LM5085

Designing Non-Inverting Buck-Boost (Zeta) Converters with a Buck P-FET Controller

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Designing Non-Inverting Buck-Boost (Zeta) Converters with a Buck P-FET Controller

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Introduction

Constant On-Time (COT) regulators provide a simple, cost-effective way of implementing step-down buck regulators with nearly fixed frequency, as shown in ***Figure 1***. COT regulators do not require loop compensation and provide excellent transient performance with minimum design effort. Non-synchronous operation results in reduced switching frequency at a very light load which delivers higher efficiency than a comparable fixed frequency converter.

In many applications, the input voltage varies above and below the required output voltage. Many articles and application notes have shown how to configure a buck regulator to work as an inverting or non-inverting buck-boost regulator to accomplish the task. However, most of these methods are based on PWM buck controllers. While it is easy to configure the power stage from buck to buck-boost topology, the compensation design remains a challenge as the power stage small signal model changes significantly. This means that the compensation design must be done from scratch. This approach also places limitations on the achievable bandwidth. Since COT topology does not require any compensation, significantly less effort is required to get a non-inverting buck-boost circuit working. This article explains how to use a COT P-FET buck controller to design a non-inverting buck-boost supply that achieves fast transient response without requiring a control loop design, as shown in ***Figure 2***. Zeta converter implementation also has the added advantage of short-circuit protection over boost converters.

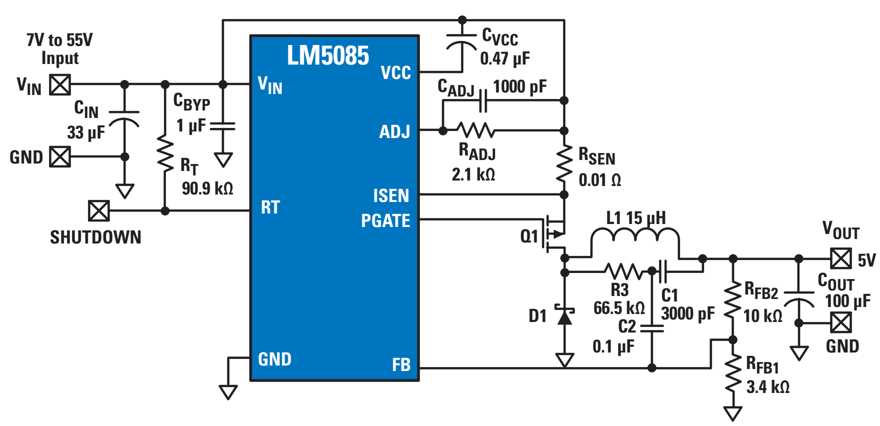

Figure 1. LM5085 Buck Application Circuit

Designing Zeta Converters with a Buck P-FET Controller

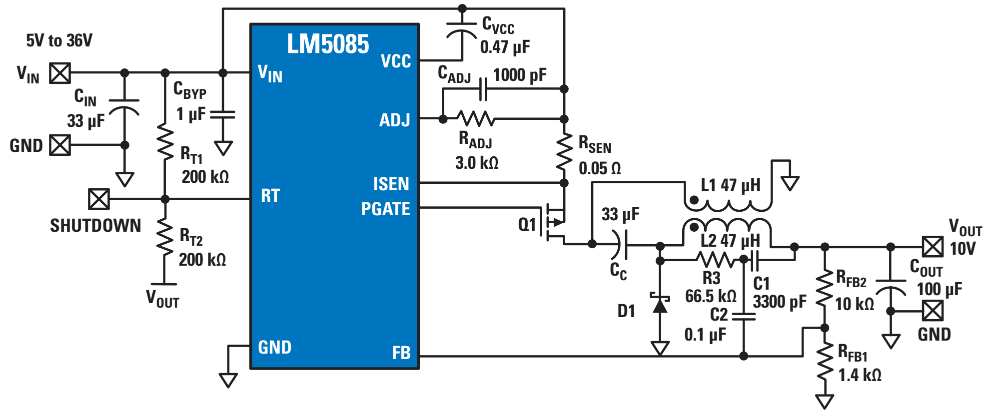

Figure 2. LM5085 Non-Inverting Buck-Boost (Inverse SEPIC or Zeta) Application Circuit

Operation of LM5085-Based Non-Inverting Buck-Boost (Zeta) Converter

Zeta converter allows operation with V_{IN} varying below and above V_{OUT} while proving short circuit protection. The output capacitor has smaller ripple because of the series inductor at the output. ***Figure 3*** shows the simplified diagram of a Zeta converter. The coupling capacitor (C_C) is charged to V_{OUT} in steady state. The blue lines show the direction of current during T_{ON} (Q1 'on') and the dark red lines show the direction of current during T_{OFF} (D1 conducting). Continuous conduction mode is assumed. ***Figure 4*** shows the ideal voltage waveforms for switch nodes (SW1, SW2) and ideal current waveforms in the inductors (I_{L1}, I_{L2}), switch (I_{Q1}), and the coupling capacitor (I_{CC}).

