-15V/1.5A Buck-Boost DC-DC Converter Using the Step-Down Controller MAX17504

MAXREFDES1050

Introduction

The MAXREFDES1050 is a positive input, negative output power supply that delivers up to 1.5A at -15V from a 18V to 30V supply voltage. It is designed for industrial control equipment that uses analog components like amplifiers and multiplexers that operate on negative supply voltage. Typically operating at ±12V, ±18V or other variations, these voltages are generated from a 24V DC bus.

The MAXREFDES1050 illustrates techniques using the synchronous buck regulators to generate negative voltages. This document explains how the MAX17504 synchronous step-down converter can be used to generate -15V from 18V to 30V input voltage. An overview of the design specification is shown in Table 1.

The MAX17504/MAX17504S high-efficiency, high-voltage, synchronously rectified step-down converter with dual integrated MOSFETs operates over a 4.5V to 60V input. Maxim's portfolio of high-voltage synchronous buck regulators offers 50% lower power loss, which allows equipment to operate 50% cooler. The device features a peak-current-mode control architecture with a MODE feature that can be used to operate the device in pulse-width modulation (PWM), pulse-frequency modulation (PFM), or discontinuous mode (DCM) control schemes. Built-in compensation across the output voltage range eliminates the need for external components. The feedback (FB) regulation accuracy over -40°C to +125°C is ±1.1%. A programmable soft-start feature allows users to reduce input inrush current. The device also incorporates an output enable/undervoltage lockout pin (EN/UVLO) that allows the user to turn on the part at the desired input-voltage level. An open-drain active-low $\overline{\text{RESET}}$ pin provides a delayed power-good signal to the system upon achieving successful regulation of the output voltage. The device is available in a compact (5mm x 5mm) TQFN lead (Pb)-free package with an exposed pad. Simulation models are available.

Table 1. Design Specification

PARAMETER	SYMBOL	MIN	MAX
Input Voltage	V_{IN}	18V	30V
Switching Frequency	f_{SW}	600kHz	
Peak Efficiency	η	89%	
Duty Cycle	D	33%	46%
Output Voltage	V_{OUT}	-15.15V	-14.85V
Output Current	I_{OUT}	0A	1.5A
Output Voltage Ripple	ΔV_{OUT}	150mV	
Output Power	P_{OUT}	22.5W	

Designed–Built–Tested

This reference design describes the hardware shown in Figure 1. It provides a detailed systematic technical guide to design a buck-boost converter using Maxim's MAX17504 step-down controller. The converter has been built and tested, details of which follow later in this document.

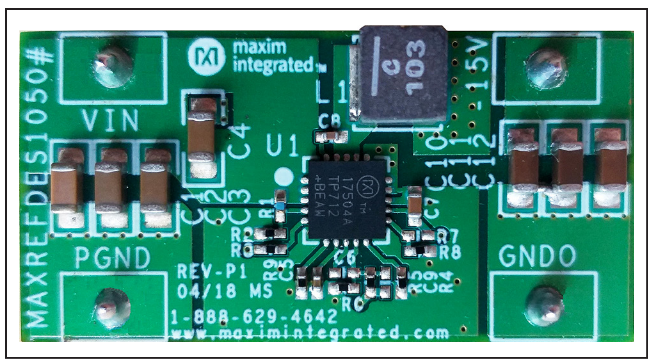

Figure 1. MAXREFDES1050 hardware.

Buck-Boost Converter

The buck-boost converter is a type of DC-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude. The output voltage of the buck-boost converter has the opposite polarity than the input voltage. Figure 2 shows the basic circuit of a buck-boost converter.

Figure 3 shows that when the switch is on, current flows through the inductor in a clockwise direction and the inductor stores some energy by generating a magnetic field. The polarity of the left side of the diode is positive. During this period, the diode D1 is reverse bias, so there is no current flow through the diode, and the output capacitor supplies energy to the output load.

Figure 4 shows that when the switch is off, current is reduced because the impedance is higher. The magnetic field that was previously created is destroyed to maintain the current toward the load. Therefore, the polarity is reversed, which means the left side of the diode is negative. During this period, the energy is transferred from the inductor to the load and the output capacitor.

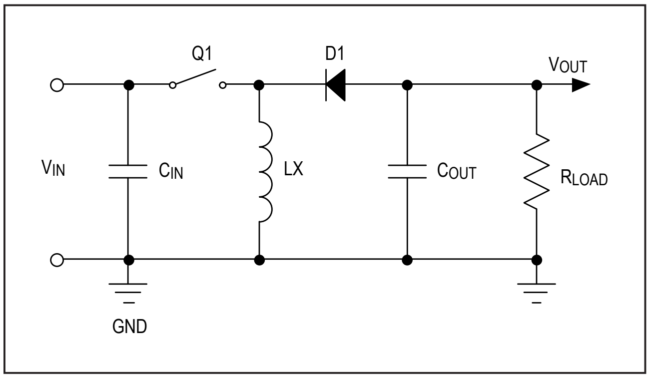

Figure 2. Buck-boost topology.

