

## Zeta Converter Basics based on Sipex's SP6125/6/7 controllers

### Introduction

A Zeta converter performs a non-inverting buck-boost function similar to that of a SEPIC, which is an acronym for Single-Ended Primary Inductance Converter. The Zeta topology is also similar to the SEPIC, in that it uses two inductors, two switches and a capacitor to isolate the output from the input (see figures 1 and 2). However, Zeta conversion requires a P-Channel MOSFET as the primary switch, while SEPIC conversion uses an N-Channel MOSFET. This architecture makes Sipex's SP6125/6/7 controllers suitable for use in a Zeta topology.

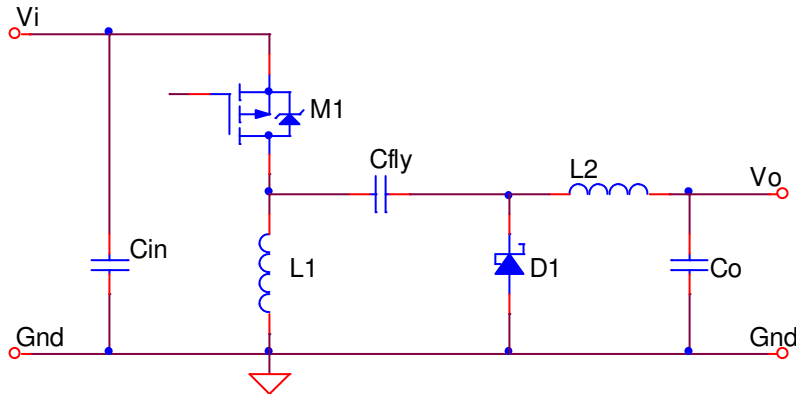


Figure 1- Zeta converter

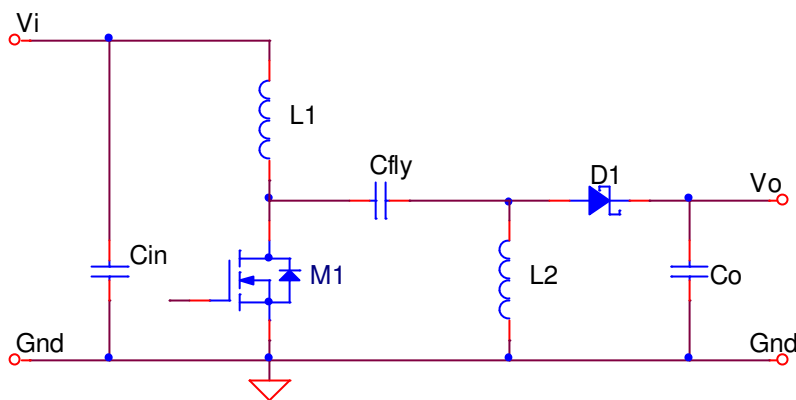


Figure 2- SEPIC converter

## Zeta Converter Waveforms

When analyzing Zeta waveforms it is helpful to keep in mind that at equilibrium, L1 average current equals  $I_{IN}$  and L2 average current equals  $I_{OUT}$ , since there is no DC current through the flying cap  $C_{FLY}$ . Also there is no DC voltage across either inductor. Therefore,  $C_{FLY}$  sees ground potential at its left side and  $V_{OUT}$  at its right side, resulting in DC voltage across  $C_{FLY}$  being equal to  $V_{OUT}$ .

When M1 is on, L1 and L2 are energized. D1 sees a potential of  $V_{IN}+V_{OUT}$  across it (see figures 3, 4, and 5). When M1 is off, energy stored in L1 and L2 is released. D1 is forward biased.