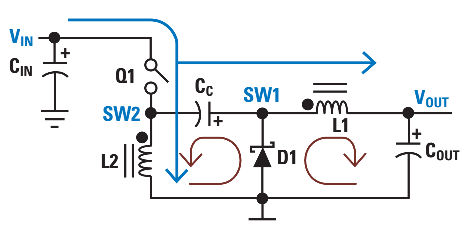

Figure 3. Zeta Converter Operation (Switching Intervals)
(Blue: Q1 'on', Red: Q1 'off')

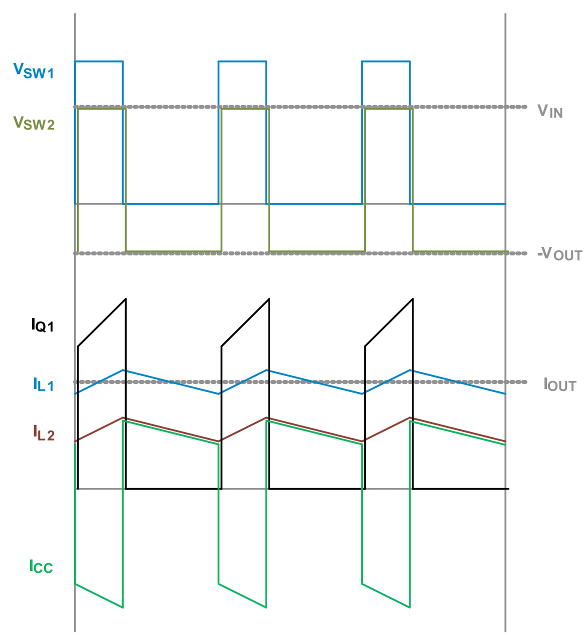

Figure 4. Zeta Converter Operating Waveforms

Figure 3 shows L1 and L2 coupled inductors. Coupled inductors may reduce the footprint of the solution under some conditions but are not necessary for the proper operation of a Zeta converter. In applications where the V_{IN} varies much below V_{OUT}, the current rating on inductor L2 is significantly higher than the current rating of output inductor L1. In such cases, it may be easier to split the inductor in two and optimize each one separately. For tightly coupled inductors, the current ripple in the two windings may have some mismatch because the ripple voltage across the coupling capacitor appears across the small leakage inductance.

Design Equations

In a Zeta converter, the input/output relationship—deduced by applying inductor voltage balance—is given by:

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

or

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

L1 and L2 are given by:

$$L1 = L2 = \frac{V_{IN} T_{ON}}{\Delta I}$$

for uncoupled inductors and half as much for coupled inductors. ΔI is the desired ripple current in L1 and L2 which is highest at the highest input voltage. The peak current in L1 is given by:

$$I_{L1(peak)} = I_{OUT} + \frac{\Delta I}{2}$$

and the peak current in L2 is given by:

$$I_{L2(peak)} = \frac{D}{1\text{-}D} I_{OUT} + \frac{\Delta I}{2}$$

D1—During T_{ON} the voltage across diode D1 is:

$$V_{D1} = V_{IN} + V_{OUT}$$

which is the same as the voltage across Q1 in T_{OFF}.

The average current through D1 is:

$$I_{D1(avg)} = I_{OUT}$$

Q1—voltage rating of P-FET switch is:

$$V_{SW} = V_{IN} + V_{OUT}$$

Q1—average current is:

$$I_{SW(avg)} = \frac{D}{1\text{-}D} I_{OUT}$$

however, the peak current through the switch is:

$$I_{SW(peak)} = \frac{1}{1\text{-}D} I_{OUT} + \Delta I$$

which is important because it affects the current limit.

CC—The coupling capacitor handles the output voltage in steady state. The ripple current is given by:

$$I_{Coup(rms)} = \sqrt{\frac{D}{1\text{-}D}} I_{OUT}$$

CIN—Input capacitor has the same ripple current as the coupling capacitor.

Designing Zeta Converters with a Buck P-FET Controller

Frequency of Operation

LM5085 is a COT controller optimized for buck operation with inverse relationship between V_{IN} and T_{ON}. In continuous conduction mode (CCM), this results in a nearly constant frequency operation as a buck converter. The inverse relation-ship between V_{IN} and T_{ON}, however, does not result in constant frequency operation when operating as a Zeta converter. In a buck-boost configuration

$$D = T_{ON}f = \frac{V_{OUT}}{V_{IN} + V_{OUT}}$$

and, therefore, T_{ON} should be made proportional to

$$\frac{1}{V_{IN} + V_{OUT}}$$

to achieve nearly constant frequency operation. This is accomplished by connecting the R_T pin to V_{OUT} and V_{IN} with equal value resistors, as shown in ***Figure 2***. The resulting T_{ON} is calculated by ***Equation 3*** in the LM5085 datasheet with V_{IN} replaced by V_{IN}+V_{OUT}.