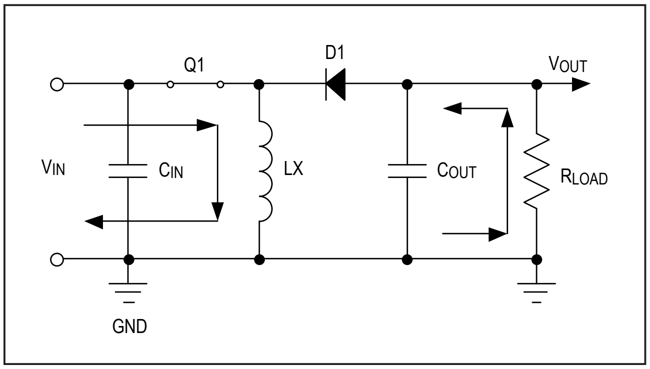

Figure 3. On-period equivalent circuit.

Design Procedure for the Buck-Boost converter

This section discusses a practical design example. Synchronous buck converters can be configured to work in a buck-boost topology to produce negative output voltage from positive input voltage. This document explains how the MAX17504 synchronous step-down converter can be used to generate -15V from 18V to 30V input voltage.

The following design parameters are used throughout:

V_{IN} = Input Voltage
V_{OUT} = Output Voltage
I_{OUT} = Output Load
I_O = Output Current
f_{SW} = Switching Frequency
D = Duty Cycle
I_{L_AVG} = Maximum Inductor Average Current
L_{MIN} = Minimum Inductor Value
C_{IN} = Input Capacitance
C_{OUT} = Output Capacitance
t_{SS} = Soft Start Time

The design parameters are sometimes followed by parentheses to indicate whether minimum or maximum values of the parameters are intended, for example: minimum input voltage is intended by the symbol $V_{IN(MIN)}$. Otherwise typical values are intended. In addition, through the design procedure, reference is made to the schematic in another document.

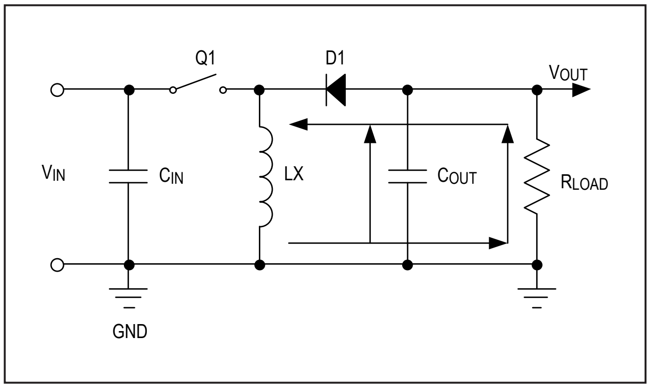

Figure 4. Off-period equivalent circuit.

Step 1: Operating Input Voltage Range Selection

The sum of the maximum operating input voltage for the negative output application and the absolute value of the output voltage must not exceed the maximum operating voltage (60V) of the MAX17504, as expressed by the following equation:

$$V_{IN(MAX)} + |V_{OUT}| \leq 60V$$

Therefore, for -15V output voltage, the maximum operating input voltage can be as high as 45V. The minimum operating input voltage for the negative output voltage application must be greater than 4.5V. In this design, we use 18V to 30V as the operating input voltage range.

Step 2: Duty Cycle Calculation

Ignoring the losses associated with the power switches and the inductor DC resistance, the duty cycle of the negative output power supply is expressed by the following equation:

$$D = \frac{|V_{OUT}|}{V_{IN} + |V_{OUT}|}$$

The maximum duty cycle is:

$$D_{MAX} = \frac{|V_{OUT}|}{V_{IN(MIN)} + |V_{OUT}|} = \frac{15}{18 + 15} \approx 0.46$$

The minimum duty cycle is:

$$D_{MIN} = \frac{|V_{OUT}|}{V_{IN(MAX)} + |V_{OUT}|} = \frac{15}{30 + 15} \approx 0.33$$

