DN0011
Design note

DESIGNS from our LABS

ST1S03 alternative topology: Using a buck in a negative buck-boost configuration

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Main components	
ST1S03	1.5 A, 1.5 MHz adjustable, step-down switching regulator

Specification

- ST1S03 (Buck regulator) in buck-boost configuration
- Vin=3.3V,
- Vout=-5V,
- Iout up to -500mA

Circuit description: From a buck to a buck-boost

1) Buck topology: Basic Working Principle in Continuous Conduction Mode

The schematic in Figure 1 shows the ST1S03 configured as a step-down converter. The Vout is adjustable through the external resistor divider R1 and R2 according to the following equation:

$$V_{OUT} = V_{FB}\left[1+\frac{R_1}{R_2}\right] \text{ with a duty cycle of } D=\frac{Vout}{Vin}.$$

During T_{ON}, the internal switch (between Vin-SW and SW) is ON and the inductor L_1 is connected between V_{IN} and V_{OUT}. The inductor current (I_L) rate of change is given by:

$$\frac{di}{dt}=\frac{Vin-Vout}{L}.$$

During T_{OFF}, the inductor starts to release the energy (stored during T_{ON}) so the voltage across it changes polarity to keep the current flowing in the same direction. Assuming for simplicity the voltage drop across diode D1 is negligible, the inductor current ramps down at a rate of:

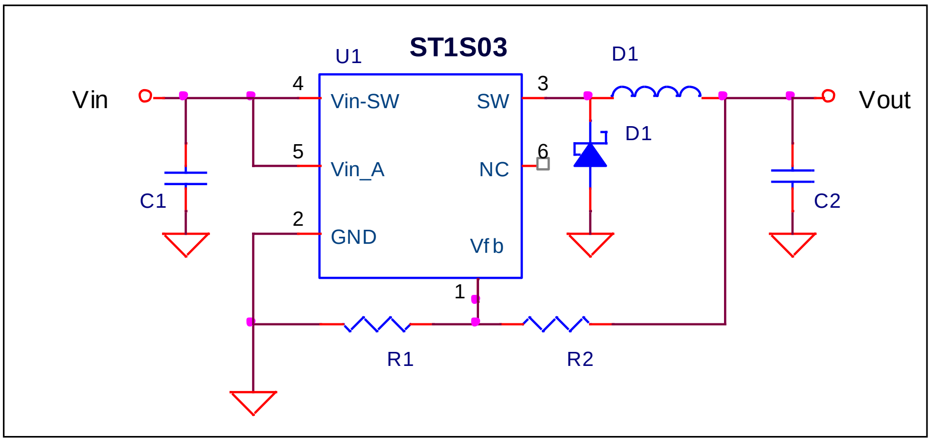
$$\frac{di}{dt} = \frac{Vout}{L}.$$

The steady-state load current is always carried by the inductor during both ON and OFF times. The average inductor current is equal to the load current, and the peak-to-peak inductor ripple current is

$$I_{L(PP)} = \frac{(Vin - Vout)D}{f_{SW}L}$$

where f_{SW} is the switching frequency, which is 1.5MHz for the ST1S03.

Figure 1. ST1S03 in Step-Down (Buck) configuration



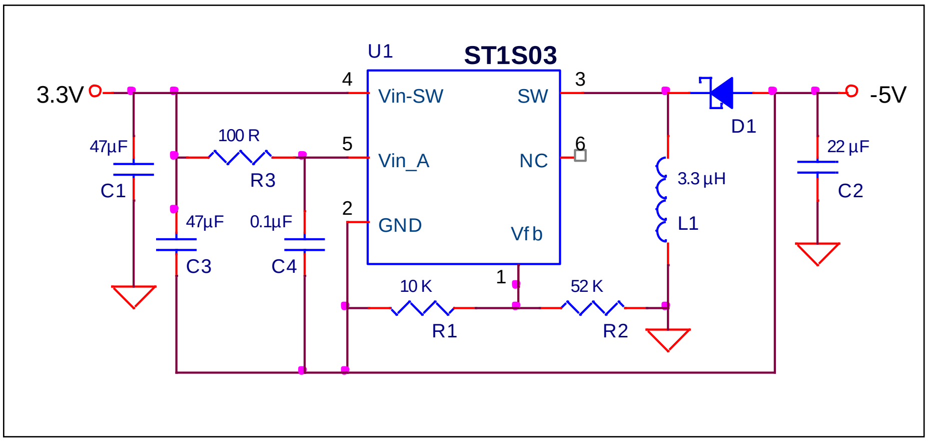
2) *Alternative Buck-boost topology:* Basic Working Principle in Continuous Conduction Mode

Starting from the application schematic in Figure 1, it is possible, with only a few adjustments, to switch from a buck configuration to an inverting buck-boost configuration.