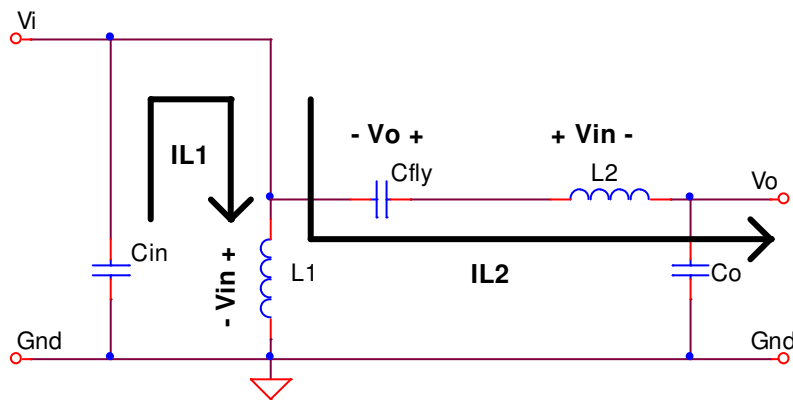


Figure 3- Zeta simplified circuit diagram during MOSFET ON time

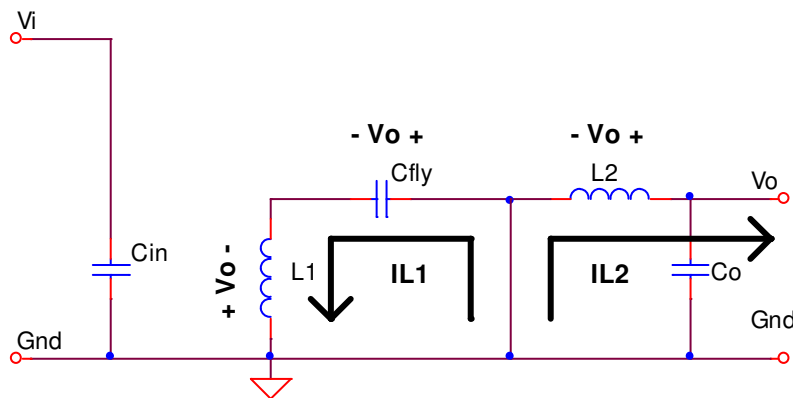


Figure 4- Zeta simplified circuit diagram during MOSFET OFF time

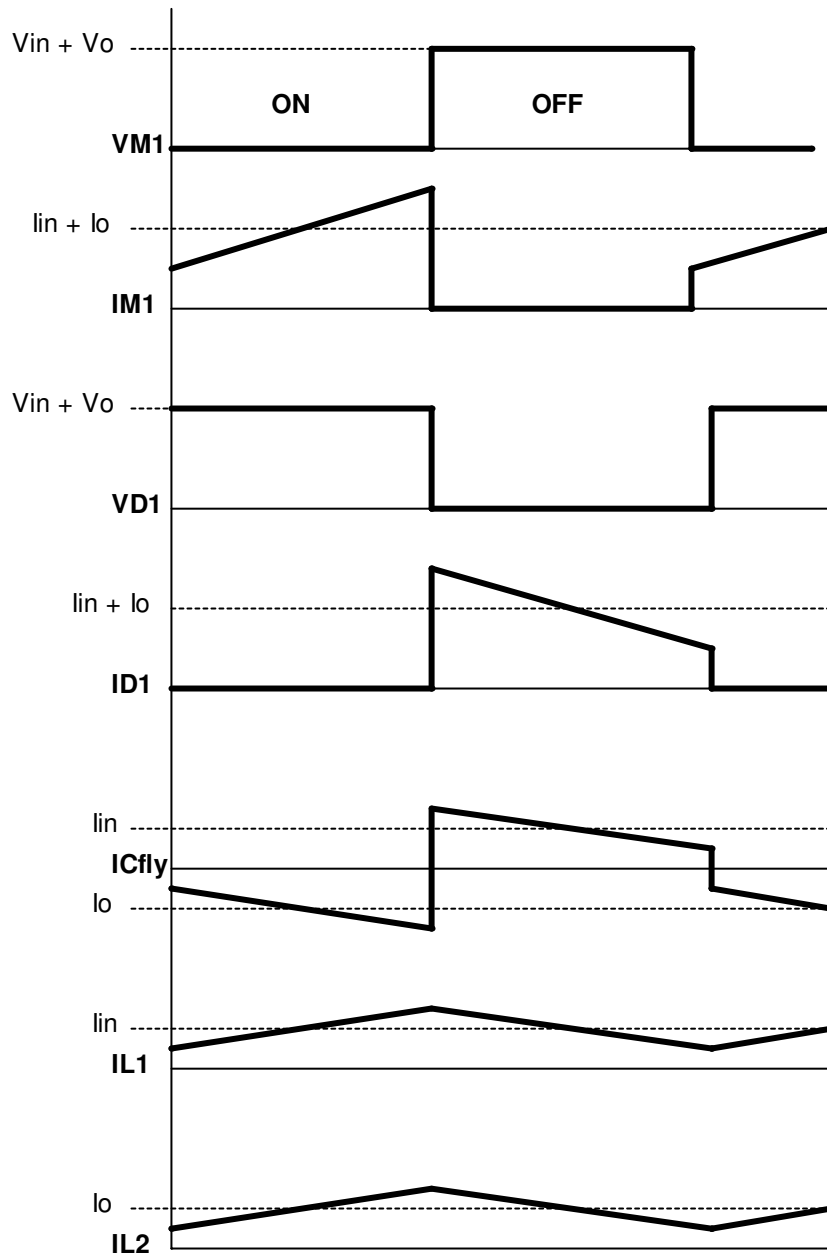


Figure 5- Zeta idealized waveforms

## Voltage Conversion Ratio

Output voltage is given by the following equation:

$$V_o = V_{in} \times \frac{D}{1-D}$$

