, V_{OUT_S}=28 V, V_{SW}=30 V.

$$\frac{V_{OUT\_P} - V_{OUT\_S}}{N} + V_{IN} = V_{SW} \tag{6}$$

$$N = \frac{V_{OUT\_P} - V_{OUT\_S}}{V_{SW} - V_{IN}} = \frac{150 - 28}{30 - 3} = 4.52 \tag{7}$$

It is suggested to chose the LPR6235-253L coupled inductor, which has 10 turns ratio and 25uH L1 inductor with 1.3A saturation current. TPS61096A uses a PFM peak current control scheme in DCM mode. VOUT_S can be calculated by Equation 8.

$$\frac{V_{OUT\_S} - V_{IN}}{L} = \frac{V_{OUT} - V_{OUT\_S}}{NL} \tag{8}$$

$$V_{OUT\_S} = 16.4V \tag{9}$$

The reverse voltage of the rectifier diode D1 is defined by Equation 10. In order to achieve the requirement, the diode BAV3004V can be used.

$$V_{DH} = V_{OUT} - V_{OUT\_S} = 150 - 16.4 = 133.6V \tag{10}$$

The maximum output current cannot be directly calculated, as TPS61096A works in PFM mode. Next is a method to determine the maximum output current. Test the waveform of the SW point, while continuously reducing the value of R_{LOAD}, until the waveform of the SW is continuous. At this time, the R_{LOAD} is maximum load of the converter, and the current is the maximum output current. The maximum output current is 1.4mA when ILIM is high logic.

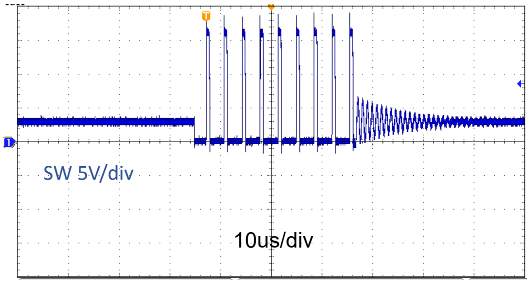

Figure 3-2. SW Waveform with Load=1M

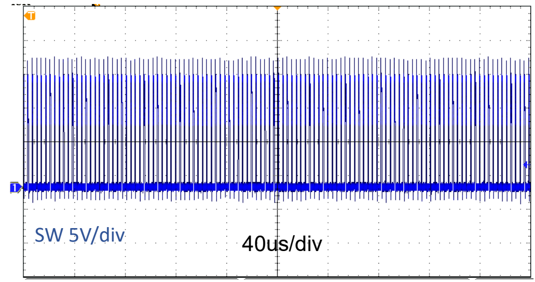

Figure 3-3. SW Waveform with Load=107K

Figure 3-4 shows the startup of the circuit through EN logic when VIN_S and VIN_P use same power supply. VIN_S is control input signal and VIN_P is power input signal. When EN is low, the output voltage is closed to the input voltage. When EN is high, the output voltage is smoothly ramps up to 150 V.

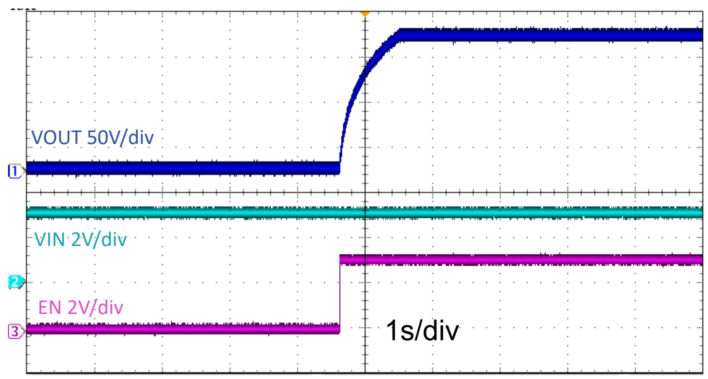

Figure 3-4. Startup of TPS61096A with Same Power Supply

Figure 3-5 shows the startup of the circuit through EN logic when the VIN_S and VIN_P are different power supply. When EN is low, the output voltage is closed to the input voltage. When EN is high, the output voltage is smoothly ramps up to 150 V.