The new schematic is shown in Figure 2. Compared to the buck configuration, the main differences are:

1) Device GND (pin2) is connected to the Output, which is the point at the lowest potential in the application.
2) The Schottky diode D1 is reversed, with the cathode toward the device and the anode toward Vout.
3) The inductor L1 is tied to the GND of the system.
4) Capacitor C3 is added between Vin and Vout as a bypass capacitor across the device voltage input (pin2 and pin 4).

Figure 2. ST1S03 in Buck-Boost configuration @ Vin=3.3V, Vout=-5V, Iout up to -500mA



At power-up (t_0 of the Vcc ramp-up), the device GND (pin2) is at the same potential as the GND system (Vout=0V). Once the input voltage rises above 2.5V, the circuit starts switching, energizing the inductor. Vout then starts to increase "negatively", until the drop across R1 reaches 0.8V above Vout.

The output voltage is still determined by the resistors divider R1 and R2, according to the equation:

$$|V_{out}| = V_{FB}\left[1 + \frac{R_1}{R_2}\right].$$

But in this case, Vout is negative. With a duty cycle of:

$$D = \frac{|Vout|}{Vin + |Vout|}.$$

During T_{ON}, the internal switch (between Vin-SW and SW) is ON, so the inductor L1 is connected between VIN and GND, and the inductor current (I_L) rate of change is given by:

$$\frac{di}{dt} = \frac{Vin}{L}.$$

During this phase, only the output capacitor C2 provides the output current.

At T_{OFF} (internal switch is off), the inductor starts to release the energy stored during T_{ON} so the voltage across it changes polarity to keep the current flowing in the same direction. The voltage across the inductor becomes approximately VOUT, and the inductor current decreases at a rate of:

$$\frac{di}{dt} = -\frac{Vout}{L}.$$

During T_{OFF} the inductor supplies current to the load and also replenishes the energy lost by the capacitor during T_{ON}. For the buck-boost circuit, the average inductor current is:

$$I_{L(avg)} = \frac{Iout}{1-D}$$

and the peak-to-peak inductor current is:

$$I_{L(PP)} = \frac{V_{in}D}{f_{SW}L}.$$

The average inductor current cannot exceed the average rated current of the switching regulator (I_{SW}); therefore the buck-boost output current is reduced by a factor of 1 – D. In this configuration, the maximum available DC output current is:

$$I_{OUT} = I_{SW}(1-D).$$

and, the ST1S03 rated current (I_{SW}) is 1.5A.

These basic differences between the two circuits' functionality must be taken in to consideration when a buck converter IC is used as a buck-boost converter.

3) Input Voltage and output current

In the buck-boost topology of Figure 2, the ST1S03 ground pin is connected to V_{OUT}. Therefore the voltage across the device is V_{IN} + $|V_{OUT}|$, rather than just V_{IN} as in the buck topology. The differential between the two voltages cannot exceed the ST1S03 maximum rating of 16V.

$$Vin + |Vout| < 16V$$

In addition, a minimum V_{IN} = 3V it is needed to guarantee the application start-up.

