DESIGN NOTES

How to Produce Negative Output Voltages from Positive Inputs Using a µModule Step-Down Regulator

Design Note 1021

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Introduction

Linear Technology's DC/DC step-down µModule® regulators are complete switchmode power supplies in a surface-mount package. They include the DC/DC controller, inductor, power switches and supporting circuitry. These highly integrated regulators also provide an easy solution for applications that require negative output voltages. In other words, these products can operate as inverting buck-boost regulators. As a result, the lowest potential in the circuit is not the standard 0V, but $-V_{OUT}$, which must be tied to the µModule regulator's GND. All signals are now referred to $-V_{OUT}$.

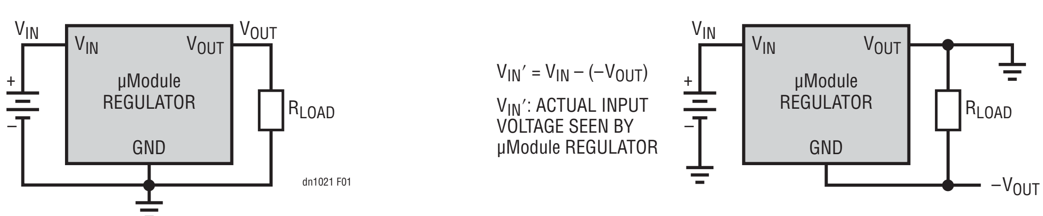
For this discussion, the LTM®8025 (36V, 3A) is used to demonstrate how a buck µModule regulator can be altered to produce a negative output voltage with level-shifting circuitry for synchronization. This approach can be applied to other µModule regulators, such as the LTM8022 (36V, 1A), LTM8023 (36V, 2A) and LTM8027 (60V, 4A).

Design Guide

A conventional buck (step-down) µModule regulator can be easily configured to generate negative output voltages by configuring it as an inverting buck-boost converter, as illustrated in Figure 1. The negative terminal of the input supply is connected to the V_{OUT} pin of the µModule regulator and the GND pin is tied to the $-V_{OUT}$ rail. The actual input voltage (V_{IN}') seen by the µModule regulator is the difference between the input supply (V_{IN}) and the output voltage ($-V_{OUT}$). This voltage must be within the allowable input range of the part. Additionally, the absolute value of the output voltage must not exceed the maximum output voltage rating of the µModule regulator. Since the part is now operating as an inverting buck-boost, the switch current is larger than in its buck counterpart. Hence, parameters such as output current, switching frequency, thermal performance, etc. must be considered to stay within the part's limits. Refer to Appendix for detailed discussions and calculations. Refer to Table 1 for a selection guide of example buck µModule regulators configured as inverters.

Table 1. Example of Buck (Step-Down) DC/DC µModule Regulators Configured as Inverters

	$I_{OUT(MAX)}$	
µModule Regulator	**$12V_{IN} \rightarrow -5V_{OUT}$**	**$24V_{IN} \rightarrow -12V_{OUT}$**
LTM8020	0.165A	See LTM8025 and LTM8027
LTM8021	0.475A	
LTM8022	1A	
LTM8023	1.6A	
LTM8025	2.95A	2.2A
LTM8027	4A	3.65A



(a) Buck µModule Regulator Configured for Positive Output Voltages

(b) Buck µModule Regulator Configured for Negative Output Voltages

Figure 1. How to Configure a Buck Module for Negative Output Voltages

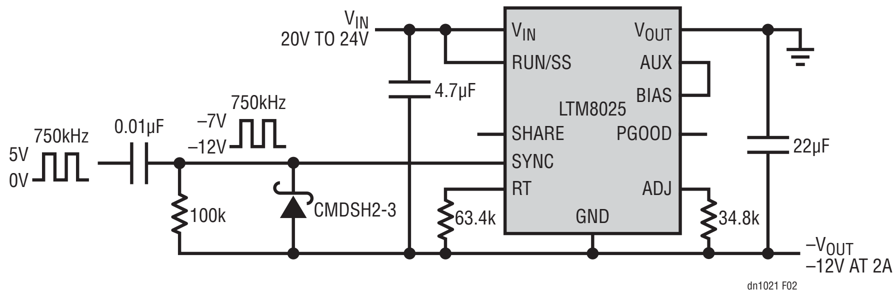


Figure 2. LTM8025 Schematic for –12V Output

–12V Output Application

The LTM8025 is a $36V_{IN}$, 3A step-down μModule converter that can support output voltages up to 24V. With minimal design effort, it can be easily configured to generate negative output voltages. Figure 2 shows an LTM8025 schematic generating –12V at 2A from an input range of 20V to 24V. The actual input voltage seen by the LTM8025 is $V_{IN}' = V_{IN} - (-V_{OUT})$. For instance, if $V_{IN} = 20V$, $V_{IN}' = 20V - (-12V) = 32V$. Because the maximum input rating of the LTM8025 is 36V, the input supply in this specific application is limited to 24V.

