24V/4A DC-DC Boost Converter Using the MAX17499B Step-Up Controller

MAXREFDES1196

Introduction

The MAXREFDES1196 is a DC-DC boost power supply that delivers up to 4A at 24V from a 10V to 18V supply voltage. It is designed for equipment that needs a high-power, 24V output voltage that is generated from a 12V DC bus.

The MAXREFDES1196 employs techniques that use the boost regulators to generate voltage higher than input voltage. This document explains how the MAX17499B current-mode PWM converter can be used to generate 24V from 10V to 18V input voltage. An overview of the design specification is shown in Table 1.

The MAX17499B current-mode PWM controller contains all the control circuitry required for the design of wide-input-voltage isolated and nonisolated power supplies. The MAX17499B is well suited for low input voltage ($9.5V_{DC}$ to $24V_{DC}$) power supplies. An input undervoltage lockout (UVLO) is provided for programming the input-supply start voltage and to ensure proper operation during brownout conditions. An open-drain UVLO flag output with 210μs internal delay allows the sequencing of a secondary-side controller. The input-supply start voltage is externally programmable with a voltage-divider. A UVLO/EN input is used to shut down the devices. Internal digital soft-start eliminates output voltage overshoot. The switching frequency for this IC is programmable with an external resistor. The MAX17499B provides a 75% maximum duty-cycle limit. This device is available in 10-pin μMAX® package and is rated for operation over the -40°C to +125°C temperature range.

Designed – Built – Tested

This document describes the hardware shown in Figure 1. It provides a detailed, systematic technical guide to design a boost converter using the MAX17499B current-mode PWM controller. The power supply has been built and tested, details of which follow later in this document.

Table 1. Design Specification

PARAMETER	SYMBOL	MIN	MAX
Input Voltage Range	V_{IN}	10V	18V
Switching Frequency	f_{SW}	500kHz	
Peak Efficiency	η	95%	
Duty Cycle	D	26.5%	59%
Output Voltage	V_{OUT}	23.76V	24.24V
Output Current	I_{OUT}	0A	4A
Output Voltage Ripple	ΔV_{OUT}	240mV	
Output Power	P_{OUT}	96W	

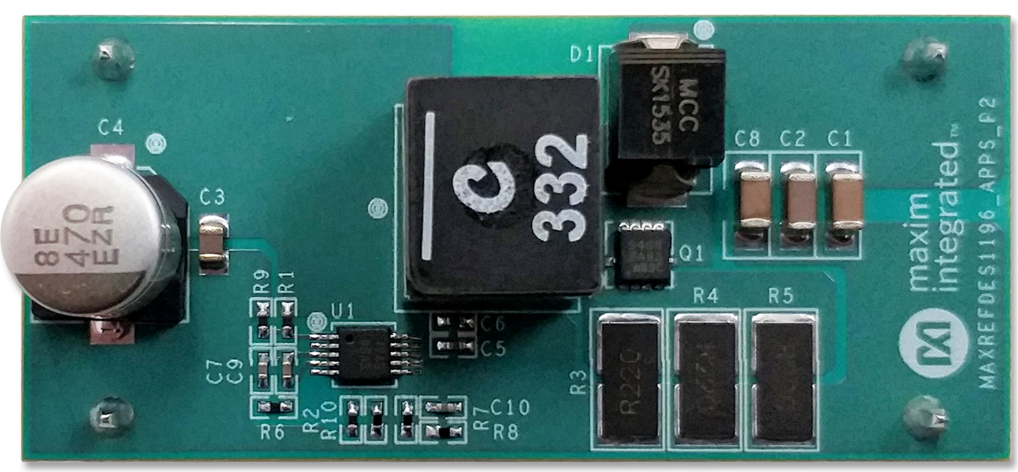

Figure 1. MAXREFDES1196 hardware.

