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MCP16311/2 Inverting Buck-Boost Application

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INTRODUCTION

This document describes the implementation of an inverting buck-boost topology, using the MCP16311/2 synchronous buck switching regulator. Generally, a buck converter is used to derive the required supply voltage level from a higher input voltage. However, there are several applications where a negative input supply is necessary; in this case, a topology such as an inverting buck-boost converter can be implemented, for which the output voltage is negative with respect to the ground.

The proposed application circuit can be used to supply a negative output voltage for devices such as: line drivers and receivers, instrumentation amplifiers, audio amplifiers, etc.

BASIC BUCK CONFIGURATION

To understand the functionality of an inverting buck-boost topology, a short explanation of the buck topology is necessary.

In Figure 1, when the high-side switch (S_1) is turned on and the low-side switch (S_2) is turned off (red loop), a DC voltage ($V_{IN} - V_{OUT}$) is applied to the inductor (L), resulting in a positive linear ramp of inductor current, given by Equation 1.

EQUATION 1: INDUCTOR CURRENT VARIATION DURING ON TIME

$$\frac{di}{dt} = \frac{V_{IN} - V_{OUT}}{L}$$

When the high-side switch (S_1) turns off and the low-side switch (S_2) turns on (blue loop), the applied inductor voltage is equal to $-V_{OUT}$, resulting in a negative linear ramp of inductor current, as shown in Equation 2.

EQUATION 2: INDUCTOR CURRENT VARIATION DURING OFF TIME

$$\frac{di}{dt} = -\frac{V_{OUT}}{L}$$

Equation 3 represents the peak-to-peak current flowing through the inductor.

EQUATION 3: PEAK-TO-PEAK INDUCTOR CURRENT

$$I_{L(PP)} = \frac{(V_{IN} - V_{OUT}) \times D}{f_{SW} \times L}$$

Where:

D	=	Duty cycle
f_{SW}	=	Switching frequency
V_{IN}	=	Input voltage
V_{OUT}	=	Output voltage
L	=	Inductance

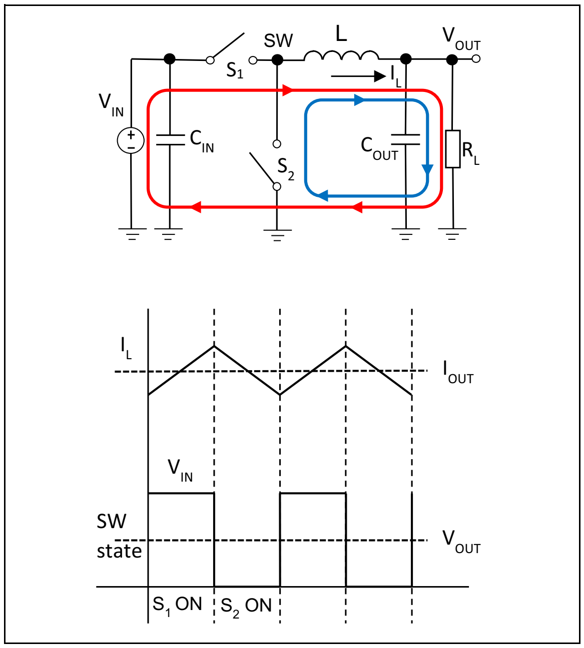

FIGURE 1: Buck Circuit and Waveforms In Continuous Conduction Mode (CCM).

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INVERTING BUCK-BOOST CONFIGURATION

A possible implementation of an inverting buck-boost converter, which is derived from a buck regulator, can be seen in Figure 2 and its functionality is described in the following paragraphs.

When the high-side switch (S_1) is turned on and the low-side switch (S_2) is turned off (red loop), the voltage applied across the inductor is V_{IN}, resulting in a positive linear ramp of inductor current, given by Equation 4.

EQUATION 4: INDUCTOR CURRENT VARIATION DURING ON TIME

$$\frac{di}{dt} = \frac{V_{IN}}{L}$$

When the high-side switch (S_1) turns off and the low-side switch (S_2) turns on (blue loop), the applied inductor voltage is equal to $-V_{OUT}$, resulting in a negative linear ramp of inductor current, as shown in Equation 5.

