APPLICATION NOTE 7242

HOW TO USE THE MAX20058 AND MAX20059 FOR NEGATIVE OUTPUT VOLTAGE APPLICATIONS

By: Fa Chen

Abstract: This article shows how to produce negative output voltages from positive input voltages using the MAX20058 and MAX20059 synchronous converters in an Inverting Buck-Boost (IBB) configuration. These types of systems are becoming more and more common place for various automotive applications. These inverted voltages are used for different applications in EV/HEV vehicles or ADAS applications such as an APD bias supply or gate drive bias supplies.

Introduction

The increasing need for ADAS features and introduction of EVs/HEVs are raising the demand for electronic content in automotive applications, driving the need for a variety of power management solutions. Many applications such as the APD bias supply for LIDAR (light detection and ranging) applications, gate driver bias supplies, bias for controllers, and other sensors need negative output voltage rails.

The Maxim portfolio of high-voltage synchronous buck regulators offers low power loss, small solution size, and low noise, thus meeting the stringent automotive requirements of customers. This application note demonstrates techniques to use a synchronous buck regulator (MAX20058/MAX20059) to generate negative voltages.

Design Considerations

The MAX20058/59 IC can be configured to work in an inverting buck-boost topology to produce negative output voltage from positive input voltage. This application note explains the process. A -24V output voltage application is used to demonstrate the principle.

Table 1. Negative Output Voltage (Power Supply Requirements)

V_{IN}	Operating Input Voltage	5V TO 40V
V_{OUT}	Output Voltage	-24V
I_{OUT}	Maximum Output Current	50mA
f_{SW}	Switching Frequency	600kHz

V_{IN}_ripple	Steady-State Input Ripple	1% of Nominal V_{IN}
V_{OUT}_ripple	Steady-State Output Ripple	1% of Nominal V_{OUT}

Range of the Operating Input Voltage

The sum of the maximum operating input voltage and absolute value of the output voltage must not exceed the maximum operating voltage (80V for MAX20059 and 65V for MAX20058) for the negative output application. It is expressed as:

VIN_MAX + | VOUT | < 80V

So, the maximum operating input voltage can be as high as 56V for a -24V output voltage. The minimum operating input voltage for the negative output voltage application must be greater than 4.5V.

Calculating the Duty Ratio

The duty ratio and output voltage, ignoring the losses associated with the power switches and inductor DC resistance, are expressed as follows:

The duty cycle varies between 0.83 at 5V to 0.38 at 40V input voltage. The highest duty ratio (D_{MAX}) occurs at the minimum operating input voltage and lowest duty ratio (D_{MIN}) at the maximum operating input voltage ($V_{IN\_}MAX$).

$$D = \frac{|V_{OUT}|}{V_{IN} + |V_{OUT}|} = \frac{24}{5 + 24} = 0.83$$

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

Applications Information

Selecting the Inductor

Specify three key inductor parameters for operation with the device: inductance value (L), inductor saturation current (I_{SAT}), and DC resistance (RDCR). Select the ratio of the inductor peak-to-peak AC current to DC average current (LIR) to select the inductor value. A 40% peak-to-peak ripple current to average-current ratio (LIR = 0.4) is a good compromise between size and loss. The peak current limit of the MAX20059 is 1.6A in the PWM (pulse-width-modulated) mode. The switching frequency, input voltage, output voltage, and selected LIR then determine the inductor value as follows:

$$L_{MIN1} = \frac{V_{IN\,(MAX)} \times D_{MIN}}{f_{SW} \times I_L \times LIR} = \frac{40 \times 0.375}{600 \times 10^3 \times 1.6 \times 0.4} = 39\mu H$$