Where D is duty cycle. VOUT is plotted as a function of D in figure 6. As can be seen, for D less than 0.5 the converter performs buck function and for D larger than 0.5 it is a boost topology.

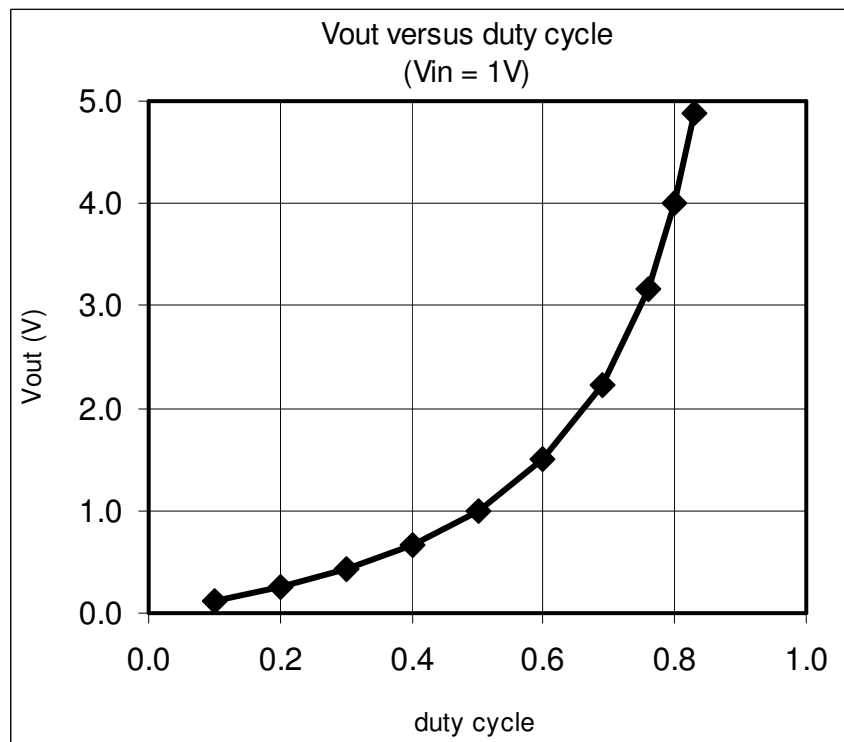


Figure 6- Output voltage versus duty cycle for VIN=1V

## COMPONENT SELECTION

### L1 Selection

Select L1 for inductance L, saturation current  $I_{SAT}$  and DC rating  $I_{DC}$ .