EQUATION 5: INDUCTOR CURRENT VARIATION DURING OFF TIME

$$\frac{di}{dt} = -\frac{V_{OUT}}{L}$$

The peak-to-peak current flowing through the inductor is given by Equation 6.

EQUATION 6: PEAK-TO-PEAK INDUCTOR CURRENT

$$I_{L(PP)} = \frac{V_{IN} \times D}{f_{SW} \times L}$$

Equation 7 represents the approximation of the duty cycle for the inverting Buck-Boost converter.

EQUATION 7: DUTY CYCLE

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

DESIGN CONSIDERATIONS

Input Voltage Range

For implementing a buck-boost topology using a buck switching regulator, the GND pin of the converter will be tied to V_{OUT} and the positive lead of the output capacitor will be connected to GND.

In this case, the voltage applied on the supply pin of the converter will be $V_{IN} - (-V_{OUT})$ and not V_{IN}, as for a typical buck application. This means that the maximum input voltage for an inverting buck-boost converter is limited to $V_{IN} - |V_{OUT}|$.

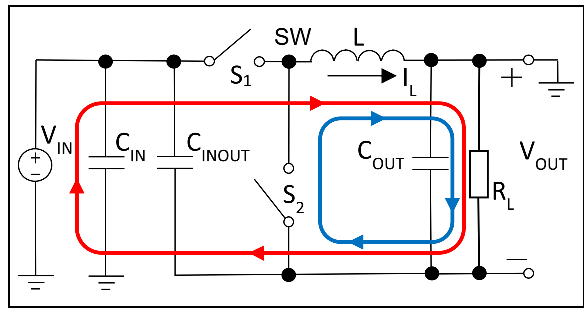

***FIGURE 2:** The Proposed Inverting Buck-Boost Circuit.*

Considering that the output voltage is negative, the operating duty cycle can be defined by using Equation 8.

EQUATION 8: DUTY CYCLE FOR AN INVERTING BUCK-BOOST

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

For a buck converter, the average inductor current is equal to the load current (I_{LOAD}). By contrast, in the case of an inverting buck-boost converter, the average inductor current is equal to $I_{LOAD}/(1 - D)$.

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Right Half Plane Zero (RHPZ) Effect

An important factor that must be considered is the behavior of this proposed circuit when operating in continuous and discontinuous conduction mode (DCM). Designs that are stable in the discontinuous mode may become unstable when the load increases and the transition to the continuous mode is done.

When the buck converter is used in a buck-boost design, a Right Half Plane Zero (RHPZ) is introduced. In this case, the gain of the loop is not affected. However, it causes a phase drop which will affect the stability of the system.

RHPZ in DCM

While operating in DCM, the frequency of the RHPZ is high enough so as to not affect the functionality.

During the on time, the inductor is charging, while the output capacitor is discharging. If there is any sudden change (an increase) of the duty cycle, the inductor current will go to a higher value, which will generate a higher drop on V_{OUT} (see Figure 3). However, because the level of the inductor current is higher, the increasing slope of V_{OUT} is steeper and the output voltage will achieve the required value during the off time. By operating in DCM, the drop on V_{OUT} caused by the RHPZ is not visible.

RHPZ in CCM

When running in CCM, if there is a sudden increase of the on time (because the off time is shorter), a drop on V_{OUT} can be noticed. Even though the slope of V_{OUT} is steeper (because of the higher level of the inductor current), the output voltage at that moment in time is still too low compared to the value before, as shown in Figure 3.

Whenever the on time is increased, the output voltage will drop initially and during the next cycles it will achieve the corresponding level; this is not acceptable for a feedback-controlled system, because during this drop, the loop will encounter a positive feedback and the system will tend to oscillate.

To eliminate the effects of the RHPZ for this kind of applications (an inverting buck-boost design), a bypass capacitor must be connected between V_{IN} and V_{OUT}.