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Boost Converter

A boost converter (step-up converter) is a DC-DC power converter that steps up voltage (while stepping down current) from its input to its output. The key principle that drives the boost converter is the tendency of an inductor to resist changes in current by creating and destroying a magnetic field. In a boost converter, the output voltage is always higher than the input voltage. A schematic of a boost power stage is shown in Figure 2.

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 inductor is positive. During this period, the diode D1 is reverse biased, so there's no current flow through the diode.

Figure 4 shows that when the switch is off, current is reduced as the impedance is higher. The magnetic field previously created is destroyed to maintain the current toward the load. Thus, the polarity is reversed, meaning the left side of the inductor is negative. As a result, the two sources are in series, causing a higher voltage to charge the capacitor through the diode D1.

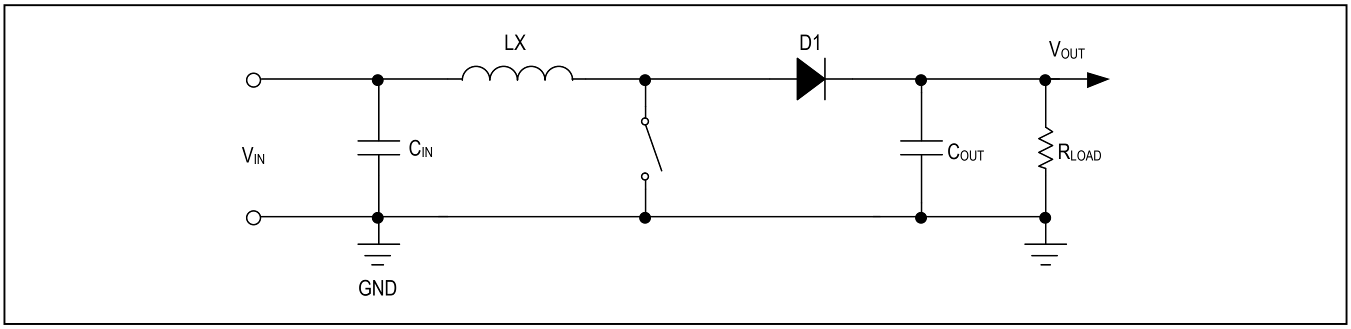

Figure 2. Conventional step-down converter topology.

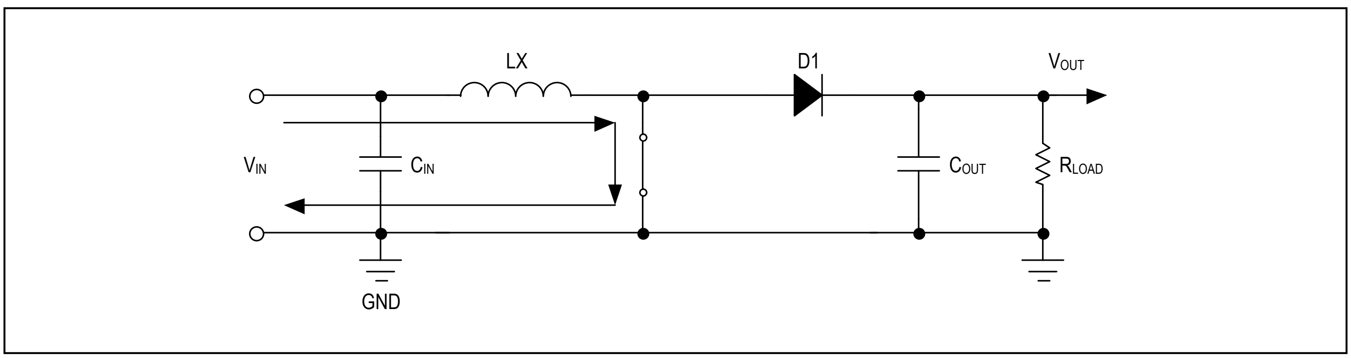

Figure 3. Switch on-period equivalent circuit.