Calculate inductance from:

$$L1 = \frac{V_{in, max} \times V_o}{I_{ripple} \times f \times (V_{in, max} + V_o)} \dots\dots\dots (1)$$

Where:

$I_{RIPPLE}$  is the permissible peak-to-peak ripple current (nominally 50% of  $I_{OUT}$ )

$f$  is switching frequency

$V_{IN,max}$  is maximum input voltage

Calculate DC rating of L1 from:

$$I_{DC} = \frac{I_o \times V_o}{V_{in, min} \times Eff} \dots\dots\dots (2)$$

Where:

$V_{IN,min}$  is the minimum input voltage

$Eff$  is converter efficiency (nominally 85%)

Calculate saturation current from:

$$I_{sat} \geq 1.15 \times I_{DC} \dots\dots\dots (3)$$

Where  $I_{DC}$  is DC rating of L1 calculated above.

### L2 Selection

Let L2 equal L1 thereby ensuring both inductors will have same ripple current. This is true since during ON time  $L = V_{in} \times \left( \frac{T_{on}}{\Delta i} \right)$  for both inductors as seen in figure 3.

Selecting  $L2=L1$  also makes it possible to wind both inductors on the same core if it is so desired.  $I_{DC}$  should be at least equal to  $I_{OUT}$ . Calculate saturation current as shown for L1.

### CFLY Selection

Select CFLY for capacitance, voltage rating  $V_{DC}$  and ripple current rating  $I_{RIPPLE}$ .

Calculate CFLY from:

$$C_{fly} = \frac{I_o \times V_o}{(V_{in} + V_o) \times f \times V_{ripple}} \dots\dots\dots (4)$$

Where:

V<sub>IN</sub> is minimum input voltage

V<sub>RRIPPLE</sub> is voltage ripple across C<sub>FLY</sub> (nominal 1% of V<sub>OUT</sub>)

DC Voltage rating should be greater than V<sub>OUT</sub> and ripple current should be greater than I<sub>OUT</sub>.

### MOSFET Selection

Select MOSFET for voltage rating B<sub>VDSS</sub>, ON resistance R<sub>DS(ON)</sub>, gate-to-drain charge Q<sub>GD</sub> and thermal resistance R<sub>TH</sub>. B<sub>VDSS</sub> should be greater than V<sub>IN</sub>+V<sub>OUT</sub>, allowing a guard band against switching transients. The MOSFET should be able to handle the combined peak inductor current of both inductors. For an in-depth procedure see the section titled “MOSFET Selection” in any Sipex controller datasheet.

### Diode Selection

Select diode for voltage rating V<sub>R</sub> and current rating I<sub>F</sub>. V<sub>R</sub> should be greater than V<sub>IN</sub>+V<sub>OUT</sub> and I<sub>F</sub> should be capable of conducting I<sub>IN</sub>+I<sub>OUT</sub>.

### C<sub>in</sub> Selection

Select the input capacitor C<sub>IN</sub> for Voltage rating, ripple current and Capacitance. A simplified expression for ripple current can be obtained by assuming D=0.5 and Efficiency =100%. Then I<sub>IN</sub> = I<sub>OUT</sub> and I<sub>RMS</sub> can be estimated from:

$$I_{cin} = 0.5 \times I_o$$

In general, input voltage ripple should be kept below 1.5% of V<sub>IN</sub> (not to exceed 0.18V). By using the same assumptions that were applied for simplifying ripple current calculation, required input capacitance can be estimated from:

$$C_{in} = I_o \times \frac{1}{2 \times f \times 0.18V} \dots\dots\dots (5)$$

Note that in the C<sub>IN</sub> equation the effect of ESR and ESL has been assumed to be negligible. This assumption is valid for ceramic capacitors and high quality Tantalum and Aluminum electrolytic capacitors.

