Application Report
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How to Extend Buck Regulator to Positive Buck-boost Configuration

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ABSTRACT

The Texas Instruments LMR140X0 series of buck regulators are monolithic integrated circuits with an internal MOSFET switch. The LMR140X0 device is widely used in automotive and industrial applications. But in some applications, a positive buck-boost function is needed. This application report introduces how to extend buck regulator to positive buck-boost configuration.

First, this report describes the working principle of this positive buck-boost converter. Second, methods are presented for protecting the gate in high-input voltage condition and for calculating the output current in full load. Finally, bench test is provided to verify the theories.

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1 Introduction of LMR140X0 Series

The LMR140X0 is a 40-V step-down regulator with an integrated high-side MOSFET. With a wide input range, it is suitable for various applications from industrial to automotive. The quiescent current of the regulator is 40 μA in sleep mode, and ultra-low 1 μA current in shutdown mode can further prolong battery life.

The device has built-in protection features such as cycle-by-cycle current limit, thermal sensing and shutdown, and output overvoltage protection. Internal loop compensation means that the user is free from the tedious task of loop compensation design. A precision enable input allows simplification of regulator control and system power sequencing.

2 Working Principle of Positive Buck-boost Converter

Figure 1 shows the topology of buck-boost. This configuration contains two MOSFETs and two diodes connected with one inductor. This buck-boost topology maintains output voltage regulation when the input voltage is either less than or greater than the output voltage, making it especially suitable for some typical applications.

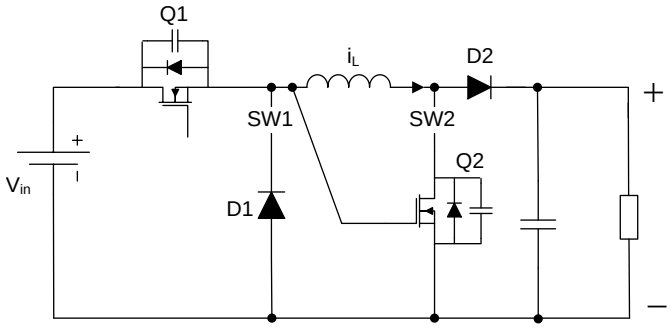

Figure 1. Positive Buck-boost Converter

During [t0-t1], Q1 and Q2 turn on. Figure 2 shows the equivalent circuit.

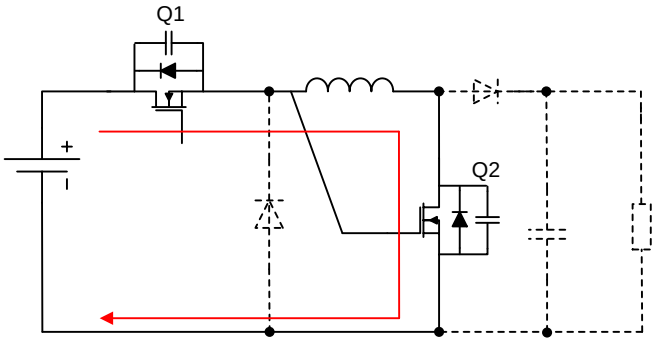

Figure 2. The Equivalent Circuit [t0-t1]

During [t1-t2], Q1 and Q2 turn off. Figure 3 shows the equivalent circuit.

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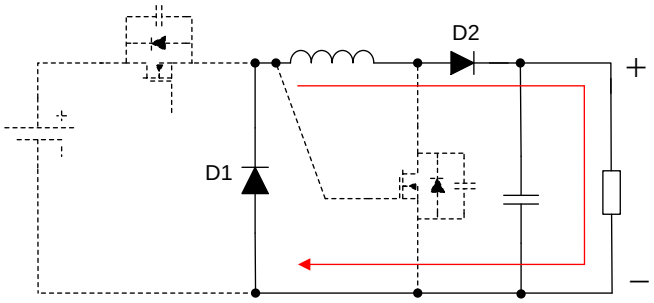

Figure 3. The Equivalent Circuit [t1-t2]

Figure 4 shows the waveforms for SW1, SW2, and inductor current i_L.