The value of this capacitor must be significantly lower than the input capacitor (C_{IN}) and its voltage rating must be greater than $V_{IN} + |V_{OUT}|$.

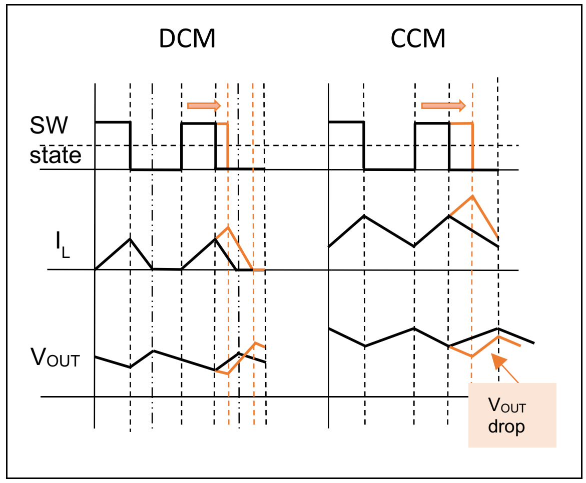

FIGURE 3: *RHPZ in DCM vs. CCM.*

APPLICATION INFORMATION

The circuit diagram of the proposed application is detailed in Figure 4.

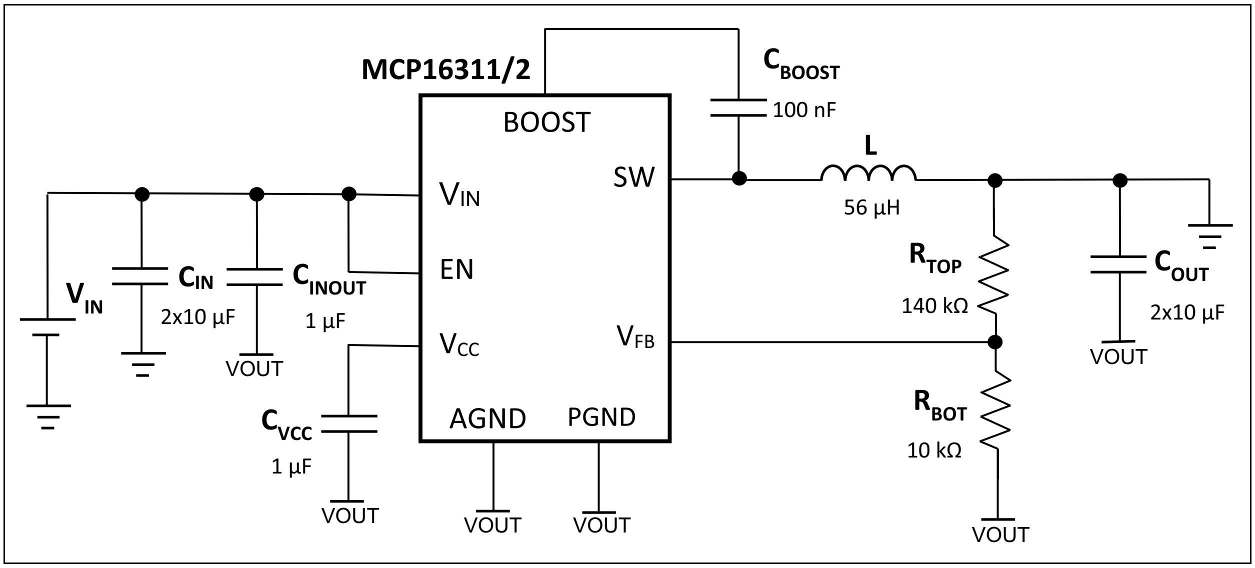

FIGURE 4: MCP16311/2 Inverting Buck-Boost Application Circuit Diagram.

The physical implementation of the converter on a board, for this design, is shown in Figure 5.