### C<sub>OUT</sub> Selection

Select the output capacitor for capacitance, voltage rating and Equivalent Series Resistance (ESR). To simplify analysis, assume that a ceramic capacitor is used with ESR = 5mOhm. Then V<sub>OUT</sub> ripple due to ESR is negligible. To calculate C<sub>OUT</sub>, let inductor current ripple equal 30% of output current and use the following equation:

$$C_o = \frac{I_{rip}}{8 \times V_{rip} \times f} \dots\dots\dots (6)$$

Where:

$I_{RIP}$  is inductor ripple current (nominally 30% of  $I_{OUT}$ )

$V_{RIP}$  is output voltage permissible ripple (nominally 1% of  $V_{OUT}$ )

### Design Example

Design a Zeta converter to operate over input range of 10V-18V with output voltage of 12V and output current of 0.7A.

#### 1- Controller selection

Use Sipex SP6126 operating at 600kHz and capable of driving a P-channel MOSFET.

#### 2- Inductor L1

From equations (1) and (2), L1 and its corresponding DC current rating are calculated at 34uH and 1A respectively. From (3), saturation current should be larger than 1.15A. An inductor that meets the above specifications is Würth Elektronik dual inductor #744877100, 10uH,  $I_{DC}=1.1A$  and  $I_{SAT}=2.8A$ . Note that due to mutual inductance of the double inductor the effective inductance for calculating ripple current is 20uH. Even though this is less than the value calculated from (1), it is sufficient to ensure Continuous Conduction Mode of operation over the full input range.

#### 3- Inductor L2

L2 is selected to be equal to L1 and thus a double inductor can be used.

#### 4- Capacitor C<sub>FLY</sub>

Using (4) C<sub>FLY</sub> is calculated to be 3.9uF. In order to make the design more conservative a 22uF ceramic capacitor is selected.

#### 5- MOSFET M1

One choice that meets this application's requirements is Vishay/Siliconix Si2319DS,  $B_{VDSS}=40V$ ,  $R_{DS(ON)}=0.13\Omega$ .

#### 6- Diode D1

ON semiconductor MBRA340T3, 40V, 3A meets requirements.

#### 7- Capacitor C<sub>IN</sub>

Using (5) C<sub>IN</sub> is calculated to be 3.2uF. A 4.7uF ceramic capacitor meets this requirement.

#### 8- Capacitor C<sub>OUT</sub>

Using (6) C<sub>OUT</sub> is calculated 0.36uF. However to allow for load transients a 22uF ceramic capacitor is selected.

The Zeta converter shown in figure 7 was thus built and tests showed satisfactory operation over voltage input range of 10V to 18V. Efficiency plots are shown in figure 8.