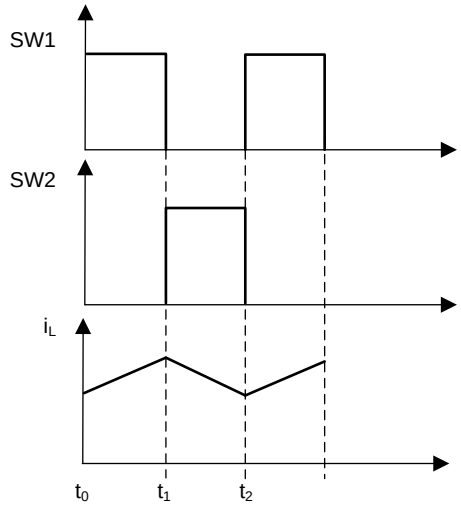

Figure 4. The Related Waveforms

From the equivalent circuit, the output voltage can be derived in Equation 1.

$$V_o = V_{in} \frac{D}{1-D} \quad (1)$$

Where D is the duty cycle.

If D>0.5, the output voltage can be regulated when the input voltage is less than the output voltage.

If D<0.5, the output voltage can be regulated when the input voltage is greater than the output voltage.

So when the duty cycle changes, this configuration can realize positive buck-boost function. Every buck regulator has output current limit. But the output current in full load for this positive buck-boost configuration is different. Assuming the buck regulator has maximum output limit I_{buck}. Equation 2 shows the output current in full load.

$$I_o = I_{buck}(1-D) = I_{buck}(1-\frac{V_{out}}{V_{in}+V_{out}}) \quad (2)$$

3 How to Protect the Gate in High-Input Voltage Condition

In Figure 1, the maximum gate to source voltage for Q_2 is about 20 V. So this circuit can only support the limited input voltage. When the input voltage becomes higher, the gate driving voltage of Q2 becomes higher, which can damage the switch.

Figure 5 shows an efficient circuit which can protect the gate in high-input voltage condition. Zener diode D3 can limit the gate driving voltage of Q2.

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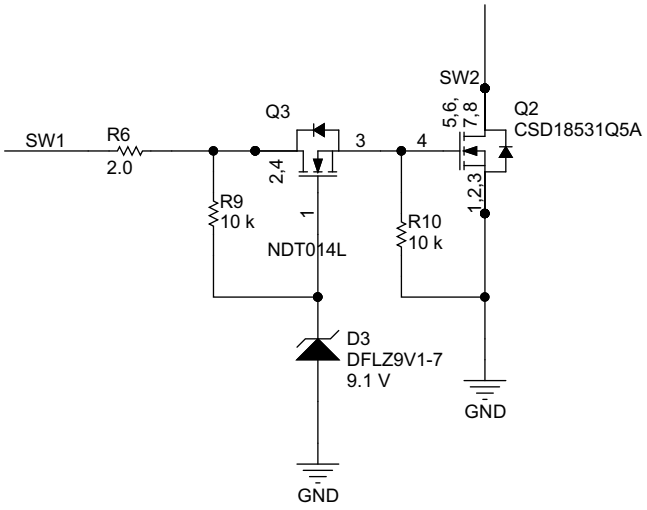

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Figure 5. The Protection Circuit

4 Bench Verification

This section introduces a real case about how to realize a positive buck-boost converter using a regulator. LMR14050 is used as an example. Table 1 lists the input and output parameters.

Table 1. Specifications

V_{in_Min}	9 V DC
V_{in_Max}	36 V DC
V_{out}	12 V DC
P_{out}	30 W Max
Target switching frequency	400 kHz

Figure 6 shows the overall schematic of using LMR14050 to configure the positive buck-boost solution.

