Keywords: negative voltage, synchronous step-down converter, inverting buck-boost, factory automation, industrial process control

APPLICATION NOTE 5775

HOW TO USE THE MAX17501 AND MAX17502 FOR NEGATIVE OUTPUT VOLTAGE APPLICATIONS

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Abstract: This article shows how to produce negative output voltages from positive input voltages using the MAX17501 and MAX17502 synchronous step-down converters.

Introduction

Industrial control equipment such as programmable logic controllers, I/O modules, mass flow controllers, and various other sensors and supporting systems use 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. Maxim's portfolio of high-voltage synchronous buck regulators offer 50% lower power loss allowing customers to operate their equipment 50% cooler. In this application note, we discuss techniques to use these synchronous buck regulators to generate negative voltages.

Design Considerations

Synchronous buck converters can be configured to work in a buck-boost topology to produce negative output voltage from positive input voltage. This application note explains how the MAX17501 and MAX17502 synchronous step-down converters can be used to generate negative output voltage from positive input voltage. A -15V output voltage application is used to demonstrate the principle.

Table 1. Negative Output Voltage Power-Supply Requirements

V_{IN}	Operating input voltage	24V ±6V
V_{OUT}	Output voltage	-15V
I_{OUT}	Maximum output current	500mA
V_{IN_ripple}	Steady-state input ripple voltage	1% of nominal V_{IN}
V_{OUT_ripple}	Steady-state output ripple voltage	1% of nominal V_{OUT}

Operating Input Voltage Range

The sum of the maximum operating input voltage for the negative output application and the absolute value of the output voltage should not exceed the maximum operating voltage (60V) of the MAX17501 and MAX17502, as expressed by the following equation:

$$V_{IN\_MAX} + |V_{OUT}| > 60V$$

Therefore, for -15V output voltage, maximum operating input voltage can be as high as 45V. The minimum operating input voltage for the negative output voltage application should be greater than 4.5V.

Calculating Duty Ratio

The expression for the duty ratio of the negative output power supply is shown below; ignoring the losses associated with the power switches and the inductor DC resistance:

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

For the specifications listed above, the duty cycle varies between 0.45 at 18V input voltage to 0.33 at 30V input voltage. At the nominal input voltage of 24V, duty cycle is 0.38. Note that the highest duty ratio (D_{MAX}) occurs at the minimum operating input voltage and the lowest duty ratio (D_{MIN}) occurs at the maximum operating input voltage (V_{IN_MAX}).

Load Current Capability and Part Number Selection

The negative output voltage design requirements are not compatible with the versions of the MAX17501 and MAX17502 that have internal compensation—so, consider only the G and H versions of the MAX17501 and MAX17502 for building negative output voltage applications.

To estimate whether the MAX17501 and MAX17502 are capable of delivering the required output current, the value of the maximum inductor average current should be calculated first, based on the following equation:

$$I_{L\_AVG} = I_{L\_MAX} - \frac{\Delta I_L}{2}$$

Assume I_{L_MAX} to be 550mA and 1.2A for the MAX17501 and MAX17502, respectively, to allow some room for the output capacitor charging current. Assuming the value of the maximum inductor ripple (ΔI_L) is 250mA for the MAX17501 and 500mA for the MAX17502, we arrive at the following maximum values of I_{L_AVG} for both parts:

I_{L_AVG} = 425mA for the MAX17501
I_{L_AVG} = 950mA for the MAX17502

The maximum load current that can be supported by the MAX17501 and the MAX17502 is expressed by the following equation:

$I_{OUT\_MAX} = I_{L\_AVG} \times (1 - D_{MAX})$

Since D_{MAX} is 0.45 for the specifications being targeted here, I_{OUT_MAX} is calculated as 234mA for the MAX17501 and 522mA for the MAX17502. Therefore, the MAX17502G is selected for this application. It is recommended to design with the MAX17501 whenever the targeted I_{OUT} is less than the maximum load current allowed by the MAX17501.

Start Voltage

When used as a buck converter, the voltage at which the MAX17501 and MAX17502 turns on/off can be adjusted by using the resistive divider connected from the V_{IN} pin to GND. When used as a negative output voltage power supply, only the start voltage can be programmed by the resistive divider. When the part turns on, the effective input voltage experienced by the part increases 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.

Applications Information

Inductor Selection

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

$$L_{MIN} = \frac{V_{IN\_MIN} \times D_{MAX}}{f_{sw} \times \Delta I_L}$$

The switching frequency (f_{SW}) is 600kHz for the MAX17501G and MAX17502G parts and 300kHz for the MAX17501H and MAX17502H. Assuming maximum inductor ripple (ΔI_L) to be 500mA for the MAX17502, L_{MIN} turns out to be 27μH for the specifications mentioned in Table 1.

Slope compensation requirements impose the following constraint on the inductor value:

$$\frac{x \times V_{IN\_MIN} \times (D_{MAX} - 0.25)}{(1 - D_{MAX})} < L < \frac{x \times V_{IN\_MIN} \times (D_{MAX} + 0.77)}{(1 - D_{MAX})}$$

where x = 4 for the MAX17502G, x = 8 for the MAX17501G and MAX17502H, and x = 16 for the MAX17501H.

