Non-Isolated 12V/0.5A 6W Step-Down Converter Using the MAX17501

MAXREFDES01209

Introduction

The MAXREFDES1209 operates over a 14V to 60V input voltage range to deliver output voltage regulated at 12V and up to 500mA of load current. The output voltage is accurate to within ±1.7% over -40°C to +125°C. The MAX17501 EV kit is available in a compact TDFN package. The device features peak-current-mode control with pulse-width modulation (PWM) with a fixed switching frequency of 600kHz at all loads. The device offers external compensation components and uses a two-layer PCB board. The low-resistance, on-chip MOSFETs ensure high efficiency (~94%) at full load and simplify the layout. A programmable soft-start feature reduces input inrush current. The device also incorporates an output enable/undervoltage lockout pin (EN/UVLO) that turns on the part at the desired input voltage level. An open-drain RESET pin provides a delayed power-good signal to the system upon achieving successful regulation of the output voltage.

Hardware Specifications

The MAX17501, an ultra-small, high-efficiency synchronous step-down DC-DC converter is demonstrated here for a 12V output application. The power supply delivers up to 0.5A load current at 12V. Table 1 is an overview of the design specifications

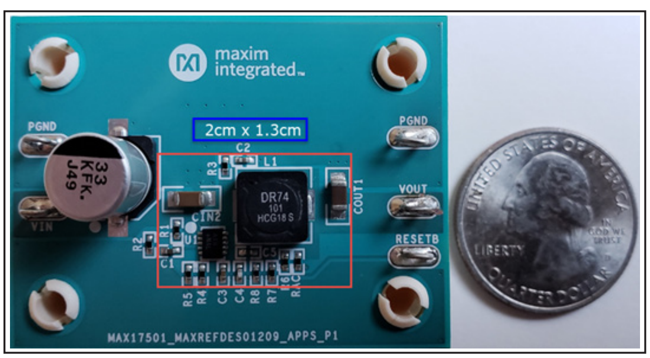

Figure 1. MAXREFDES01209

Table 1. Design Specifications

PARAMETER	SYMBOL	MIN	TYP	MAX
Input Voltage	V_{IN}	14V	24V	60V
Output Voltage	V_{OUT}		12V	
Output Current	I_{OUT}		0.5A	
Output Ripple	ΔV_{OUT}		1%	
Input Ripple	ΔV_{IN}		1%	
Output Undershoot	V_{US}		3%	
Output Overshoot	V_{OS}		3%	
Frequency	f_{SW}		600kHz	

Designed–Built–Tested

This document describes the hardware in Figure 2. It provides a detailed, systematic technical guide to design a step-down (buck) DC-DC converter using Maxim's MAX17501 synchronous step-down DC-DC converter. The power supply was built and tested. The details follow later in this document.

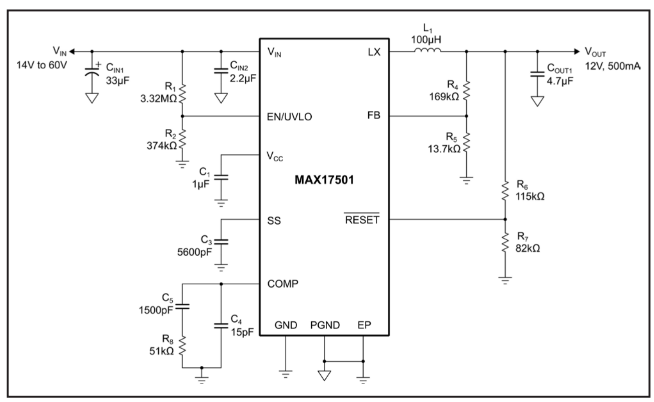

Figure 2. MAX17501 circuit (12V output, 500mA maximum load current, 600kHz switching frequency).

Design Procedure for the MAXREFDES1209

Step 1. Input Capacitor

The discontinuous input-current waveform of the buck converter causes large ripple currents in the input capacitor. The switching frequency, peak inductor current, and the allowable peak-to-peak voltage ripple that reflects to the source distance the input capacitance requirement. The device's high switching frequency allows the use of smaller value input capacitors. A 2.2μF X7R capacitor is used for the input capacitor as X7R capacitors are used for their stability over temperature in industrial applications. An additional 33μF electrolytic capacitor can be added in parallel to the 2.2μF ceramic capacitor to provide necessary damping for potential oscillations caused by a longer input power path and to reduce line side ripples.