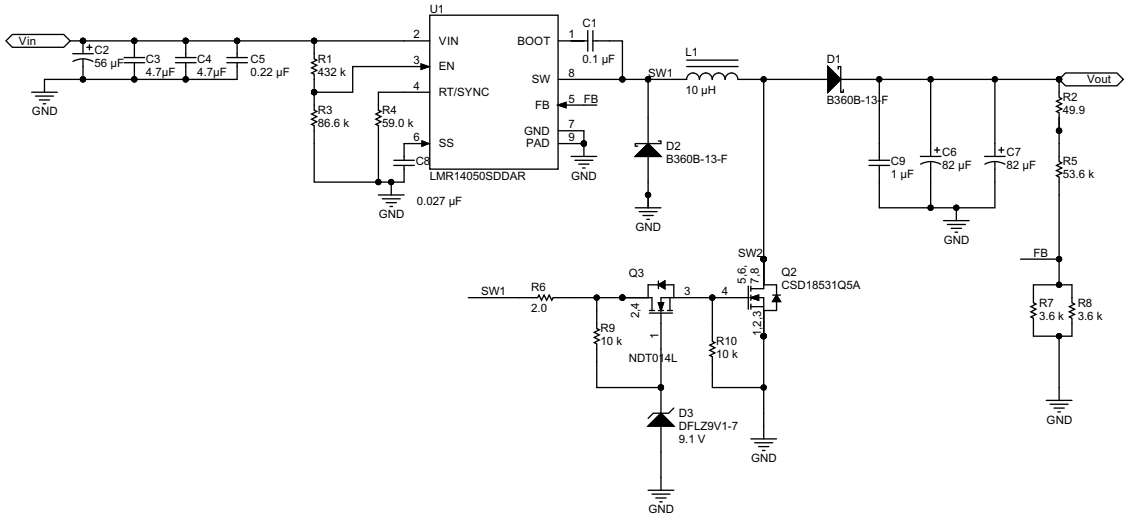

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Figure 6. LMR14050 Buck-boost Schematic

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Figure 7, Figure 8, Figure 9, and Figure 10 are waveforms that show the two switching node waveforms in different input voltage and in different load condition. It is shown that this configuration can work formally and realize buck-boost in CCM and DCM mode.

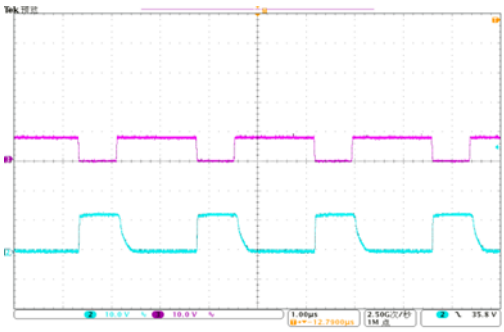

Figure 7. Waveforms for V_{in} = 9 V, V_{out} = 12 V / 2 A

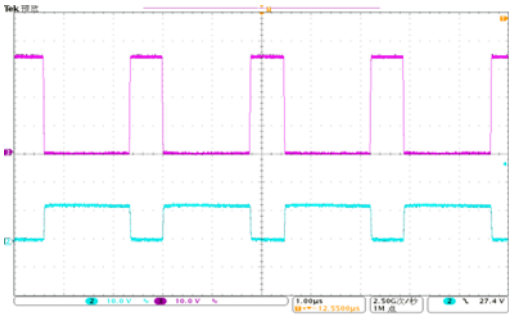

Figure 8. Waveforms for V_{in} = 36 V, V_{out} = 12 V / 2.5 A

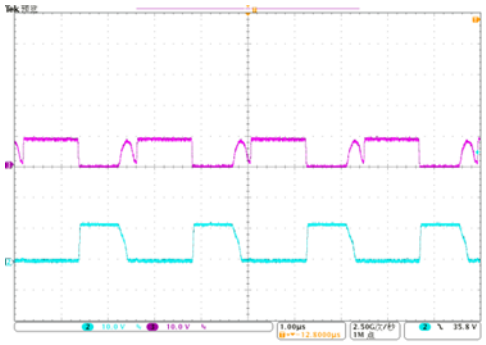

Figure 9. Waveforms for V_{in} = 9 V, V_{out} = 12 V / 0.2 A

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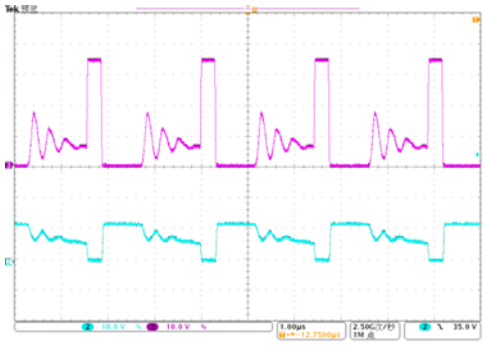

Figure 10. Waveforms for V_{in} = 36 V, V_{out} = 12 V / 0.2 A

Figure 11 shows the output current in full load for LMR14050-buck-boost, which is verified with the previous theory analysis.