The constraint shown above is valid only if the maximum duty ratio is greater than 0.25. Since MAX17502G has been selected for this application, the inductor value should be between 27μH and 160μH for the specifications mentioned in Table 1. A 33μH inductor has been used for this application.

Ensure that the saturation current of the selected inductor is greater than the peak current limits of the MAX17501 and MAX17502.

Input Capacitor Selection

The minimum value of the input capacitor is expressed as follows:

$$C_{IN\_MIN} = \frac{\Delta I_L}{8 \times f_{sw} \times V_{IN\_RIPPLE}}$$

Inductor ripple (ΔI_L) in the above equation should be calculated based on the actual inductance value chosen for the application:

$$\Delta I_L = \frac{V_{IN\_MIN} \times D_{MAX}}{f_{sw} \times L_{SEL}}$$

where L_{SEL} is the selected inductance. For the specifications mentioned in **Table 1**, the C_{IN_MIN} turns out to be 0.36μF. A 2.2μF capacitor in 1206 package has been used for this design. The capacitance derates to approximately 1.3μF at 24V input voltage.

Output Capacitor Selection

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

$$C_{OUT\_MIN} = \frac{I_{OUT} \times D_{MAX}}{f_{sw} \times V_{OUT\_RIPPLE}}$$

For the specifications mentioned in Table 1, the C_{OUT_MIN} turns out to be 2.5μF. A 4.7μF capacitor in 1206 package has been used for this design. The capacitance derates to approximately 2.5μF at 15V output voltage.

Adjusting Output Voltage

Set the output voltage with a resistive voltage-divider connected from the ground terminal of the inductor to V_{OUT}. Connect the center node of the divider to the FB/VO pin. Select the values of resistors R4 and R5 as follows:

$$R4 = 16.7 \times |V_{OUT}|$$

$$R5 = \frac{R4 \times 0.9}{(|V_{OUT}| - 0.9)}$$

where R4 and R5 are in k½. The values of R4 and R5 selected for this application are 243k½ and 15.4k½, respectively.

Setting the Input Turn-On Voltage

Set the input voltage at which the MAX17501 and MAX17502 turn on with a resistive voltage-divider connected from V_{IN} to V_{OUT} (see Figure 1). Connect the center node of the divider to the EN/UVLO pin. Choose R1 to be 3.3M½, and then calculate R2 as:

$$R2 = \frac{R1 \times 1.218}{(V_{INU} - 1.218)}$$

where V_{INU} is the input voltage at which the MAX17501 and MAX17502 are required to turn on. Selecting a value of 261k½ for R2 results in the part turning on at 16.6V input voltage.

External Loop Compensation

Compensation components R3 and C5 should be calculated as follows:

$$R3 = \frac{x \times 188 \times {V_{OUT}}^2 \times C_{OUT} \times (1 - D_{MAX})}{L \times I_{OUT} \times D_{MAX}}$$

where k = 1 for the MAX17502 and k = 2 for the MAX17501.

The value of C5 should be calculated as follows:

$$C5 = \frac{V_{OUT} \times C_{OUT}}{R3 \times I_{OUT} \times (1 + D_{MAX})}$$

Use the DC voltage derated value of the output capacitor (COUT) while calculating the values of R3 and C5. DC voltage derating curves are available from all major capacitor vendors. Using the derated value of output capacitance (2.5μF), the value of R3 turns out to be 7.8k½. Choosing R3 of 7.5k½ results in the value of C5 being 6800pF.

Soft-Start Capacitor Selection

The MAX17501 and MAX17502 implement adjustable soft-start operation to reduce inrush current. A capacitor connected from the SS pin to V_{OUT} programs the soft-start period. The soft-start time (t_{SS}) is related to the capacitor connected at SS (C_{SS}) by the following equation:

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

where t_{SS} is in milliseconds and C_{SS} is in nanofarads. For example, to program a 1.2ms soft-start time, a 6800pF capacitor should be connected from the SS pin to V_{OUT}.