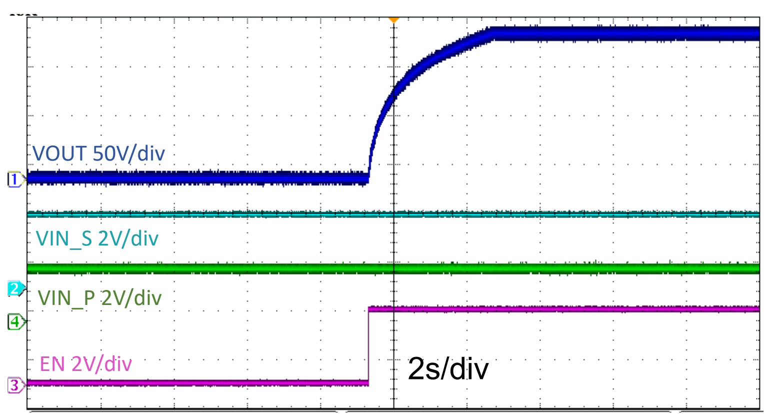

Figure 3-5. Startup of TPS61096A with Different Power Supply Voltage of VIN_S and VIN_P

Figure 3-6 shows the stable waveform of output ripple and SW voltage when the VIN_S and VIN_P are same and R_{LAOD} is 1M. The output ripple is 256mV, and the voltage of SW is about 16.4 V. The converter operates at PFM mode.

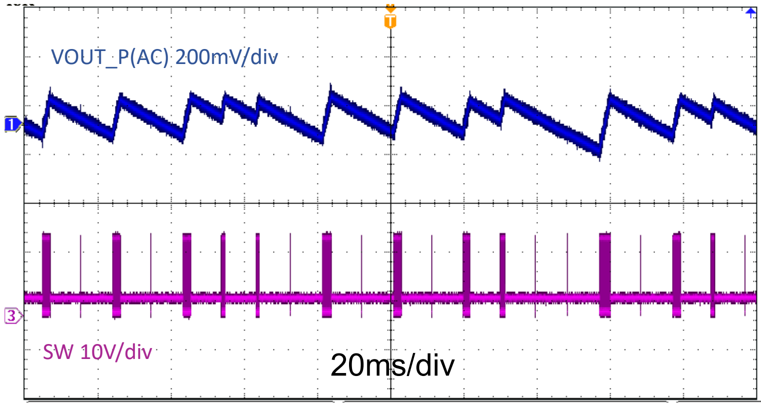

Figure 3-6. Stable Ripple of the TPS61096A Circuit with Same Power Supply

Figure 3-7 shows the stable waveform of output ripple and SW voltage when the VIN_S and VIN_P are different and R_{LAOD} is 1M. The output ripple is 280mV, and the voltage of SW is about 15 V. The converter operates at PFM.

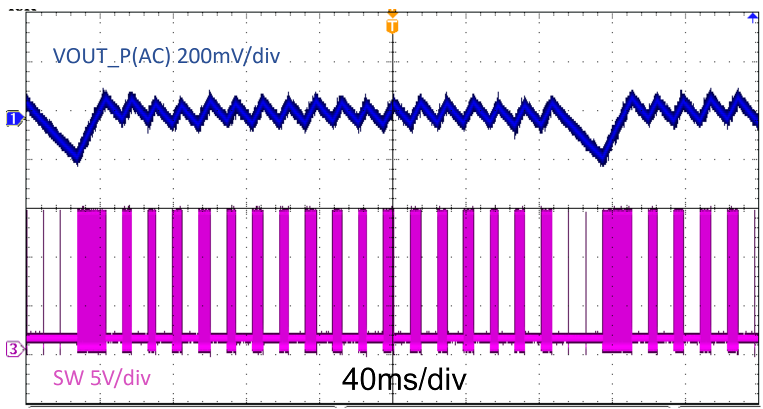

Figure 3-7. Stable Ripple of the TPS61096A Circuit with Different Power Supply

Table 3-1 shows the relationship between input voltage and input current without load when VIN_S and VIN_P use same power supply.

Table 3-1. No Load Input Current When VIN_S and VIN_P are Same

VIN/V	3	2.8	2.6	2.4	2.2	2	1.8
IIN/uA	757	828	840	878	943	1054	1180

Table 3-2 shows the relationship between input voltage and input current without load when VIN_S and VIN_P use different power supply.

Table 3-2. No Load Input Current When VIN_S and VIN_P are Different

VIN_S/V	3	3	3	3	3	3	3
VIN_P/V	3	2.8	2.6	2.4	2.2	2	1.8
IIN/uA	730	760	790	830	930	1070	1190
VIN_P/V	1.6	1.4	1.2	1	0.8	0.6	0.4
IIN/uA	1400	1678	2000	2480	3530	5810	11300

According to the test results in Table 3-1 and Table 3-2, when the appropriate input voltage is selected, the input current at no load can be less than 1 mA.

4 Summary

This application note improves the output voltage level of the boost converter by introducing a coupled transformer. It mainly introduces the three working modes of CCM, BCM, and DCM, and gives the calculation formulas and device selection. Finally, taking TPS61096A as an example, a 150-V output boost converter example is designed, and various test waveforms are given. The test results show that the method is feasible.

5 References

- Texas Instruments, *Coupled inductors broaden DC/DC converter usage* technical brief.
- Texas Instruments, *Extend the Boost Converter Output Voltage With a Coupled Inductor* application note.

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