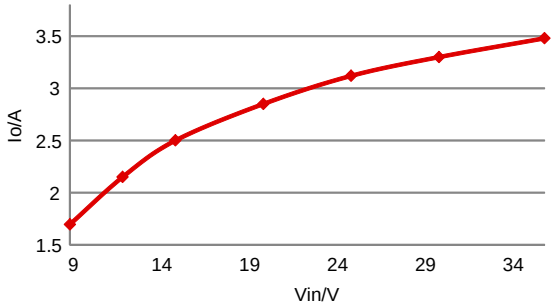

Figure 11. The Output Current in Full Load

Figure 12 shows the loop-response characteristics. Gain and phase plots are shown for V_{in} voltage of 12 V with load current of 2.5 A. Figure 13 shows the load transients performance. The current step is from 0 to 2.5 A at V_{in} = 12 V with 100 mA/µs slew rate.

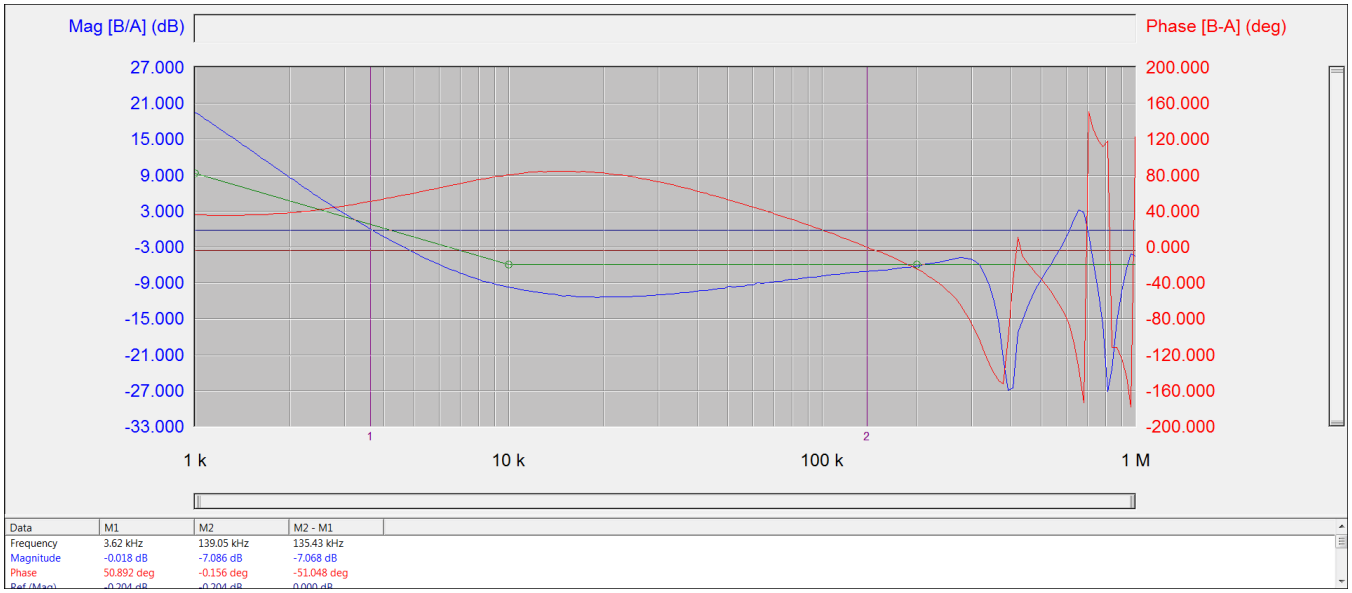

Figure 12. Loop Measurement Result

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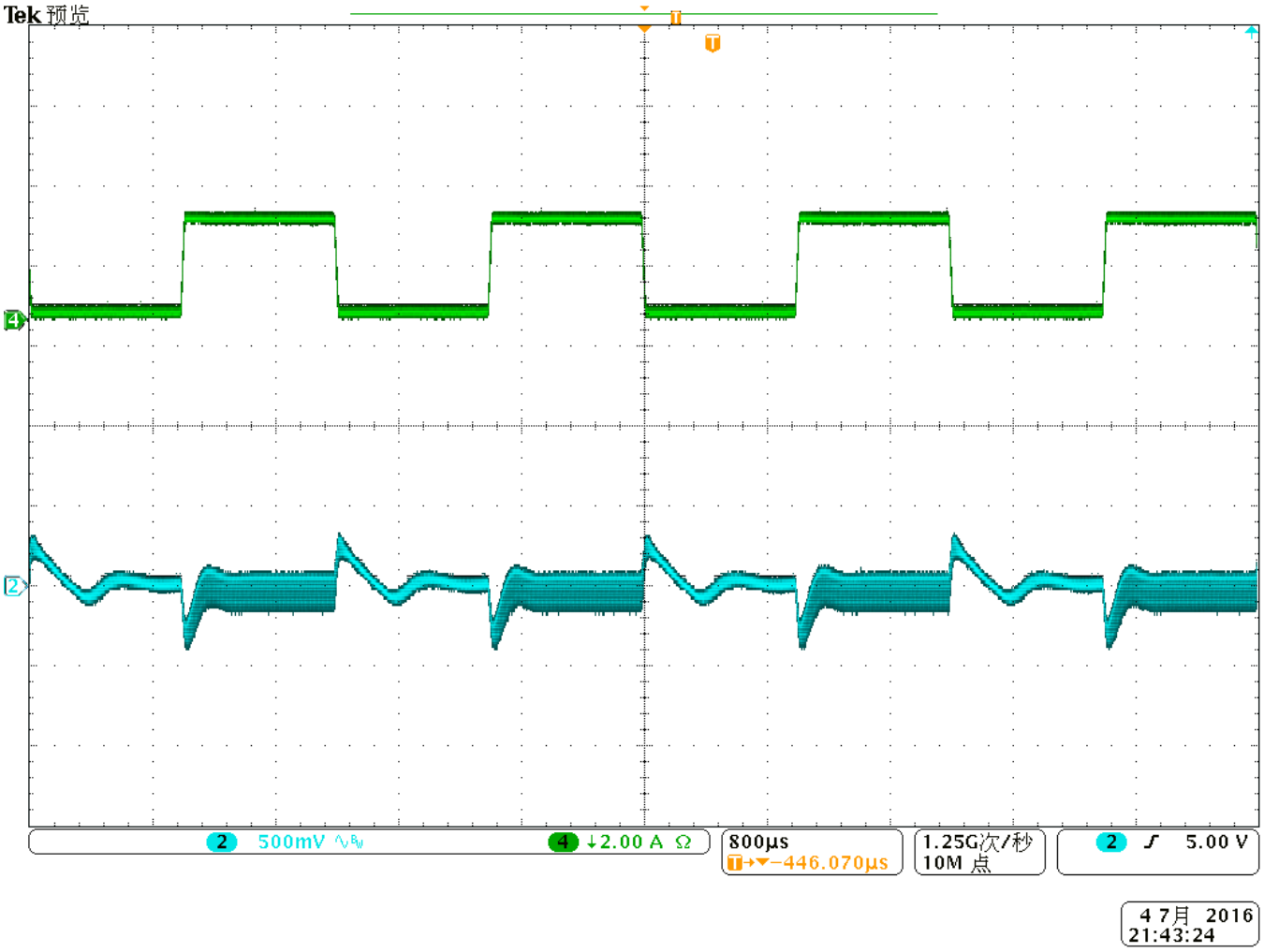

Figure 13. Load Transient Response

5 Conclusion

This application note introduces how positive buck-boost function can be realized by using a buck regulator to meet the customer application demands. Also, the problem of the gate protection can be solved, and the output current in full load of this configuration should be recalculated. Finally, using LMR14050 as an example, test results are used to demonstrate this solution.

6 References

- Texas Instruments, *LMR14050 data sheet*
- Texas Instruments, *LMR14050SEVM User's Guide*

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