Schematic for the Design

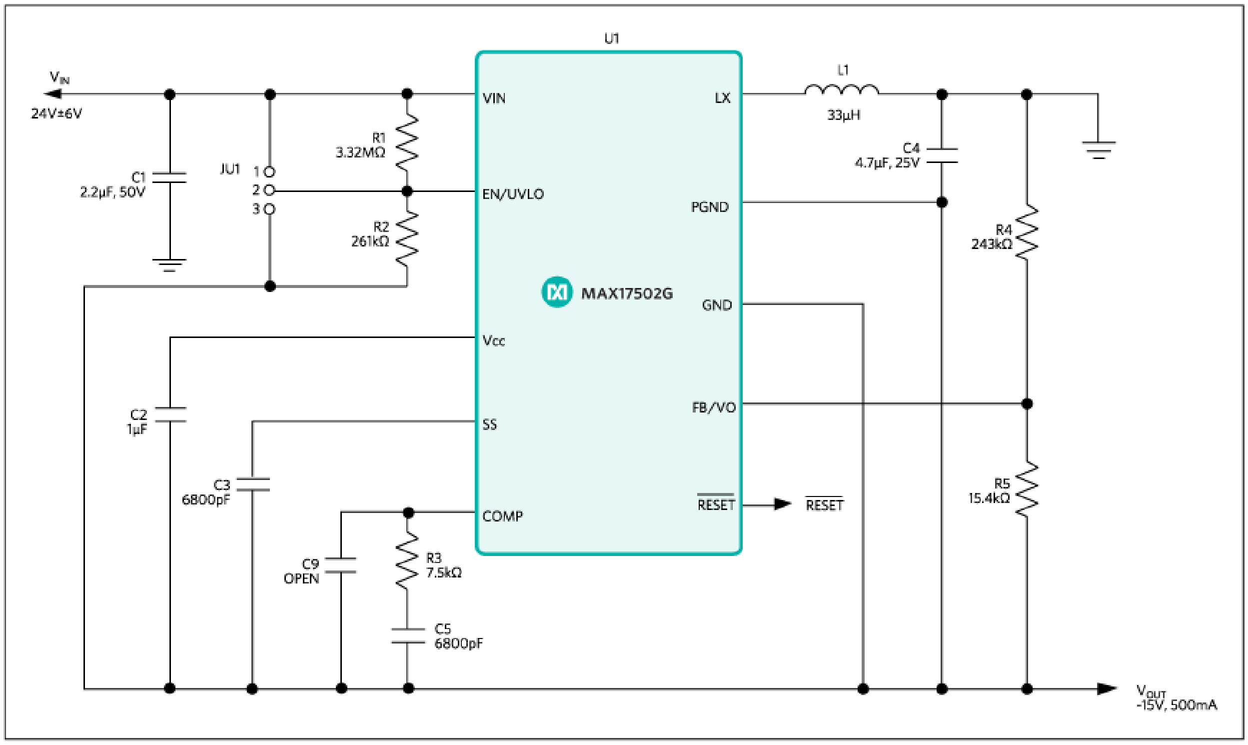

Figure 1. Schematic for the design.

Bill of Materials

Table 2. Bill of Materials

Designator	Value	Description	Part Number	Manufacturer	Package	Qty
C1	2.2µF/X7R/50V	Input bypass capacitor	GRM31CR71H225KA88L	Murata	1206	1
C2	1µF/X7R/6.3V	VCC bypass capacitor	GRM188R70J105KA01	Murata	0603	1
C3	6800pF/X7R/25V	Soft-start capacitor	GRM155R71E682KA01D	Murata	0402	1
C4	4.7µF/X7R/25V	Output capacitor	GRM31CR71E475KA88L	Murata	1206	1
C5	6800pF/X7R/25V	Compensation capacitor	GRM155R71E682KA01D	Murata	0402	1
C9	Not installed				0402	0
L1	33µH	Inductor	MSS1048-333ML	Coilcraft	10.2mm x 10mm	1
R1	3.32M½ ±1%	EN/UVLO resistor-divider			0402	1
R2	261k½ ±1%	EN/UVLO resistor-divider			0402	1
R3	7.5k½ ±1%	Compensation resistor			0402	1
R4	243k½ ±1%	FB resistor-divider			0402	1
R5	15.4k½ ±1%	FB resistor-divider			0402	1
U1		Internal switch buck converter	MAX17502GATB+	Maxim	10 TDFN 3 x 2	1

Experimental Results

- **Efficiency of the Negative Output Power Supply**

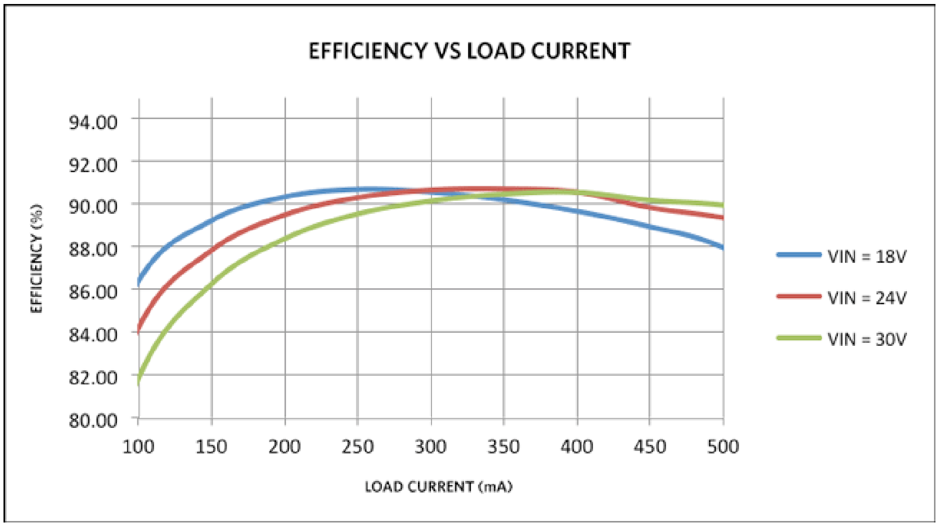

Figure 2. Efficiency vs. load current.