Additionally, the internal oscillator of the LTM8025 can be synchronized by applying an external 250kHz to 2MHz clock signal to the SYNC pin. For negative output voltages, the clock must be level-shifted to account for the lower potential. This example has a 0V to 5V, 750kHz input clock signal. By adding a few passive components, the input clock is level-shifted to produce a –12V to –7V signal, which is then applied to the SYNC pin of the LTM8025. Figure 3 shows the start-up waveforms for the –12V output application.

Run/Shutdown

The LTM8025 has a RUN/SS pin that provides shutdown along with soft-start functions. In order to shut down the part, the RUN/SS pin must be pulled below 0.2V. For negative output applications, the LTM8025 GND is tied to $-V_{OUT}$. So, the RUN/SS voltage must be below 0.2V above $-V_{OUT}$ to turn off the part, whereas it must be tied to 2.5V above $-V_{OUT}$ for normal operation.

Conclusion

Step-down μModule regulators, such as the LTM8025, can be easily configured for negative output voltages. For negative outputs, the LTM8025 operates as an inverting buck-boost, so the maximum allowable output current is lower than typical buck topologies. If synchronization is desired, proper level-shifting circuitry is required. For a complete description of the LTM8025, including operation and applications information, refer to the data sheet.

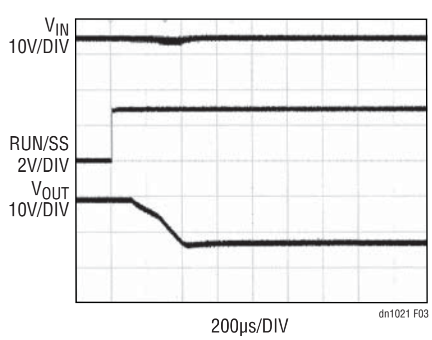


Figure 3. LTM8025 Start-Up Waveforms for –12V Output

Data Sheet Download

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APPENDIX

Level-Shifting the Run Pin in a Negative Output Application

Step-down µModule regulators are equipped with a Run pin to enable and shut down the part. For negative output applications, the Run voltage must be level-shifted to properly turn off the part. Using just a single PNP transistor and a few resistors, level-shifting can be achieved to utilize the shutdown feature, as seen in Figure 4. When the logic input is high, the Run voltage increases by an amount determined by the voltage divider resistors R2 and R3. Once the Run voltage exceeds the shutdown threshold, the µModule regulator will turn on; as a result, the output will drop to the programmed negative voltage. To shut down the part, apply a logic low input to force the Run voltage to the same potential as the negative output.

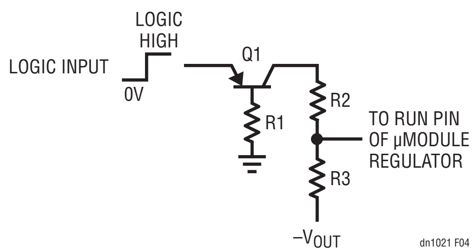

Figure 4. Run Level-Shift Circuit for Negative Output Configuration

The shutdown threshold varies with each µModule regulator and is listed in their respective data sheet tables. Scale the resistors R2 and R3 according to the logic high input voltage and the µModule regulator's shutdown threshold. Figure 5 shows an example of an LTM8027 –12V output application with the level-shifting circuitry. In this example, the LTM8027 has a 5V logic input and a Run pin resistor divider for about 2.5V, enough to exceed the part's 1.4V shutdown threshold.

External Schottky Diode for Start-Up Protection

When configuring a µModule regulator for negative output voltages, the combination of input and output capacitors creates an AC voltage divider at the output. During start-up, the output ($-V_{OUT}$) will initially go positive for a short period of time before dropping down to the intended negative potential. The positive voltage peak is dependent on both the capacitance values and the input voltage step. To limit the amount of positive voltage, an external Schottky diode between $-V_{OUT}$ and the input supply ground may be required. Figure 6 shows a simplified µModule regulator schematic with the Schottky diode protection.