V_{OUT}, I_{OUT}, and fSW are nominal values here. Select a low-loss inductor closest to the calculated value with acceptable dimensions and lowest possible DC resistance. The saturation current rating (I_{SAT}) of the inductor must be high enough so that saturation occurs only above the peak current-limit value. The next equation ensures the internal compensation slope is greater than 50% of the inductor current down slope:

$$m \geq \frac{m_2}{2}$$

m is the internal compensating slope and m_2 is the sensed inductor current downslope as follows:

$$m_2 = \frac{|V_{OUT}| \times R_L}{L}$$

m is the internal slope compensation with the value in Table 2, m_2 is the inductor current downslope, and R_l is the current-sense gain of 0.5 (typ):

$$L_{MIN2} = \frac{|V_{OUT}| \times R_L}{2 \times m} = \frac{24 \times 0.5}{2 \times 0.11364 \times 10^6} = 53\mu H$$

Table 2. Internal Slope Compensation vs. Switching Frequency

Switching Frequency (kHz)	Internal Slope Compenation m(V/µs)
200	0.03676
300	0.05514
400	0.07576
600	0.11364
2000	0.3676

Select the larger of LMIN1 and LMIN2 as the nominal inductor value:

$$L = \max(L_{MIN1}, L_{MIN2})$$

Select the inductor with the standard inductor value closest to L. The saturation current of the selected inductor must be greater and peak current smaller than the peak current limits of the MAX20059.

The small inductance can reduce the negative impact of the right half plane on the phase margin of the crossover frequency. Choose a 56µH inductor here.

Selecting the Input Capacitor

The input capacitor is important to reduce the current peaks drawn from the input supply, increase efficiency, and reduce noise injection. The value of CIN largely depends on the source impedance of the input supply. The higher the source impedance, higher the input capacitance. Place a ceramic capacitor at the input of the MAX20059 to reduce the voltage ripple. An X7R ceramic capacitor is recommended for automotive industry standards. The following equation determines the minimum value needed for this design:

$$C_{IN\,(MIN)} = \frac{I_{OUT} \times D_{MAX}}{f_{SW} \times \Delta V_{IN}} = \frac{0.05 \times 0.83}{600 \times 10^3 \times 5 \times 1\%} = 1.4\mu F$$

A 2.2µF, 100V, and 10% X7R is chosen because of the derating value of the capacitor. The actual capacitance is properly derated in ceramic capacitors according to the applied DC voltage. Refer to the manufacturer data sheets for the ceramic capacitors for more accurate derating models.

Selecting the Output Capacitor

The output ripple comprises ΔV_Q (caused by the capacitor discharge) and ΔV_{ESR} (caused by the ESR of the output capacitor). Use low-ESR ceramic or aluminum electrolytic capacitors at the output. The ΔV_{ESR} contributes the entire output ripple for aluminum electrolytic capacitors. The output filter capacitor must have enough capacitance and sufficiently low ESR to meet the output-ripple requirements. The output capacitance, to satisfy the specified output-voltage ripple, is calculated as:

$$C_{OUT\,(MIN1)} = \frac{I_{OUT} \times LIR}{8 \times f_{sw} \times (\Delta V_Q - ESR \times I_{OUT} \times LIR)}$$
$$= \frac{0.05 \times 0.4}{8 \times 600 \times 10^3 \times (24 \times 1\% - 2 \times 10^{-3} \times 0.05 \times 0.4)} = 17nF$$

The size, when using low-ESR (e.g., ceramic) output capacitors, is usually determined by the capacitance required to maintain the output voltage within the specification during load transients. It is estimated as:

$$C_{OUT\,(MIN2)} = \frac{(1 - D) \times V_{REF} \times G_M \times R_{COMP}}{2 \times \pi \times |V_{OUT}| \times R_I \times f_C} = \frac{(1 - 0.83) \times 0.8 \times 60 \times 10^{-6} \times 185 \times 10^3}{2 \times 3.14 \times 24 \times 0.5 \times 10 \times 10^3} = 1.95\mu F$$

V_{REF} is the reference of the feedback voltage with the value of 0.8V, GM is the gain of the transconductance error amplifier with the value of 60µA/V (typ), R_{COMP} is the compensation network resistor with the value of 185kΩ, R_I is the current-sense gain of 0.5 (typ), f_C is the desired loop crossover frequency, and 10kHz is assumed.