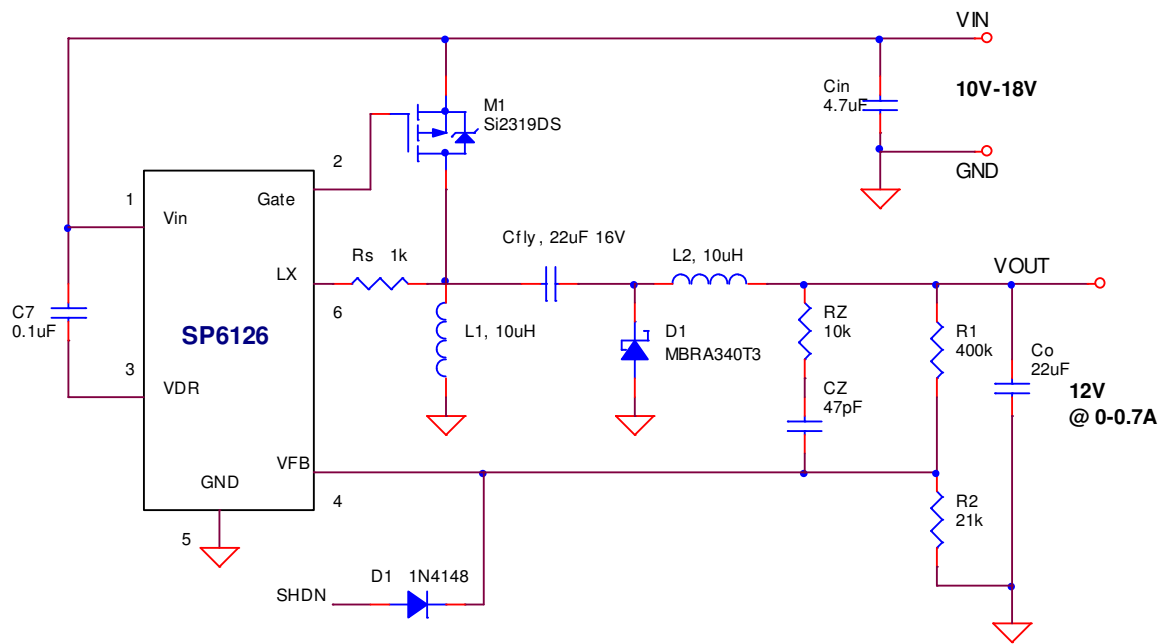


Figure 7- Zeta converter design example

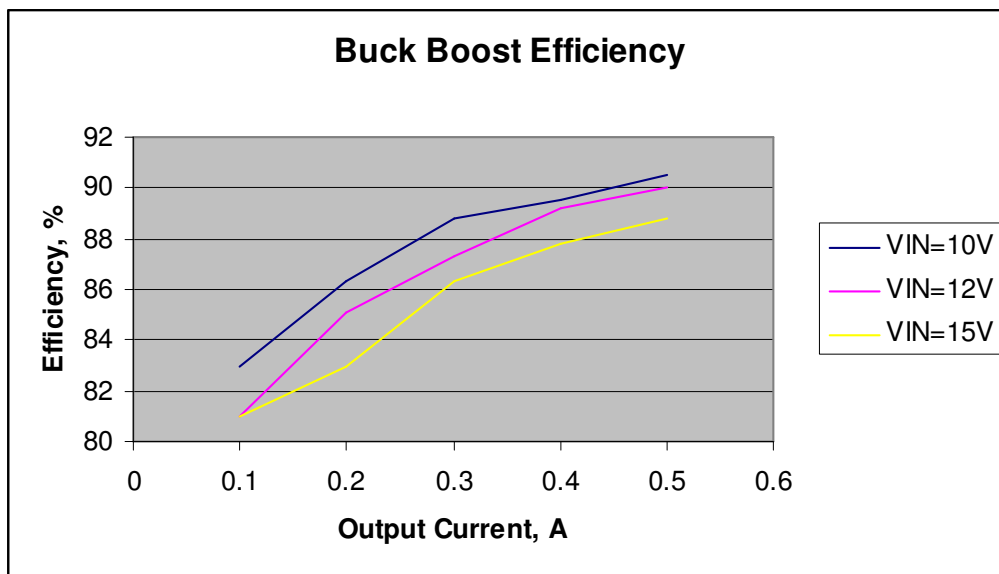


Figure 8- Zeta converter efficiency

Although Sipex's SP6125/6/7 are primarily used as buck controllers, by adding few inexpensive components they can be used as the heart of a Zeta non-inverting buck-boost converter that can provide output current up to 1A. The simple procedure outlined above can be followed to select the necessary components for a simple and inexpensive ZETA converter.



For further assistance:

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Sipex Application Notes: <http://www.sipex.com/applicationNotes.aspx>



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