Step 2. Selecting the Inductor

There are three key parameters specified for operation with the device: inductance value (L), saturation current rating (ISAT), and DC resistance. The inductor value is determined by the output voltage as in the following data sheet equation:

$$L = \frac{4.8 \times V_{OUT}}{f_{SW}} = \frac{4.8 \times 12V}{600kHz} = 96\mu H$$

The maximum peak inductor current can reach up to 750mA with full load current of 0.5A and ripple current of 150mA to 250mA (considering an LIR ratio of 0.3 to 0.5). Hence, a 100μH inductance with ISAT of 990mA was selected, which is approximately 4% higher than the calculated inductance value.

Step 3. Output Capacitor

The output capacitor is selected to support a step load of 50% of the load current specified in design specifications. So, the output-voltage deviation is contained to ±1% of the output-voltage change. The output capacitance, for a 12V output, is determined by the load step current (I_{STEP}), response time of the controller ($t_{RESPONSE}$), allowable output-voltage deviation (ΔV_{OUT}), target closed loop crossover frequency (f_C), and switching frequency(f_{SW}). The capacitance is calculated using the following equations in the data sheet:

$$t_{RESPONSE} \cong \left(\frac{0.33}{f_C} + \frac{1}{f_{SW}}\right) = \left(\frac{0.33}{\left(\frac{600kHz}{13}\right)} + \frac{1}{600kHz}\right) \approx 8.27\mu s$$

$$C_{OUT} = \frac{1}{2} \times \frac{I_{STEP} \times t_{RESPONSE}}{\Delta V_{OUT}} = \frac{1}{2} \times \frac{0.5A \times 8.27\mu s}{120mV} = 2.87\mu F$$

The calculated response time of the controller is 8.27μs and required output capacitance is 2.87μF based on the transient parameters following the above equations. The capacitance value is calculated as following for an output ripple of 1% (120mV for 12V output voltage):

$$\Delta i_L = \frac{(V_{IN-MAX} - V_{OUT}) \times D_{MIN} \times t_{SW}}{2 \times L}$$

$$= \frac{(60 - 12) \times \left(\frac{12}{60}\right) \times 1.67 \times 10^{-6}}{2 \times 100 \times 10^{-6}} = 80mA$$

$$C_{OUT} = \frac{\Delta i_L \times t_{SW}}{8 \times \Delta V_{OUT}} = \frac{80mA \times 1.67\mu s}{8 \times 120mV} = 0.14\mu F$$

Consider the maximum of the above calculated output capacitor values to select components. The nominal capacitance of the capacitor is derated based on the bias voltage. So, considering 20% tolerance, any capacitor with actual capacitance value greater than or equal to 3.44μF is sufficient to achieve the specifications. Capacitor C1206C475K3RAC is chosen as it offers 3.9uF actual capacitance considering the DC bias. The voltage rating of the capacitor must be greater than the output voltage.

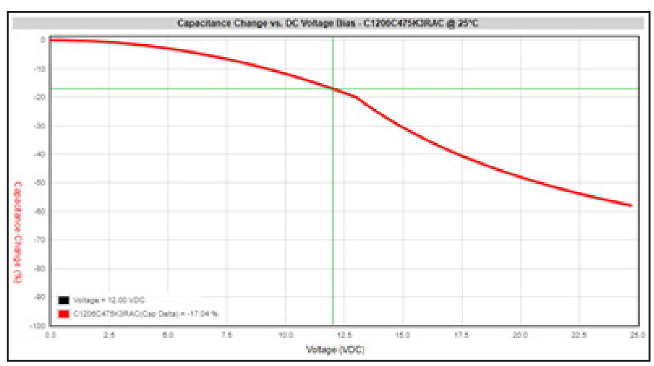

Figure 3. Output capacitor DC bias.