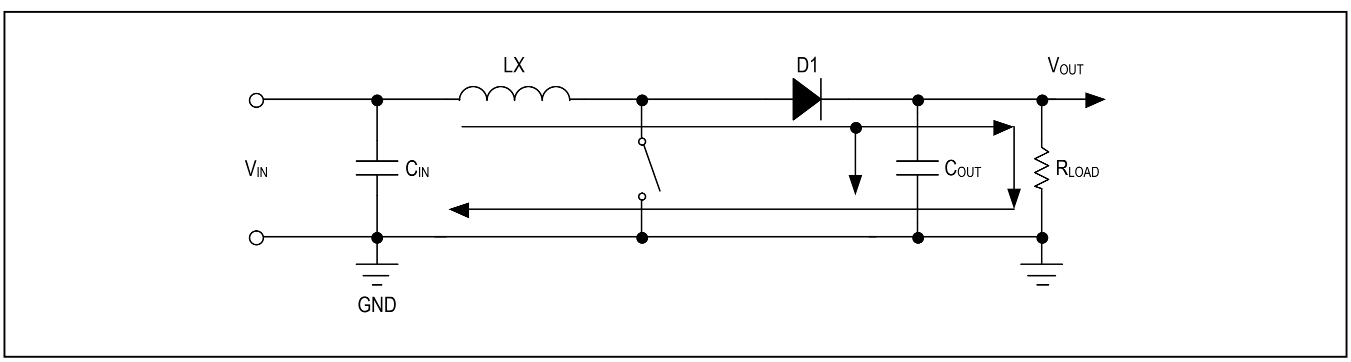

Figure 4. Switch off-period equivalent circuit.

In a steady-state operating condition, the average voltage across the inductor over the entire switching cycle is zero. This implies that the average current through the inductor is also in a steady state. This is an important rule governing all inductor-based switching topologies. Taking this one step further, we can establish that for a given charge time (t_{ON}) and a given input voltage and with the circuit in equilibrium, there is a specific discharge time (t_{OFF}) for an output voltage. Because the average inductor voltage in steady state must equal zero, we can calculate for the boost circuit as follows:

$$V_{IN} \times t_{ON} = t_{OFF} \times V_L$$

And because:

$$V_{OUT} = V_{IN} + V_L$$

we can then establish the following relationship:

$$V_{OUT} = V_{IN} \times \left(1 + \frac{t_{ON}}{t_{OFF}}\right)$$

Using the relationship for duty cycle (D):

$$D = \frac{t_{ON}}{t_{ON} + t_{OFF}}$$

Then for the boost circuit:

$$V_{OUT} = \frac{V_{IN}}{1 - D}$$

Design Procedure for the Boost Converter

The previous section introduced the principles of boost operation. This section discusses a practical design example. The design process can be divided into the following selection stages: switching frequency and output voltage, inductor and capacitors, and MOSFET and diode. This document complements the information contained in the MAX17499B data sheet. The following abbreviations are used throughout this document.

PARAMETER	SYMBOL
Output Load	I_{OUT}
Inductor Peak Current	I_{PK}
Inductance of the Inductor	L_{IN}
Input Capacitance	C_{IN}
Output Capacitance	C_{OUT}

The design parameters are sometimes followed by parentheses to indicate whether minimum or maximum values of the parameters are intended, such as $V_{IN(MIN)}$ to indicate minimum input voltage. Otherwise, typical values are intended.