- **Load and Line Regulation of Output Voltage**

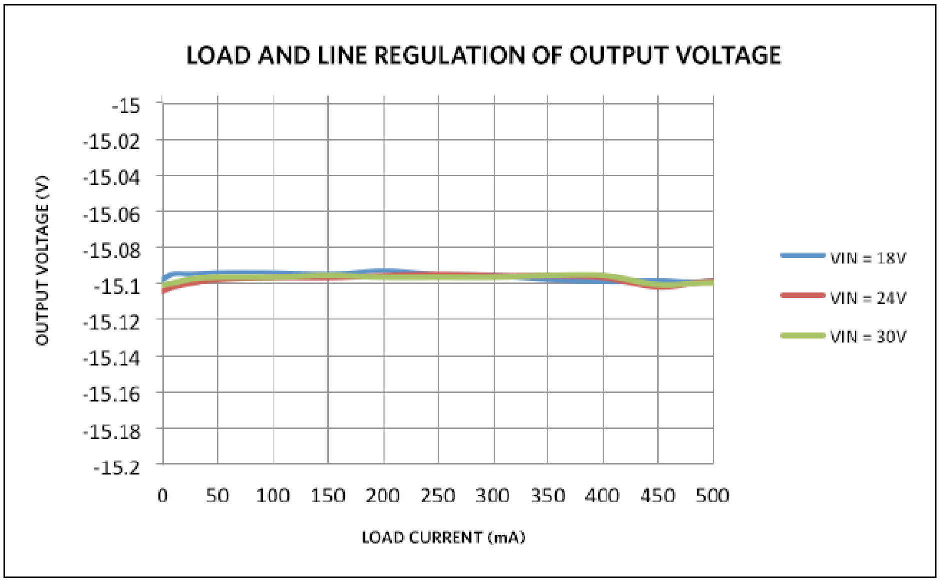

Figure 3. Load and line regulation of output voltage.

- **Soft-Start/Turn-Off of Output Voltage**

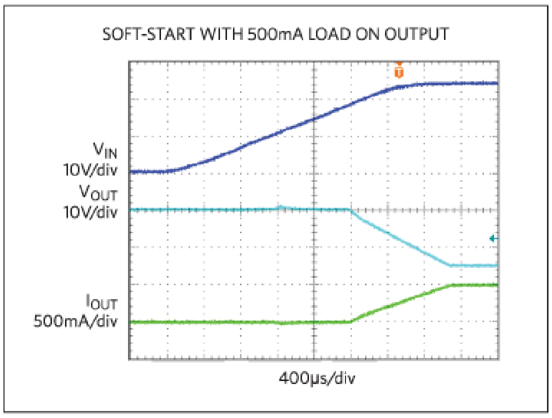

Figure 4. Soft-start with 500mA load on output.

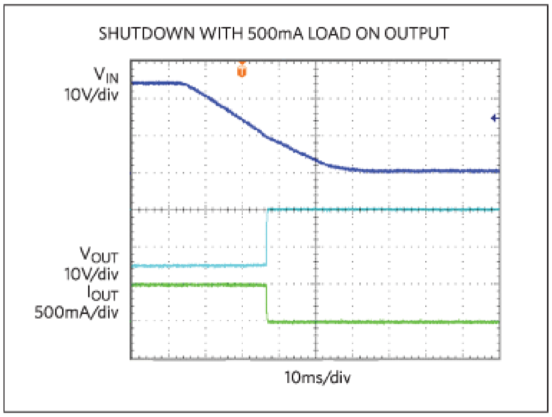

Figure 5. Shutdown with 500mA load on output.

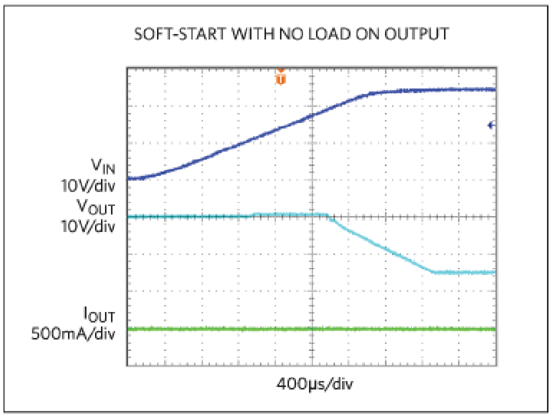

Figure 6. Soft-start with no load on output.

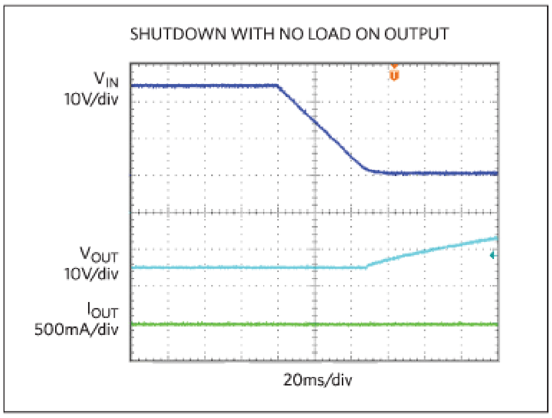

Figure 7. Shutdown with no load on output.

- **Switching Waveforms**

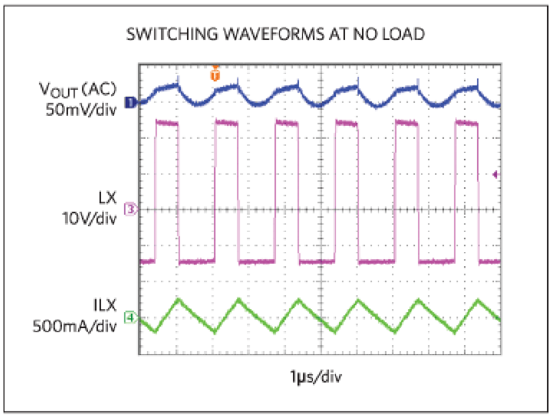

Figure 8. Switching waveforms at no load.