Select the larger of C_{OUT}(MIN1) and C_{OUT}(MIN2) as the output capacitor.

$$C_{OUT} = \max(C_{OUT(MIN1)}, C_{OUT(MIN2)})$$

A 2.2µF, 100V, and 10% X7R is chosen because of the derating value of the capacitor. Consider capacitance tolerance, temperature, and voltage derating for any calculations involving C_{OUT}. The actual capacitance is properly derated in ceramic output capacitors according to the applied DC voltage. Refer to the manufacturer’s data sheets for the output capacitors for more accurate derating models.

Selecting the Feedforward Cap

Increase the phase margin and bandwidth by paralleling C_6 with the top resistor R5 of the feedback resistance divider to provide a zero around the desired crossover frequency (f_c). Assign a fixed value for R_5 and vary R_6 to set the output voltage.

$$C_S = \frac{1}{2 \times \pi \times R_S \times f^C} = \frac{1}{2 \times \pi \times 294 \times 10^3 \times 10 \times 10^3} = 54\text{pF}$$

A 47pF cap can increase the phase margin and bandwidth here. A feedforward cap is not used for this design.

Adjusting the Output Voltage

Set the output voltage with a resistive voltage-divider connected from the ground terminal of the inductor to the output voltage. Connect the center node of the divider to the FB (feedback) pin. Assign a fixed value for R_5 and vary R6 to set the output voltage. Select the values of resistors R_5 and R_6 as:

$$R_6 = \frac{R_S \times 0.8}{|V_{OUT}| - 0.8} = \frac{294 \times 0.8}{24 - 0.8} = 10.13\text{k}\Omega$$

Here, R5 and R6 are in kΩ, and their values are 294kΩ and 10kΩ, respectively.

Setting the Input Turn-On Voltage

Set the input voltage to turn on the MAX20059 with a resistive voltage-divider connected from V_{IN} to V_{OUT} (**Figure 2**). Connect the center node of the divider to the EN/UVLO (enable/undervoltage lockout) pin. Choose R_1 as 3.32MΩ and calculate R_2 to increase the voltage in the center node of the divider than the EN threshold (1.115V).

$$R2 = \frac{R1 \times 1.1}{6 - 1.1} = 745\text{k}\Omega$$

Here, V_{IN} is the input voltage to turn on the MAX20059. An R_2 value of 750kΩ turns it on at around 6V input voltage.

Internal Loop Compensation

The internal compensation network is as follows:

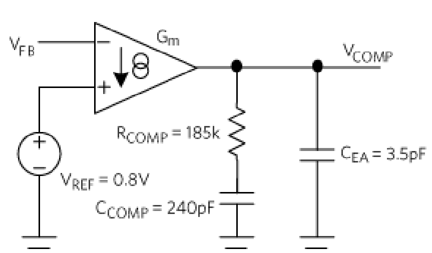

Figure 1.Internal compensation network.

Selecting the Soft-Start Capacitor

The MAX20059 implements an adjustable soft-start operation to reduce the inrush current. A capacitor connected from the SS (soft-start) pin to the V_{OUT} programs the soft-start period. The soft-start time (t_{SS}) is related to the capacitor connected at the SS (C_{SS}) by the following equation:

$$C_{SS} = 6.25 \times t_{SS}$$

Here, t_{SS} is measured in milliseconds and C_{SS} in nanofarads. For example, a 12nF capacitor must be connected from the SS pin to the V_{OUT} to program a 2ms soft-start time.

