

LM5085

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



Literature Number: SNVA608

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

— By Vijay Choudhary, Applications Engineer and Robert Bell, Design Center Director

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.

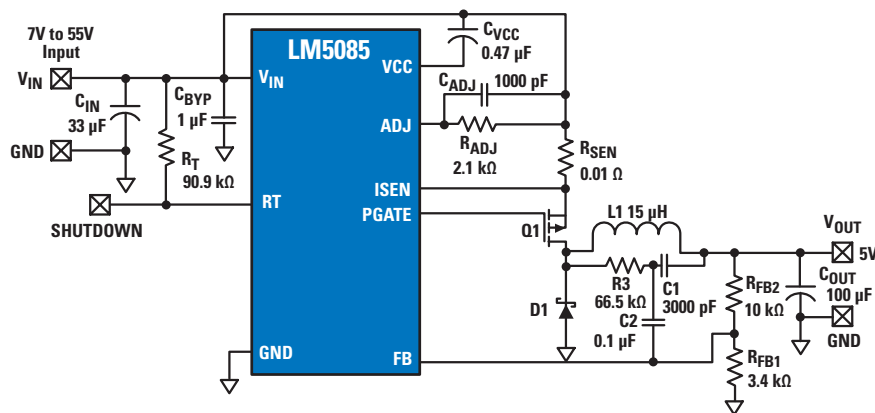


Figure 1. LM5085 Buck Application Circuit

Designing Zeta Converters with a Buck P-FET Controller

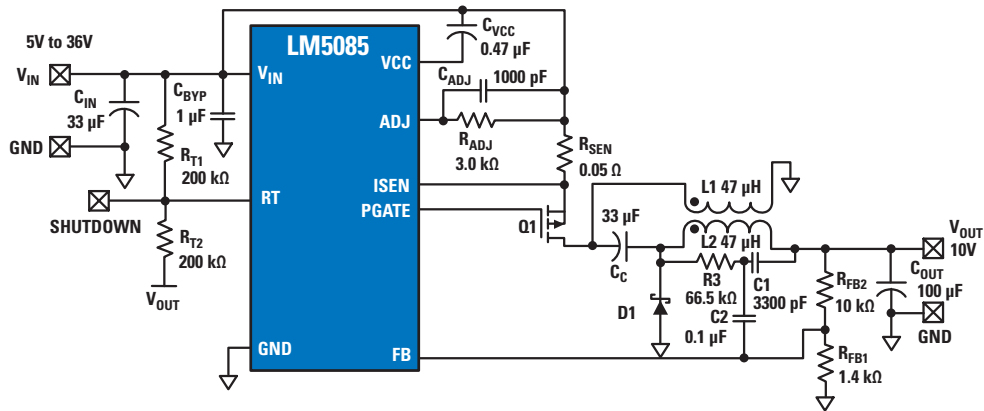


Figure 2. LM5085 Non-Inverting Buck-Boost (Inverse SEPIC or Zeta) Application Circuit

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

Zeta converter allows operation with V_{IN} varying below and above V_{OUT} while providing 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}).

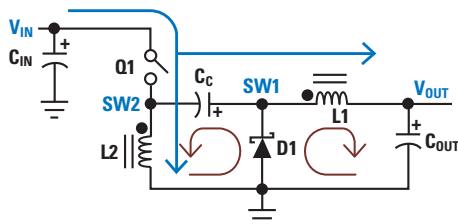


Figure 3. Zeta Converter Operation (Switching Intervals) (Blue: Q1 'on', Red: Q1 'off')

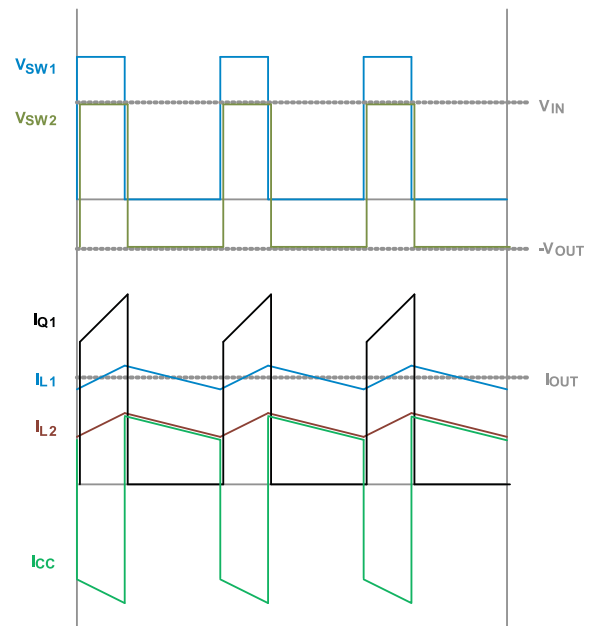


Figure 4. Zeta Converter Operating Waveforms

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:

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

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:

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

and the peak current in L2 is given by:

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

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:

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

Q1—voltage rating of P-FET switch is:

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

Q1—average current is:

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

however, the peak current through the switch is:

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

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:

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

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 relationship 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 in **Figure 5** and **6**, and the efficiency for the I_{OUT} and V_{IN} design range is shown in **Figure 7**.