Step 1: Switching Frequency Selection

To reduce the total size of the solution, choose 500kHz as the switching frequency. Use an external resistor at the RT pin to program the MAX17499B's internal oscillator frequency between 50kHz and 2.5MHz. The MAX17499B output switching frequency is 25% of the programmed oscillator frequency with a 75% maximum duty cycle, which is from 12.5kHz to 625kHz. Use the following equation to determine the appropriate value of resistor R7 needed to generate 500kHz at the NDRV output:

$$R7 = \frac{10^{10}}{4 f_{SW}} = \frac{10^{10}}{4 \times (500 \times 10^3)\ Hz} = 5000\Omega$$

where R7 is the resistor connected from RT to GND. A 5.1kΩ resistor was chosen for R7 in this reference design. Connect an RC network in parallel with R7. The RC network should consist of a 100nF capacitor, C10, (for stability) in series with resistor R8, which serves to further minimize jitter. Use the following equation to determine the value of R8:

$$R8 = 88.9 \times (R7)^{\frac{1}{4}} = 88.9 \times (5100\Omega)^{\frac{1}{4}} = 751\Omega$$

Step 2: Output Voltage Calculation

The MAX17499B includes an internal error amplifier to regulate the output voltage in the case of a nonisolated power supply. Calculate the output voltage using the following equation:

$$V_{OUT} = \left(1 + \frac{R2}{R10}\right) \times V_{REF} = \left(1 + \frac{56k\Omega}{3k\Omega}\right) \times 1.23V = 24.19V$$

where V_{REF} = 1.23V. The amplifier's noninverting input is internally connected to a digital soft-start circuit that gradually increases the reference voltage that is applied to this input during startup. This forces the output to come up in an orderly and well-defined manner under all load conditions.

Step 3: Inductor Selection

The design procedure for continuous conduction mode (CCM) boost starts with calculating the boost converter's input inductor at the minimum input voltage. The inductor ripple current (LIR) can be chosen between 30% and 60% of the maximum output current.

$$L_{IN} = \frac{V_{IN(MIN)} \times D_{MAX} \times (1 - D_{MAX})}{LIR \times I_{OUT} \times f_{SW}}$$

$$= \frac{10V \times 0.59 \times (1 - 0.59)}{0.36 \times 4A \times (500 \times 10^3)\ Hz} = 3.36\mu H$$

where LIR is 36% in this reference design and D_{MAX}, the maximum duty cycle, is calculated as:

$$D_{MAX} = \frac{V_{OUT} + V_D - V_{IN(MIN)}}{V_{OUT} + V_D} = \frac{24V + 0.5V - 10V}{24V + 0.5V} = 0.59$$

V_D is the voltage drop across the output diode of the boost converter at maximum output current. A 3.3µH inductor is used in this reference design.

Step 4: Peak Current and Current-Sense Resistor Calculation

For the purposes of setting current limit, the peak current in the inductor and MOSFET can be calculated as follows:

$$I_{PK} = \frac{0.25 \times V_{OUT}}{L_{IN} \times f_{SW}} + \frac{I_{OUT}}{1 - D_{MAX}} = \frac{0.25 \times 24V}{(3.3 \times 10^{-6})H \times (500 \times 10^3)Hz} + \frac{4A}{1 - 0.59} = 13.4A$$

The value of current limit, in MOSFET Q1, is set as:

$$I_{LIM} = I_{PK} \times 1.2 = 13.4A \times 1.2 = 15.6A$$

In the case of the MAX17499B, the current-sense resistor R_{CS}, which is connected between the source of the MOSFET Q1 and PGND, sets the peak current limit. The current-limit comparator has a voltage trip level ($V_{CS\text{-}PEAK}$) of 1V. Use the following equation to calculate the maximum value of R_{CS}:

$$R_{CS} = \frac{1}{I_{LIM}} = \frac{1V}{15.6A} = 64m\Omega$$

Step 5: Input Capacitor Selection

The minimum required input ceramic capacitor can be calculated based on the ripple allowed on the input DC bus.

$$C_{IN(MIN)} = \frac{LIR \times I_{OUT}}{8 \times \Delta V_{IN} \times f_{SW} \times (1 - D_{MAX})} = \frac{0.36 \times 4A}{8 \times (10 \times 0.01)V \times (500 \times 10^3)Hz \times (1 - 0.59)} = 8.78\mu F$$

where ΔV_{IN} is the ripple voltage allowed on input DC bus, $\Delta V_{IN} = 1\% V_{IN}$ in this design.