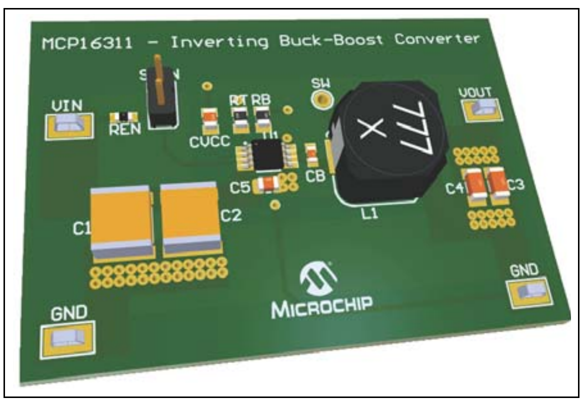

FIGURE 5: MCP16311 Inverting Buck-Boost Converter Board.

APPLICATION EXAMPLE

- Input voltage range: 4.4V – 18V
- Output voltage: –12V
- Output current:
  - 0.32A @ V_{IN} = 8V, T_{AMB} = +25ºC
  - 0.5A @ V_{IN} = 12V, T_{AMB} = +25ºC
  - 0.54A @ V_{IN} = 16V, T_{AMB} = +25ºC

The Maximum Output Current vs. Input Voltage curve (at 25ºC) is presented in Figure 6.

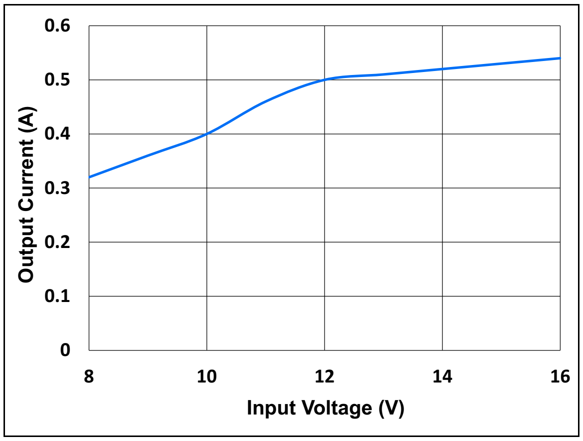

FIGURE 6: *Maximum Output Current vs. Input Voltage @T_{AMB} = +25ºC.*

The Efficiency vs. Output Current graph, measured at an ambient temperature of 25ºC, is shown in Figure 7.

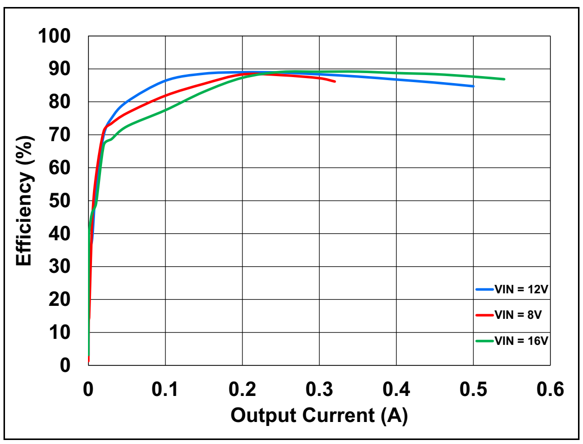

FIGURE 7: *Efficiency vs. Output Current @T_{AMB} = +25°C.*

CONCLUSIONS

This technical brief presents the utilization of an MCP16311/2 synchronous buck switching regulator in an inverting buck-boost design implementation. The proposed circuit reflects the main advantages of this type of application: buck and boost capabilities, negative output voltage with respect to the input, while utilizing only one additional passive component. By contrast to a regular buck typology, such an implementation offers lower current capabilities and a lower input voltage range. However, the MCP16311/2 synchronous buck switching regulator can be a viable solution for an inverting buck-boost application thanks to its high versatility, with minimum additional components needed.

REFERENCES

- MCP16311/2 Data Sheet – *"30V Input, 1A Output, High-Efficiency, Integrated Synchronous Switch Step-Down Regulator"* (DS20005255)
- AN2102 – *"Designing Applications with MCP16331 High-Input Voltage Buck Converter"* (DS00002102)

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