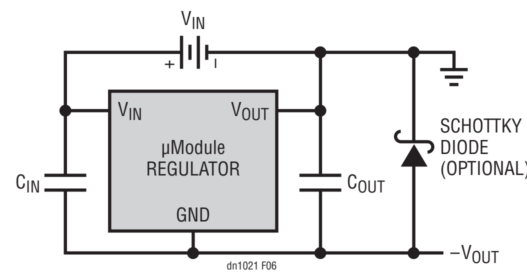

Figure 6. Step-Down µModule Regulator with Schottky Diode Protection for Negative Output

Design Considerations for Negative Output Applications

For negative output applications, the input voltage seen by the µModule regulator (V_{IN}') is the difference between the input supply voltage (V_{IN}) and the output voltage ($-V_{OUT}$):

$$V_{IN}' = V_{IN} - (-V_{OUT}) \qquad \text{(Equation 1)}$$

As a result, the maximum input voltage ($V_{IN(MAX)}'$) must be below the µModule regulator's abs max input voltage ($V_{IN\_MODULE(MAX)}$).

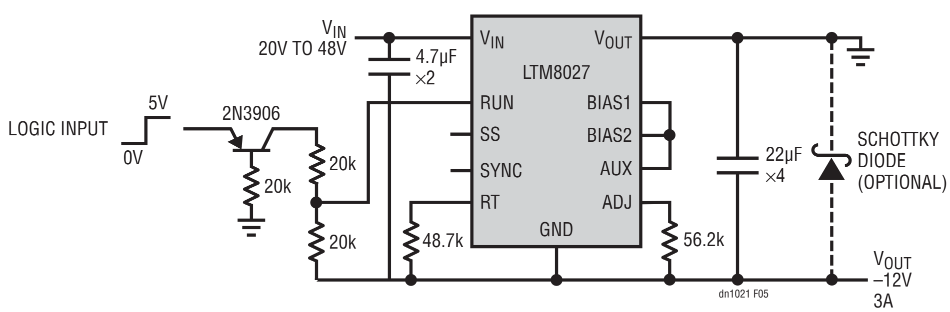

Figure 5. LTM8027 with Run Level-Shift Circuitry for –12V Output

Additionally, the switch current is higher for inverting applications compared to the positive output configuration. Hence, the maximum output current ($I_{OUT(NEG)}$) must be derated from the µModule regulator's typical rating ($I_{OUT(POS)}$) according to the following equation:

$$I_{OUT(NEG)} \leq (I_{OUT(POS)}) \bullet (1 - DC_{MAX}) \quad \text{(Equation 2)}$$

where the max duty cycle,

$$DC_{MAX} = \frac{|V_{OUT}|}{V_{IN(MIN)} + |V_{OUT}|} \quad \text{(Equation 3)}$$

Equation 2 is only an approximation. The following parameters need to be considered to get a more accurate value: switching frequency, inductor current ripple, efficiency, switch current limit derating at high duty cycle, etc.

Design Example:

Inverting power supply requirements:

V_{IN} = 15V nominal (range: 12V to 18V)

V_{OUT} = –5V

$I_{OUT(NEG)}$ = 2A

Selected µModule regulator: LTM8025

LTM8025 data sheet ratings:

$V_{IN\_MODULE(MAX)}$ = 36V

$I_{OUT(POS)}$ = 3A

Calculations:

Using Equations 1 to 3, the following values were determined:

$$V_{IN(MAX)}' = V_{IN(MAX)} - (V_{OUT}) = 18 - (-5) = 23V$$

$$DC_{MAX} = \frac{|V_{OUT}|}{V_{IN(MIN)} + |V_{OUT}|} = \frac{5}{12+5} = 0.294$$

$$(I_{OUT(POS)}) \bullet (1 - DC_{MAX}) = (3A) \bullet (1 - 0.294) = 2.12A$$

The above calculations determined that the LTM8025 is a good candidate for this inverting application. The maximum input voltage across the µModule regulator is 23V, well below the 36V maximum operating voltage. With a max duty cycle of 29.4%, the maximum output current is approximately 2.12A—sufficient for the 2A requirement of this application.