Step 4. Soft-Start Capacitor

The soft-start capacitor connected from the SS pin to the GND programs the soft-start period. Soft-start is used to reduce the inrush current by slowly ramping up the output voltage. A longer soft-start time reduces the charging rate of the output capacitor and limits the inrush current. The output capacitance (C_{OUT}) and the output voltage determine the minimum required soft-start capacitor as:

$$C_3 \geq 19 \times 10^{-6} \times C_{OUT} \times V_{OUT}$$
$$\geq 19 \times 10^{-6} \times 4.7\mu F \times 12V \geq 1.07nF$$

C_3 is chosen as 5600pF, which is sufficiently above the minimum requirement.

The soft-start time (t_{SS}) is related to the soft-start capacitor and is calculated as:

$$t_{SS} = \frac{C_3}{5 \times 10^{-6}} = \frac{5.6nF}{5 \times 10^{-6}} = 1.12ms$$

Step 5. Output Voltage

The MAX17501G offers an adjustable output voltage from 0.9V to 92% V_{IN}. The output voltage is set by placing a resistor divider from the V_{OUT} to the ground (GND) using resistors R_4 and R_5. The parallel combination of R_4 and R_5 (R_P) must be less than 30kΩ. R_P is selected to be 12.675kΩ, R_4 is calculated as:

$$R_4 = \frac{R_P \times V_{OUT}}{0.9} = \frac{12.675k\Omega \times 12V}{0.9} = 169k\Omega$$

Thus, R_4 =1 69kΩ ±1%, and it is connected from the V_{OUT} to the FB/VO.

Next, calculate R_5, which is connected from the FB/VO to the GND:

$$R_5 = \frac{R_4 \times 1.218}{(V_{OUT} - 1.218)} = \frac{169k\Omega}{(12V - 0.9)} = 13.7k\Omega$$

Thus, R_5 = 13.7kΩ ±1%, and it is connected from the FB/VO to the GND.

Step 6. Input Undervoltage Lockout Level

The Undervoltage Lockout Level (UVLO) sets the voltage at which the device turns on. The UVLO is set using a resistor divider connected from the V_{IN} to the GND, with the center node connected to the EN/UVLO. R_1 is selected as 3.3MΩ as recommended by the data sheet and R_2 is calculated using the following equation to produce an 11V input threshold:

$$R_1 = 3.32M\Omega$$

Thus, R_1 = 3.32MΩ ±1% standard value resistor.

$$R_2 = \frac{R_1 \times 1.218}{V_{INU} - 1.218} = \frac{3.32M\Omega \times 1.218}{(12 - 1.218)} = 375k\Omega$$

where V_{INU} is the voltage at which the device is required to turn on and it must be higher than 0.8 x V_{OUT}. Here, V_{INU} is chosen as 12V. Thus, R_2 = 374kΩ ±1% standard value resistor.

Step 7. Compensation Network

A type II compensator network is placed on the COMP pin of the MAX17501 to produce a stable high-bandwidth control loop. The basic regulator loop is modeled as a power modulator, an output feedback divider, and an error amplifier. The power modulator has DC gain $G_{MOD(DC)}$ with a pole and zero pair. The following equation defines the power modulator DC gain:

$$G_{MOD} = \frac{1}{\frac{1}{R_{LOAD}} + \frac{0.2}{V_{IN}} + \left(\frac{0.5 - D}{f_{SW} \times L_{SEL}}\right)}$$
$$= \frac{1}{\frac{1}{24} + \frac{0.2}{60} + \left(\frac{0.5 - \frac{12}{60}}{600k \times 100\mu}\right)} = 20$$

R_8 is calculated as:

$$R_8 = 12000 \times f_C \times C_{SEL} \times V_{OUT} = 12000 \times \frac{600kHz}{12}$$
$$\times 4.7\mu F \times 12 = 33.84k\Omega$$

where f_C is chosen as 1/12th of the switching frequency.

C_Z is calculated as:

$$C_5 = \frac{C_{SEL} \times G_{MOD}}{R_8} = \frac{4.7\mu \times 20}{33.84k} = 2.8nF$$

C_P is calculated as:

$$C_4 = \frac{1}{\pi \times R_8 \times f_{SW}} = \frac{1}{\pi \times 33.84k \times 600k} = 15pF$$

A reasonably stable AC loop response of the converter is derived for the above compensation values. The crossover frequency is 58kHz and the phase margin is 60° per EE-SIM simulation (Figure 4).