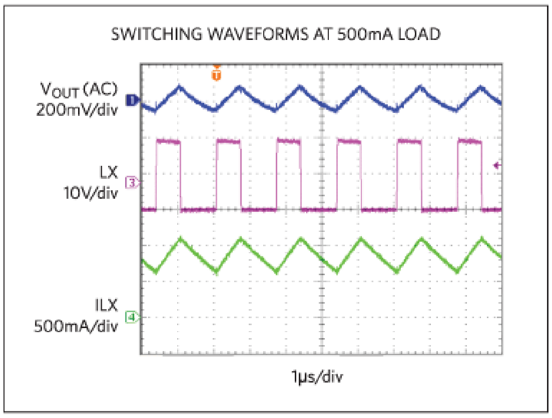

Figure 9. Switching waveforms at 500mA load.

- **Load Transient Waveforms**

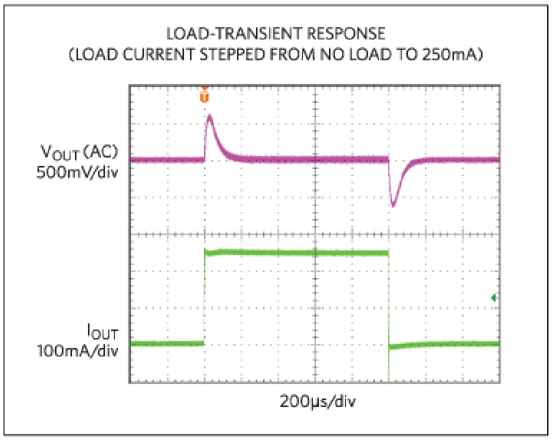

Figure 10. Load-transient response from no load to 250mA.

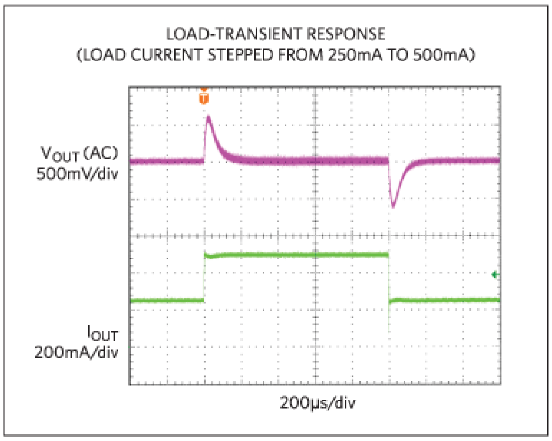

Figure 11. Load transient response from 250mA to 500mA.

- **Bode Plot**

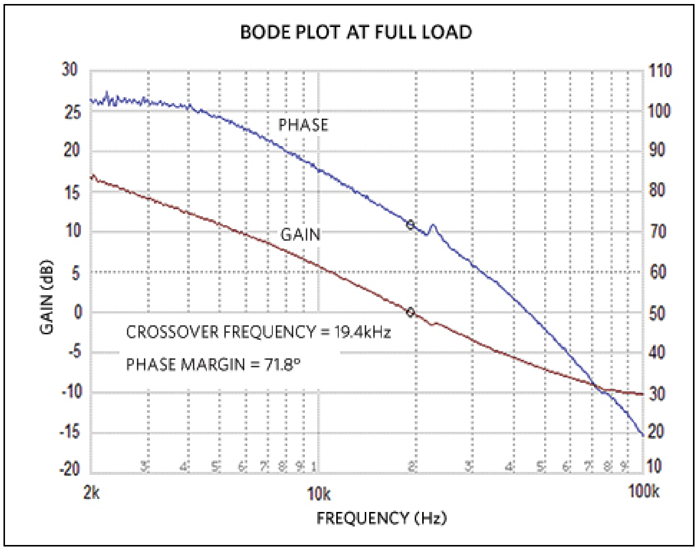

Figure 12. Bode plot at full load.