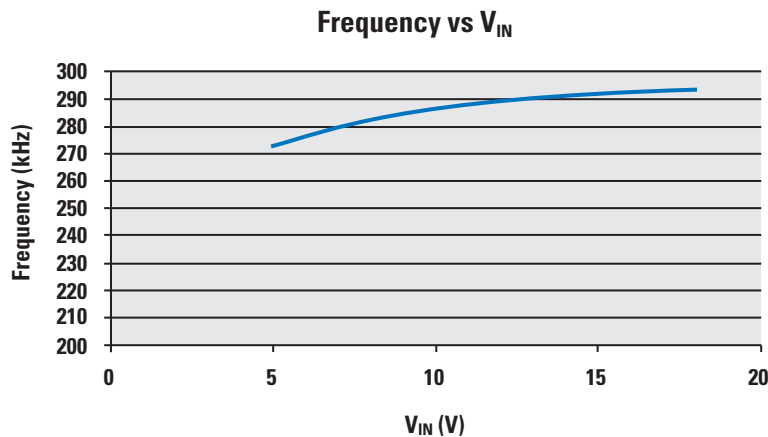


Figure 5. Frequency vs. V_{IN} in Zeta Configuration Based on LM5085

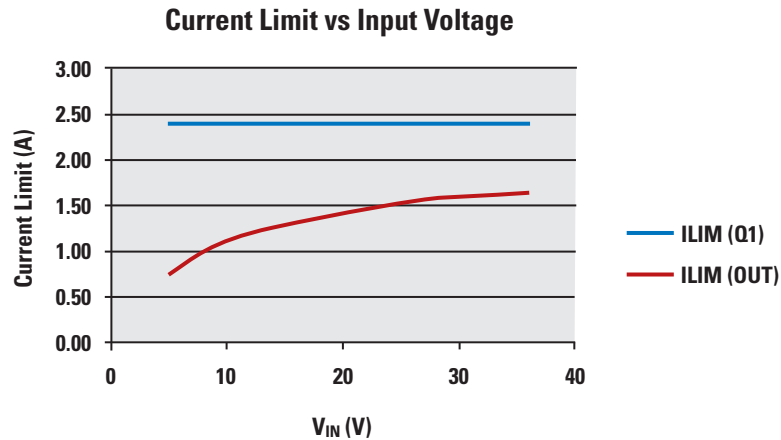


Figure 6. Peak Currents (I_{Q1} and I_{OUT}) Variation with V_{IN} , $V_{OUT} = 10V$

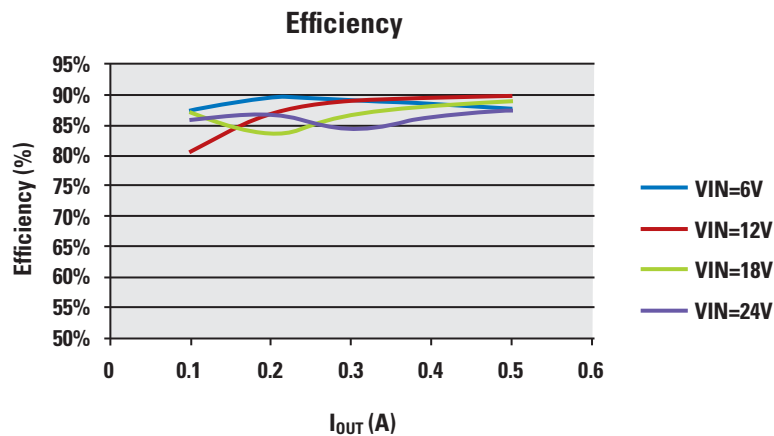


Figure 7. Efficiency of Zeta Converter, $V_{OUT} = 10V$

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

Power Design Tools



Design, build, and test analog circuits in this online design and prototyping environment.

national.com/webench



Expand your knowledge and understanding of analog with our free online educational training tool.

national.com/training



National's monthly analog design technical journal.

national.com/edge

Tools for Energy-Efficient Designs

Access white papers, reference designs, and application notes on PowerWise® products and systems.

national.com/powerwise

National Semiconductor
2900 Semiconductor Drive
Santa Clara, CA 95051
1 800 272 9959

Mailing address:
PO Box 58090
Santa Clara, CA 95052

Visit our website at:
national.com

**For more information,
send email to:**
new.feedback@nsc.com

Don't miss a single issue!

Subscribe now to receive email alerts when new issues of Power Designer are available:

national.com/powerdesigner

Read our Signal Path Designer® online today:

national.com/spdesigner



IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Mobile Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Transportation and Automotive	www.ti.com/automotive
Video and Imaging	www.ti.com/video

TI E2E Community Home Page

e2e.ti.com

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2011, Texas Instruments Incorporated