Step 3: Load Current Capability Calculation

To estimate whether the MAX17504 can deliver the required output current, the value of the maximum inductor average current must be calculated first, as expressed by the following equation:

$$I_{L(AVG)} = I_{L(MAX)} - \frac{\Delta I_L}{2}$$

Choose $I_{L(MAX)}$ to be 4A for the MAX17504 to allow room for the output capacitor charging current. Choose the value of the maximum inductor ripple (ΔI_L) to be 1.75A for the MAX17504, and then calculate the maximum values for $I_{L(AVG)}$ as follows:

$$I_{L(AVG)} = I_{L(MAX)} - \frac{\Delta I_L}{2} = 4 - \frac{1.75}{2} = 3.125A$$

The maximum load supported by the MAX17504 is expressed by the following equation:

$$I_{OUT(MAX)} = I_{L(AVG)} \times (1 - D_{MAX}) = 3.125 \times (1 - 0.46) = 1.6875A$$

The maximum load of this reference design is 1.5A.

Step 4: Inductor Selection

Based on the ripple current requirements, the minimum value of the inductance is calculated by the following equation:

$$L_{MIN} = \frac{V_{IN(MIN)} \times D_{MAX}}{f_{SW} \times \Delta I_L} = \frac{18 \times 0.46}{600 \times 10^3 \times 1.75} = 7.89\mu H$$

A 10µH inductor is used in the reference design.

Step 5: Input Capacitor Selection

The minimum value of the input capacitor is expressed by the following equation:

$$C_{IN(MIN)} = \frac{\Delta I_L}{8 \times f_{SW} \times V_{IN(RIPPLE)}} = \frac{1.38}{8 \times 600 \times 10^3 \times 0.01 \times 18} \approx 1.6\mu F$$

where $V_{IN(RIPPLE)}$ is the input voltage ripple, which is normally 1% of the minimum input voltage. Calculate the inductor ripple (ΔI_L) based on the actual inductance value chosen for the application as follows:

$$\Delta I_L = \frac{V_{IN(MIN)} \times D_{MAX}}{f_{SW} \times L_{SEL}} = \frac{18 \times 0.46}{600 \times 10^3 \times 10 \times 10^{-6}} = 1.38A$$

where L_{SEL} is the selected inductance.

One 10µF capacitor in parallel with two 2.2µF input capacitors are used in this design to reduce the input voltage ripple. Another 2.2µF from the positive terminal of the input to the ground of the MAX17504 is needed to prevent the MAX17504 from damage when the load is high.

Step 6: Output Capacitor Selection

The minimum required value of the output capacitor is calculated by the following equation:

$$C_{OUT(MIN)} = \frac{I_{OUT} \times D_{MAX}}{f_{SW} \times V_{OUT(RIPPLE)}} = \frac{1.5 \times 0.46}{600 \times 10^3 \times 0.01 \times 15} \approx 7.67\mu F$$

where $V_{OUT(RIPPLE)}$ is the input voltage ripple, which is normally 1% of the minimum output voltage.

This reference design uses three 4.7µF ceramic capacitors.

Step 7: Output Voltage Selection

Set the output voltage with a resistive voltage divider that is connected from the ground terminal of the inductor to the -15V output. Connect the center node of the divider to the FB pin. Select the resistor values according to the MAX17504 data sheet.

Step 8: Soft-Start Capacitor Selection

The MAX17504 implements adjustable a soft-start operation to reduce inrush current. A capacitor connected from the SS pin to SGND programs the soft-start time. Determine the minimum required soft-start capacitor using the selected output capacitance (C_{OUT}) and the output voltage (V_{OUT}) as expressed in the following equation:

$$C_{SS} \geq 28 \times 10^{-6} \times C_{OUT} \times V_{OUT} =$$
$$28 \times 10^{-6} \times 4.7 \times 3 \times 10^{-6} \times 15 = 5.992\text{nF}$$

The soft-start time (t_{SS}) is related to the capacitor connected at SS (C_{SS}), as expressed by the following equation:

$$C_{SS} = 5.55 \times t_{SS}$$

where t_{SS} is in milliseconds and C_{SS} is in nanofarads.

Step 9: Setting the Input Under-Voltage Lockout Level

When the MAX17504 is used as a buck converter, the voltage at which the MAX17504 turns on/off can be adjusted by using the resistive divider connected from the V_{IN} pin to GND. When the MAX17504 is used as a negative output voltage power supply, only the start voltage can be programmed by the resistive divider. When the MAX17504 turns on, the part experiences an increase in the effective input voltage as the output voltage builds up to full regulation voltage. The input voltage must drop by the absolute value of the output voltage to shut down the part.

Design Resources

Download the complete set of **Design Resources** including the schematics, bill of materials, PCB layout, and test files.

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	2/19	Initial release	—