In practice, a 470µF electrolytic capacitor is provided to decouple any source inductance formed by the input cables. The electrolytic capacitor may also be used as an energy storage element, which can supply power when input power fails.

Capacitor values change with temperature and applied voltage. Refer to capacitor data sheets to select capacitors that would guarantee the required C_{IN} and C_{OUT} values across the operating range. Use the worst-case derated value of capacitance based on temperature range and applied voltage for further calculations.

Step 6: Output Capacitor Selection

The output capacitor is calculated by the following equation:

$$C_{OUT} = \frac{I_{STEP} \times T_{RESPONSE}}{2 \times \Delta V_{OUT}} = \frac{2A \times (35 \times 10^{-6})s}{2 \times (24 \times 0.01)V} = 150\mu F$$

$$T_{RESPONSE} = \frac{0.33}{f_C} + \frac{1}{f_{SW}} = \frac{0.33}{(10 \times 10^3)Hz} + \frac{1}{(500 \times 10^3)Hz} = 35\mu s$$

where I_{STEP} is the load step, $T_{RESPONSE}$ is the response time of the controller, ΔV_{OUT} is the allowable output voltage deviation, and f_C is the target closed-loop crossover frequency. Frequency f_C is chosen in the range of 1/10 to 1/5 of the right half plane (RHP) zero frequency $f_{RHP,ZERO}$, which is calculated as follows:

$$f_{RHP,ZERO} = \frac{V_{OUT} \times (1 - D_{MAX})^2}{I_{OUT} \times 2 \times \pi \times L_{IN}} = \frac{24V \times (1 - 0.59)^2}{4A \times 2 \times 3.14 \times (3.3 \times 10^{-6})H} = 48.67kHz$$

For a boost converter, the output capacitor supplies the load current when the main switch is on and, therefore, the output voltage ripple is a function of duty cycle and load current. Use the following equation to calculate the output capacitor steady-state ripple voltage:

$$\Delta V_{COUT} = \frac{I_{OUT} \times D_{MAX}}{C_{OUT} \times f_{SW}} = \frac{4A \times 0.59}{(150 \times 10^{-6})F \times (500 \times 10^3)Hz} = 32mV$$

Step 7: Output Diode Selection

Ideally, the voltage rating of the output diode for a boost converter equals the output voltage. In practice, parasitic inductances and capacitances in circuit layout and components interact to produce voltage overshoot during the turn-off transition of the diode, which occurs when the main switch Q1 turns on. The diode voltage rating should, therefore, be selected with the necessary margin to accommodate extra voltage stress. A voltage rating of 1.3 x V_{OUT} provides this necessary design margin in most cases.

The current rating of the output diode is chosen to minimize the power loss in the component. The average power loss is given by the product of forward voltage drop and average diode current. Minimizing the power loss in the diode at its peak current level (I_{PK}) gives the least dissipation in the component. Choose a diode with minimum voltage drop at I_{PK}. Select fast recovery diodes with a recovery time of less than 50ns or Schottky diodes with low junction capacitance.

Step 8: External MOSFET Selection

The voltage stress on the MOSFET ideally equals the sum of the output voltage and the forward drop of the output diode. In practice, voltage overshoot and ringing occur due to action of circuit parasitic elements during the turn-off transition. The MOSFET voltage rating should be selected with the margin that is necessary to accommodate this extra voltage stress. A voltage rating of 1.3 x V_{OUT} provides the necessary design margin in most cases. The RMS current in the MOSFET is useful in estimating the conduction loss, and is given as:

$$I_{MOSFETRMS} = \frac{I_{OUT} \times \sqrt{D_{MAX}}}{1 - D_{MAX}} = \frac{4\,A \times \sqrt{0.59}}{1 - 0.59} = 7.5A$$

where D_{MAX} is the duty cycle at the lowest operating input voltage, and I_{OUT} is the maximum load current.

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	3/19	Initial release	—