Layout of the Evaluation Board

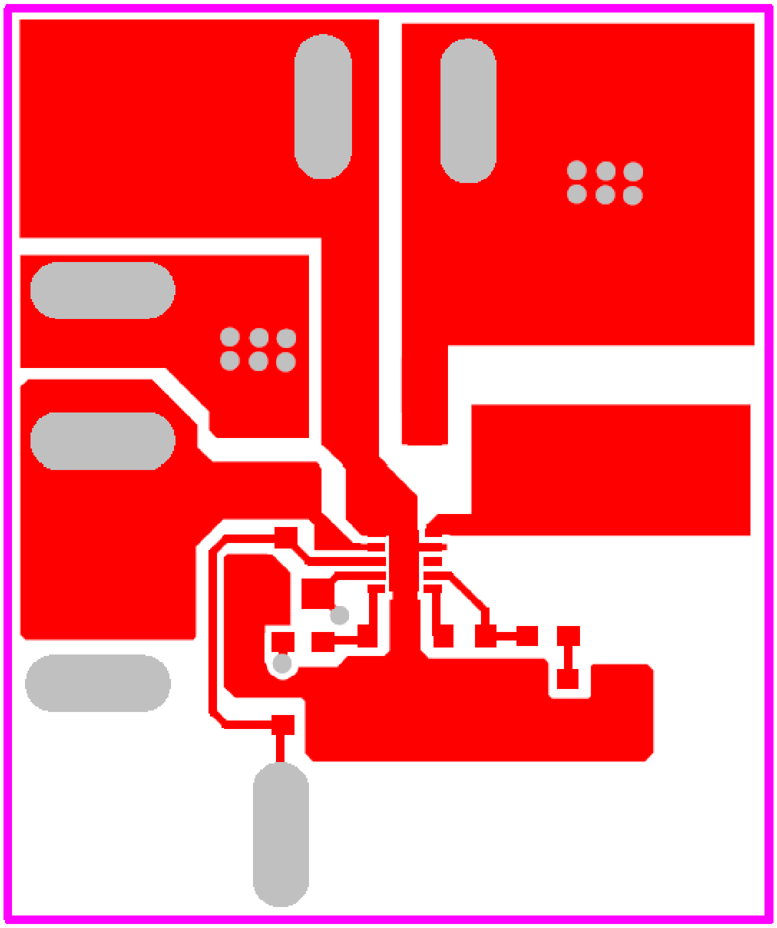

Figure 13. Component-side PCB layout.

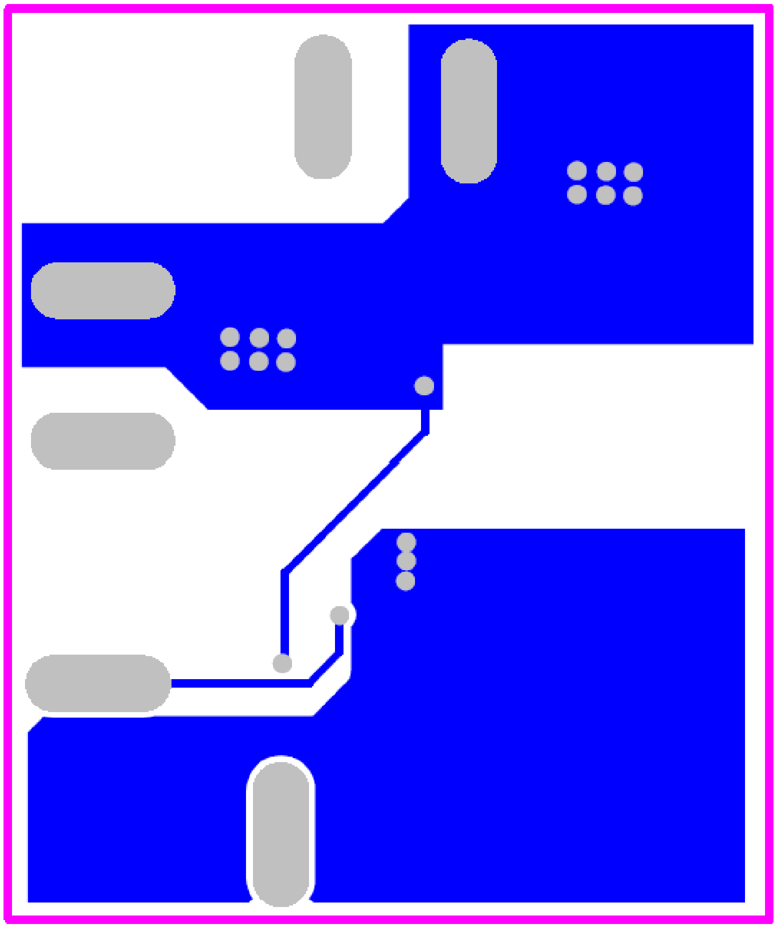

Figure 14. Solder-side PCB layout.