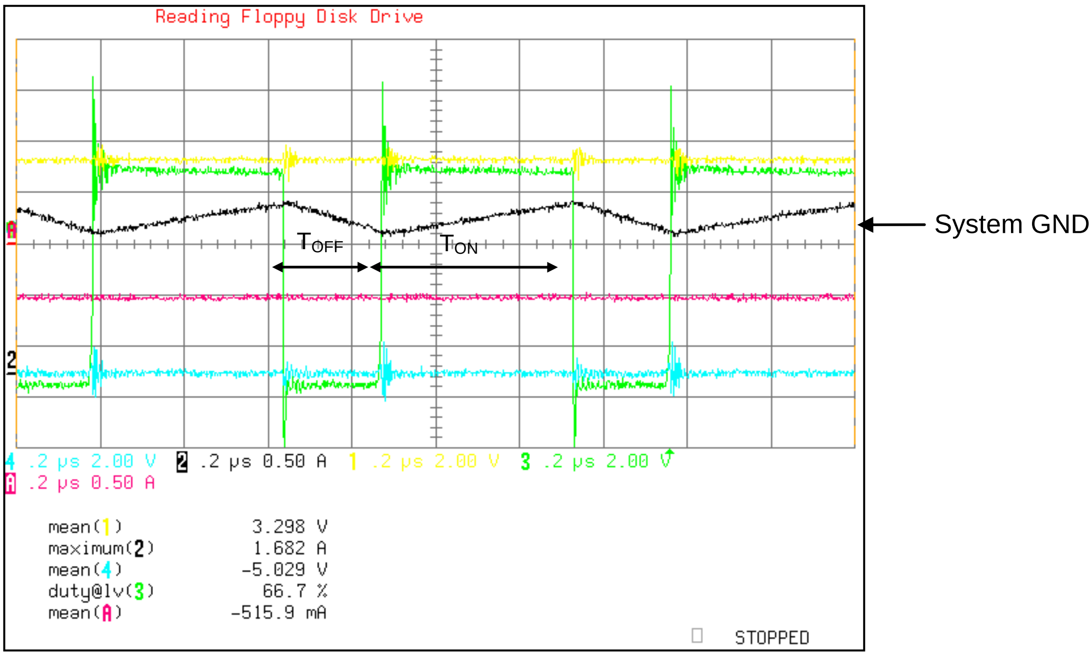
The current capability depends on the application's input and output voltages, which dictate the duty cycle and therefore the maximum output current.

Measurement results

The suggested buck- boost topology (based on ST1S03) was tested using the schematic in Figure 2. The waveforms in Figure 3 show a typical behavior under the following conditions:

- ○ Vin = 3.3V
- ○ Vout = -5V
- ○ Iout = – 500mA

Figure 3. Buck-Boost waveforms @ Vin= 3.3V, Vout= -5V, Iout= -500mA



- Channel 1 (yellow) is Vin = 3.3V
- Channel 2 (black) is the inductor current; 1.7A max
- Channel 3 (green) is the switching node (pin 3 on the ST1S03), duty-cycle 66%
- Channel 4 (light blue) is Vout = -5.0V
- A (purple) is Iout= -500mA

The test results show the impact of the losses due to the ST1S03, diode and the additional components, which are not accounted for in the formulas here presented (Table 1).

Consideration

When an asynchronous buck converter such as the ST1S03 is used in an inverting buck-boost configuration, certain considerations must be made. The basic design equations of the two topologies presented here are collected in Table 1. These equations address the continuous conduction mode in simplified form because they assume the losses on the semiconductors and other components are negligible.

Table 1. Basic design equations in continuous conduction mode

	Buck	Buck-boost
Duty cycle	$D = \frac{Vout}{Vin}$	$D = \frac{\lvert Vout \rvert}{Vin + \lvert Vout \rvert}$
Average inductor current	$I_{L(avg)} = Iout$	$I_{L(avg)} = \frac{Iout}{1-D}$
Peak-to-peak inductor ripple current	$I_{L(PP)} = \frac{(Vin - Vout)D}{f_{SW}L}$	$I_{L(PP)} = \frac{V_{in}D}{f_{SW}L}$
Ramp-up inductor current	$\frac{di}{dt} = \frac{Vin - Vout}{L}$	$\frac{di}{dt} = \frac{Vin}{L}$
Ramp-down inductor current	$\frac{di}{dt} = \frac{Vout}{L}$	$\frac{di}{dt} = -\frac{Vout}{L}$

Variations

The following are some of the ST asynchronous buck regulators that can be configured as negative buck-boost

- L497x family
- L597x family
- L5980,1, 3, 5, 6 & 7
- L798x family

Support material

Product Evaluation board: • STEVAL-ISA042V2: 1.5 A / 3.3 V step-down DC-DC converter demonstration board based on the ST1S03 • STEVAL-ISA042V1: 1.5 A / 1.2 V step-down DC-DC converter demonstration board based on the ST1S03
Datasheet – ST1S03: 1.5 A, 1.5 MHz adjustable, step-down switching regulator
Application note : • AN2093: ST1S03 buck converters for HDD power supplies • AN2837: Positive to negative buck-boost converter using ST1S03 asynchronous switching regulator

Revision history

Date	Version	Changes
30-Aug-2012	1	Initial release