Schematic for the Design

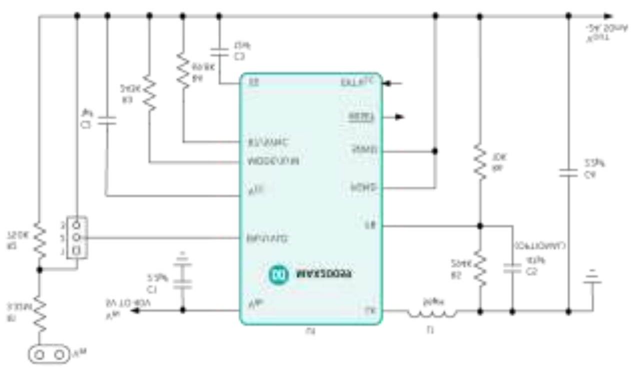

Figure 2.Schematic for the design.

Reference Design 1

V_{IN} = 5V to 40V, V_{OUT} = -24V, I_{OUT} = 50mA, and f_{SW} = 600kHz.

Bill of Materials

Table 3. Bill of Materials for Reference Design 1

Desgnator	Value	Description	Part Number	Manufacturer	Package	Quantity
C1	2.2µF/X7R/100V	Input Bypass Capacitor	GRM32ER72A225KA35	Murata	1206	1
C2	1µF/X7R/6.3V	VCC Bypass Capacitor	GRM188R70J105KA01	Murata	0805	1
C3	12000pF/X7R/25V	Soft-Start Capacitor	Soft-Start Capacitor	Murata	0603	1
C4	2.2µF/X7R/100V	Output Capacitor	C1210X225K1RAC7800	KEMET	1210	1
C5	Not Solder					1
R1	3.32M ±1%	EN/UVLO Resistor-Divider	CRCW04023M32FK	VISHAY DALE	0402	1
R2	750k ±1%	EN/UVLO Resistor-Divider	CRCW0402750KFK	VISHAY DALE	0402	1
R3	243k ±1%	Current Limit and Mode of Operation	ERJ-2RKF2433X	PANASONIC	0402	1
R4	69.8k±1%	Set the Switching Frequency and Current Limit	CRCW0402105KFK	VISHAY DALE	0402	1
R5	294k½ ±1%	FB Resistor-Divider	CRCW0402294KFKED	VISHAY DALE	0402	1

R6	10k½ ±1%	FB Resistor-Divider	CRCW040210K0FKEDC	VISHAY DALE	0402	1
L1	56µH	Inductor		Wurth		1
U1	MAX20059	Internal Switch Buck Converter		Maxim Integrated	10 TDFN 3 x 3	1

Experimental Results

Typical Performance

Figure 3.Steady-state operation with 50mA load, 5VIN, -24V$_{OUT}$, and 600kHz.

Figure 4. Load transient response from no load to 50mA, 5V$_{IN}$, -24V$_{OUT}$, and 600kHz.

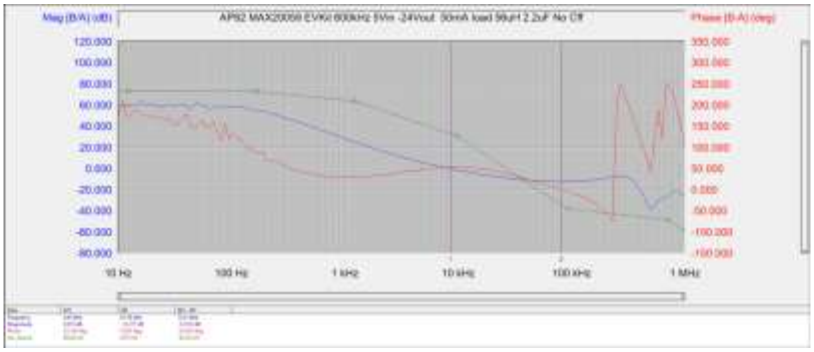

Figure 5. Bode plot at 50mA load, $5V_{IN}$, $-24V_{OUT}$, and 600kHz.

Related Parts	
MAX20058	60V, 1A, Automotive Synchronous Step-Down DC-DC Converter
MAX20059	72V, 1A, Automotive Synchronous Step-Down DC-DC Converter