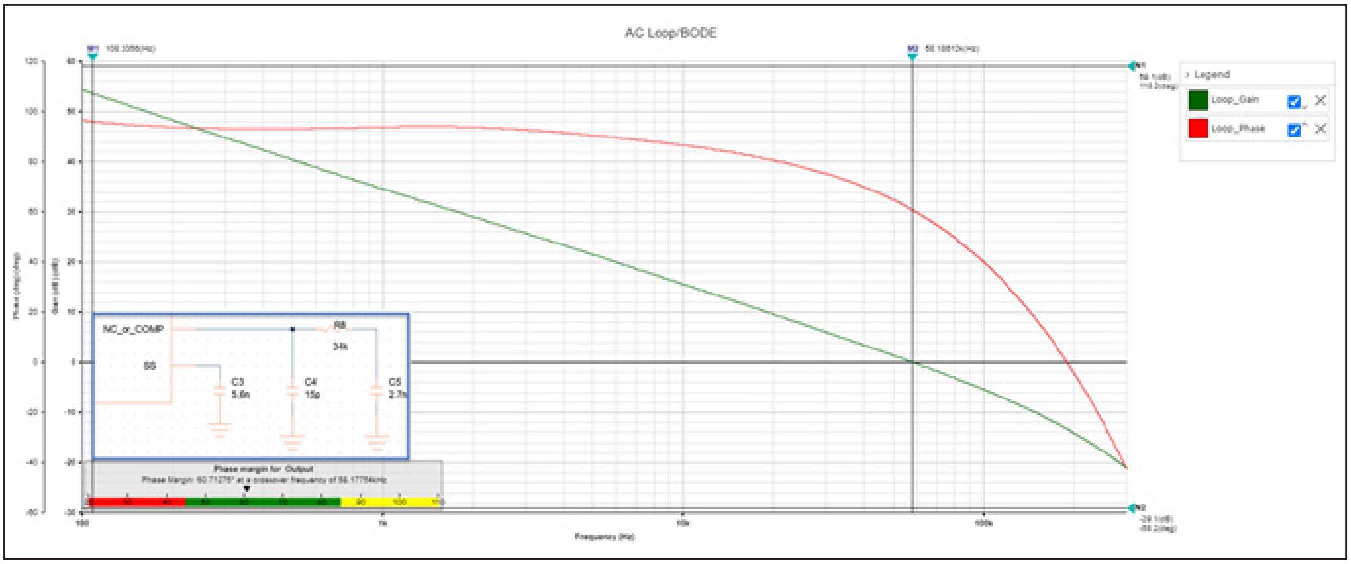

Figure 4. AC loop simulation to measure the phase margin and crossover frequency using the EE-SIM tool.

However, these values are tweaked and set to the final values as following to achieve higher bandwidth and improve transient response:

R_8 is selected as 51kΩ, C_5 as 1.5nF, and C_4 as 15pF.

Step 8. RESETB Network

The MAX17501G offers an adjustable RESETB output voltage. The output voltage is set by placing a resistor divider from the V_{OUT} to the GND using resistors R_6 and R_7.

R_6 = 115kΩ ±1%, and it is connected from the V_{OUT} to the RESETB.

Next, calculate R_7, which is connected from the RESETB to the GND:

$$\text{RESETB} = \frac{V_{OUT} \times R_7}{(R_6 + R_7)}$$

where RESETB is chosen as 5V.

$$R_7 = \frac{R_6 \times \text{RESETB}}{(V_{OUT} - \text{RESETB})} = \frac{115k \times 5}{(12 - 5)} = 82k\Omega$$

Thus, select R_7 = 82kΩ ±1%, and connect it from the FB/VO to the GND.

Step 9. RC Snubber Circuit

This additional circuit was added in this reference design to adjust the RC snubber to reduce ringing at the switching node.

Design Resources

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

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	11/20	Initial release	—