Performance

A Zeta converter was designed for input voltage range 5V-36V and maximum load current of 600 mA at 10V output. The complete schematic is shown in ***Figure 2***. The frequency and maximum available I_{OUT} variation with V_{IN} are shown is ***Figure 5*** and ***6***, and the efficiency for the I_{OUT} and V_{IN} design range is shown in ***Figure 7***.

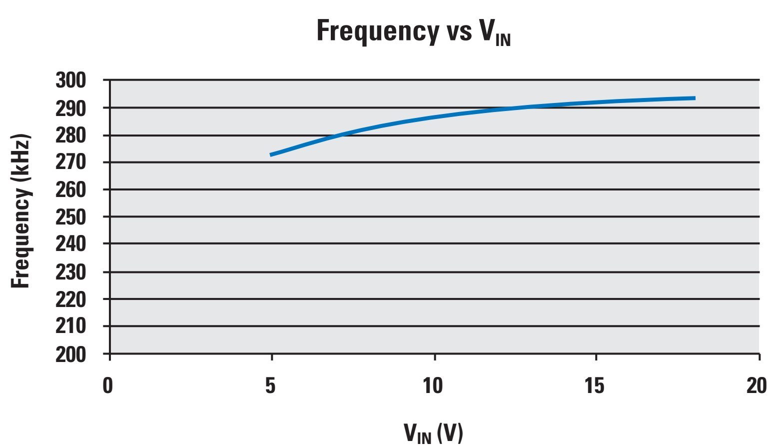

Figure 5. Frequency vs. V_{IN} in Zeta Configuration Based on LM5085

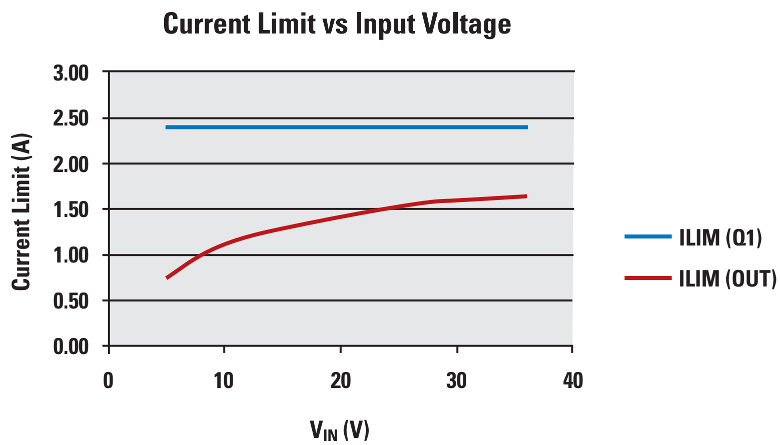

Figure 6. Peak Currents (I_{Q1} and I_{OUT}) Variation with V_{IN}, V_{OUT} = 10V

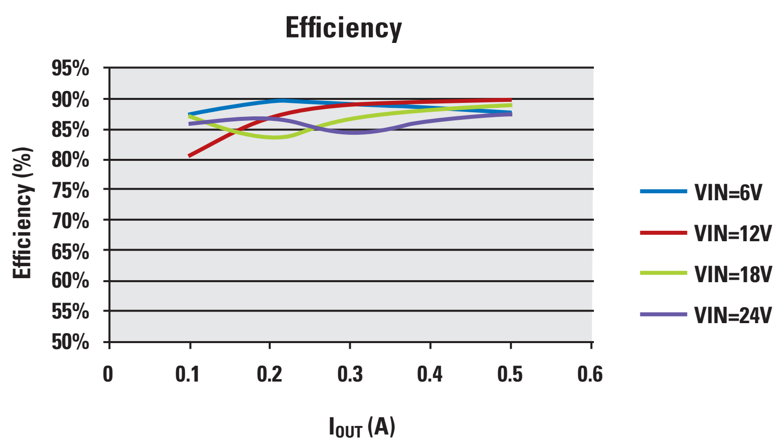

Figure 7. Efficiency of Zeta Converter, V_{OUT} = 10V

Conclusion

A non-inverting buck-boost with 10V regulated output voltage and 5-36V input voltage range with up to 600mA of guaranteed output current is presented based on the LM5085 COT P-FET buck controller. The operating principle of a Zeta converter is explained with the help of a simplified schematic and waveforms. The design equations and performance characteristics are also presented. LM5085 allows design of a non-inverting buck-boost converter based on a Zeta topology with minimum effort, low solution cost, short circuit protection, and excellent transient response without any loop compensation design.

References

LM5085 Datasheet
Application Note AN-1878
LM5085 Evaluation Board
LM(2)5085 Quick Start Calculator

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WEBENCH® Online Design Tools

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