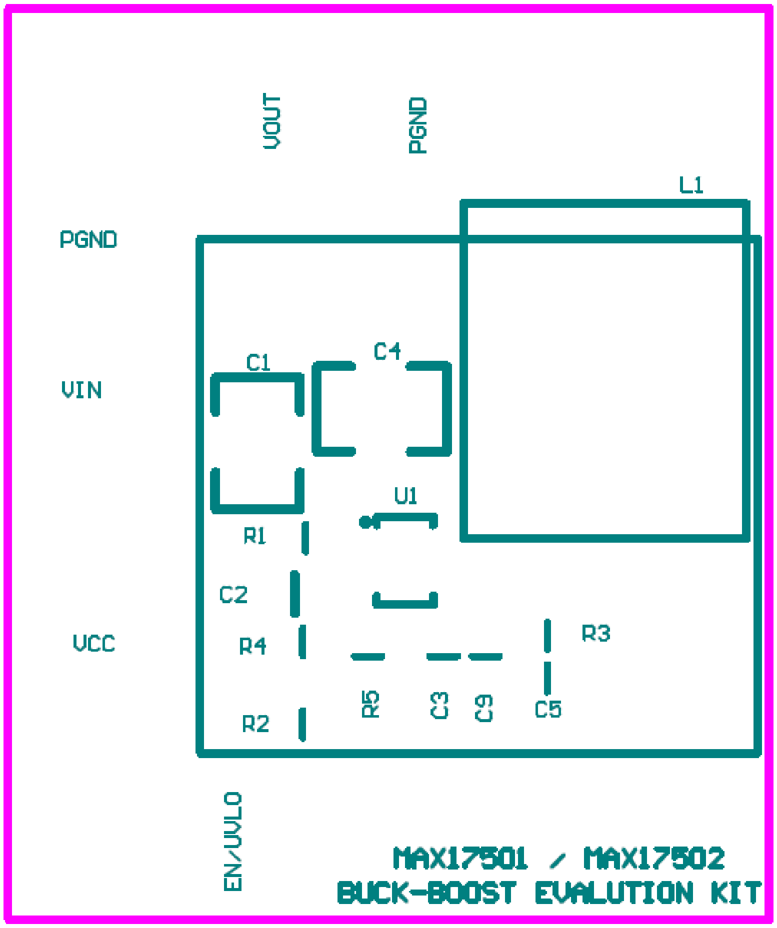

Figure 15. Component placement guide.

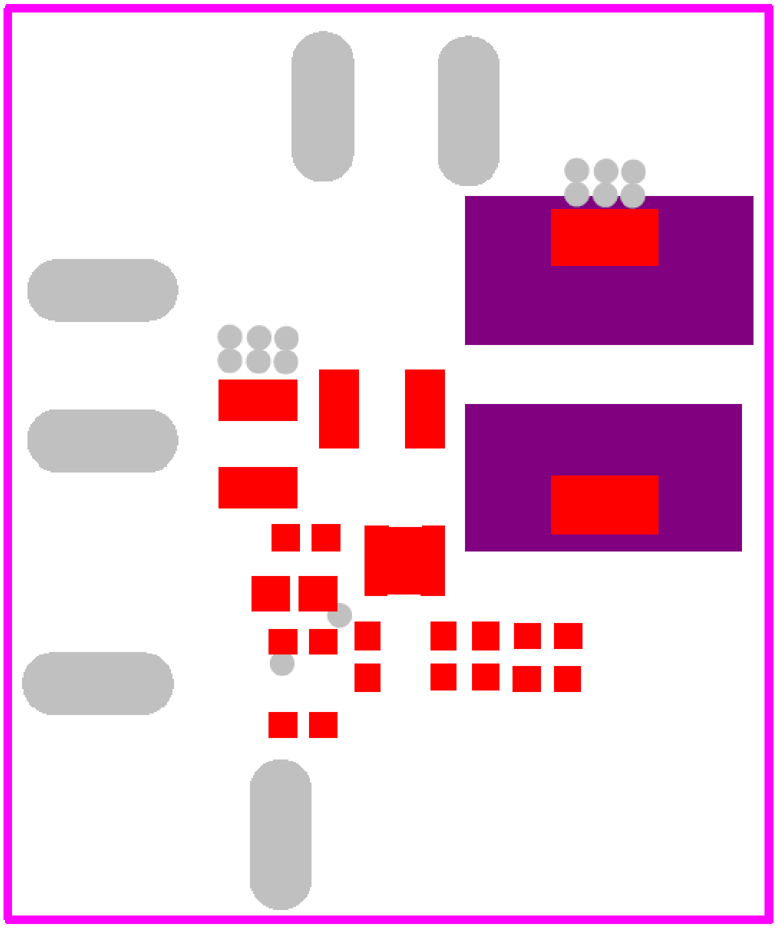

Figure 16. Top solder mask.

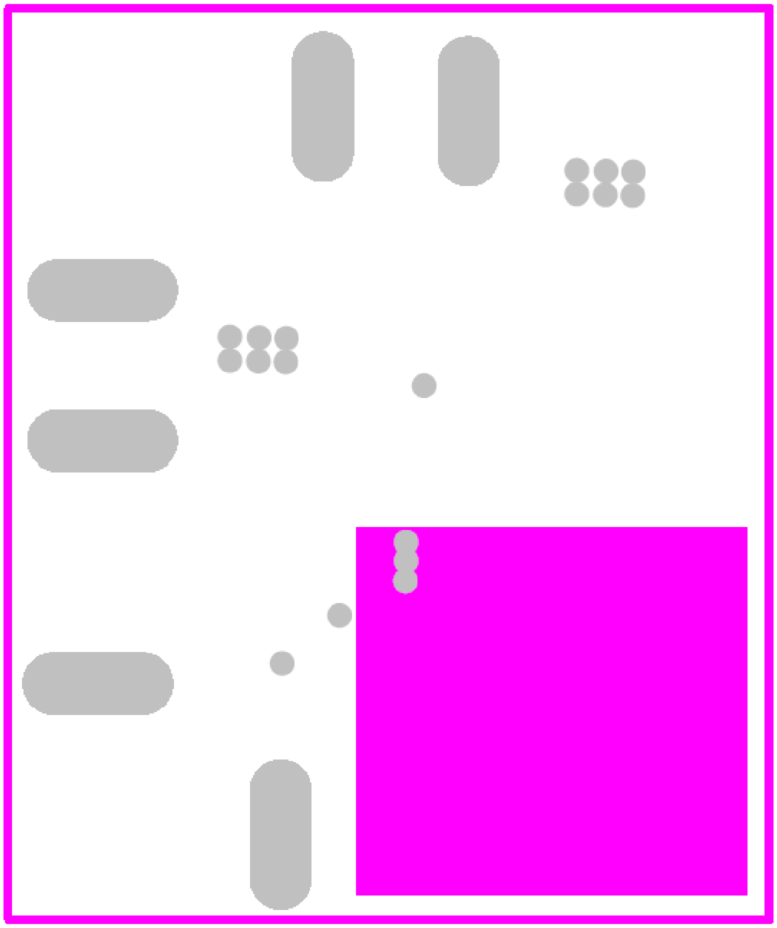

Figure 17. Bottom solder mask.

Appendix: Additional Reference Designs

The schematic shown in Figure 1 corresponds to all the following reference designs.

- **Reference Design 2:** V_{IN} = 22V to 30V, V_{OUT} = -24V, I_{OUT} = 150mA

Table 3. Bill of Materials for Reference Design 2

Designator	Value	Description	Part Number	Manufacturer	Package	Qty
C1	0.47µF/X7R/50V	Input bypass capacitor	GRM31MR71H474KA01	Murata	1206	1
C2	1µF/X7R/6.3V	VCC bypass capacitor	GRM188R70J105KA01	Murata	0603	1
C3	6800pF/X7R/25V	Soft-start capacitor	GRM155R71E682KA01D	Murata	0402	1
C4	2.2µF/X7R/50V	Output capacitor	GRM31CR71H225KA88	Murata	1206	1
C5	12000pF/X7R/25V	Compensation capacitor	GRM155R71E123KA61D	Murata	0402	1
C9	Not installed				0402	0
L1	150µH	Inductor	VLP8040T-151M	TDK	8mm x 7.7mm	1
R1	3.32M½ ±1%	EN/UVLO resistor-divider			0402	1
R2	215k½ ±1%	EN/UVLO resistor-divider			0402	1

R3	10.7k½ ±1%	Compensation resistor			0402	1
R4	392k½ ±1%	FB resistor-divider			0402	1
R5	15.4k½ ±1%	FB resistor-divider			0402	1
U1		Internal switch buck converter	MAX17501GATB+	Maxim	10 TDFN 3 x 2	1

- **Reference Design 3:** V_{IN} = 4.5V to 5.5V, V_{OUT} = -12V, I_{OUT} = 100mA
  Table 4. Bill of Materials for Reference Design 3

Designator	Value	Description	Part Number	Manufacturer	Package	Qty
C1	0.47µF/X7R/50V	Input bypass capacitor	GRM31MR71H474KA01	Murata	1206	1
C2	1µF/X7R/6.3V	VCC bypass capacitor	GRM188R70J105KA01	Murata	0603	1
C3	6800pF/X7R/25V	Soft-start capacitor	GRM155R71E682KA01D	Murata	0402	1
C4	2.2µF/X7R/16V	Output capacitor	GRM31MR71C225KA35	Murata	1206	1
C5	33000pF/X7R/25V	Compensation capacitor	GRM155R71E333KA88J	Murata	0402	1
C9	Not installed				0402	0
L1	100µH	Inductor	VLC6045T-101M	TDK	6mm x 6mm	1
R1	3.32M½ ±1%	EN/UVLO resistor-divider			0402	1
R2	1.5M½ ±1%	EN/UVLO resistor-divider			0402	1
R3	3.24k½ ±1%	Compensation resistor			0402	1
R4	200k½ ±1%	FB resistor-divider			0402	1
R5	16.2k½ ±1%	FB resistor-divider			0402	1
U1		Internal switch buck converter	MAX17501GATB+	Maxim	10 TDFN 3 x 2	1

- **Reference Design 4:** V_{IN} = 18V to 30V, V_{OUT} = -5V, I_{OUT} = 150mA
  Table 5. Bill of Materials for Reference Design 4

Designator	Value	Description	Part Number	Manufacturer	Package	Qty
C1	0.47µF/X7R/50V	Input bypass capacitor	GRM31MR71H474KA01	Murata	1206	1
C2	1µF/X7R/6.3V	VCC bypass capacitor	GRM188R70J105KA01	Murata	0603	1
C3	6800pF/X7R/25V	Soft-start capacitor	GRM155R71E682KA01D	Murata	0402	1
C4	2.2µF/X7R/10V	Output capacitor	GRM31MR71A225KA01	Murata	1206	1
C5	3900pF/X7R/25V	Compensation capacitor	GRM155R71b92KA01D	Murata	0402	1
C9	Not Installed				0402	0
L1	33µH	Inductor	LPS6235-333ML	Coilcraft	6mm x 6mm	1
R1	3.32M½ ±1%	EN/UVLO resistor-divider			0402	1
R2	261k½ ±1%	EN/UVLO resistor-divider			0402	1
R3	12.1k½ ±1%	Compensation resistor			0402	1
R4	84.5k½ ±1%	FB resistor-divider			0402	1
R5	18.7k½ ±1%	FB resistor-divider			0402	1
U1		Internal switch buck converter	MAX17501GATB+	Maxim	10 TDFN 3 x 2	1

Related Parts		
MAX17501	60V, 500mA, Ultra-Small, High-Efficiency, Synchronous Step-Down DC-DC Converter	Free Samples
MAX17502	60V, 1A, Ultra-Small, High-Efficiency, Synchronous Step-Down DC-DC Converter	Free Samples

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More Information
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