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AN-8023
Negative Voltage Management Using a FAN8303 Buck Regulator

Abstract

FAN8303 is a 2A, 370kHz monolithic integrated buck regulator with internal power MOSFETs. It is simple to use and needs minimal external components. This application note describes how to generate negative voltage using FAN8303. It introduces application examples and discusses optimized designs for a buck-boost circuit.

Introduction

Buck regulators are widely used for higher voltage to lower voltage DC conversion. Likewise, FAN8303 was originally designed for application needing regulated DC voltage, such as set-top box microcontrollers and efficient pre-regulators for linear regulators in PC monitor and TV applications. In some cases, a non-synchronous buck regulator also can be utilized for buck-boost circuit to generate negative voltage with respect to ground. These applications include audio amplifier, timing control circuit for LCD panel, and so on.

Figure 1 shows a practical application of an LCD panel; it needs negative voltage for contrast control. In this block diagram, a charge pump is usually adopted due to the simple design and low cost. However, it has an amount of power dissipation and poor output voltage regulation relative to input voltage variation. FAN8303 with negative output would be a solution to overcome these problems.

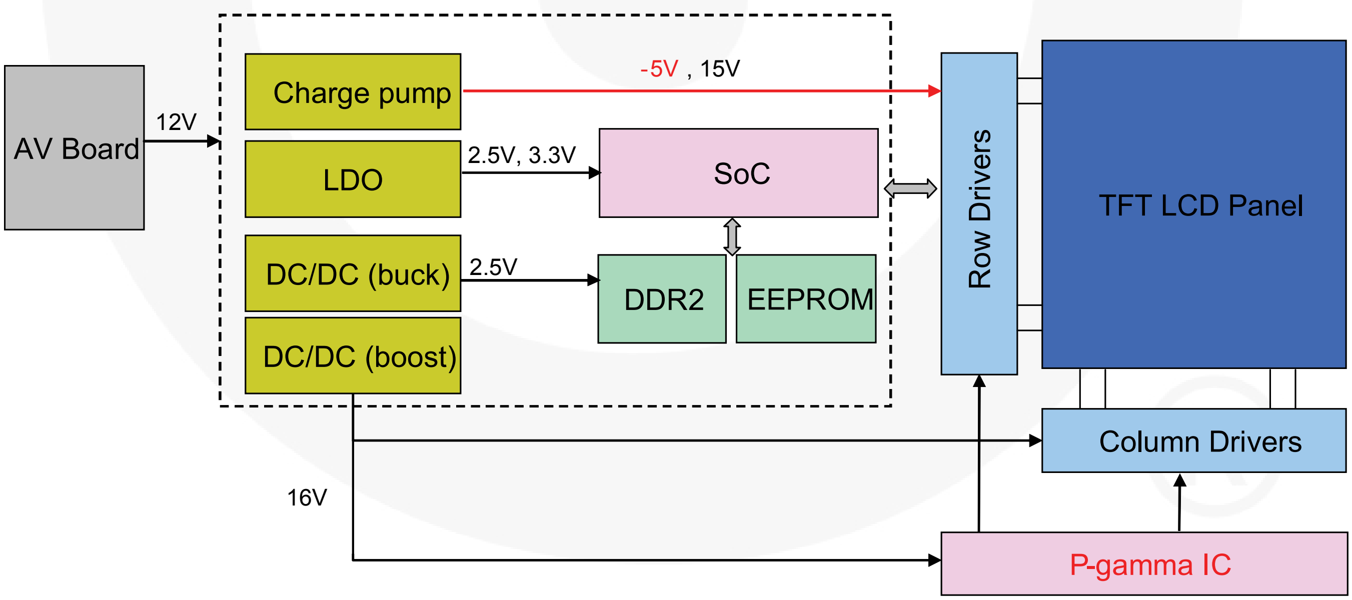

Figure 1. Example of Timing Control Block

Principle of Operation

To understand buck-boost topology, buck topolgy is briefly compared below. When the MOSFET switch (Q1 in Figure 3) is turned on, the voltage across inductor (V_L) is V_{IN} -V_{OUT}. During Q1 off-time, V_L is equal to -V_{OUT} in buck topology. So the inductor current (I_L) ramps up with (V_{IN}-V_{OUT})/L and ramps down with V_{OUT}/L slope. Thus, the energy can be transferred to the load with positive output voltage. Meanwhile, in buck-boost topology, the inductor and freewheeling diode switch positions. When the MOSFET switch Q1 (Figure 2) is turned on, V_L is same as V_{IN}, so I_L ramps up with V_{IN}/L. During the Q1 off-time, V_L has reverse polarity to maintain continuous inductor current with -V_{OUT}. Therefore, it can generate negative output voltage.

Buck-boost circuit with buck regulators require several design considerations. Table 1 summarizes the design parameter comparison between buck and buck-boost circuit.

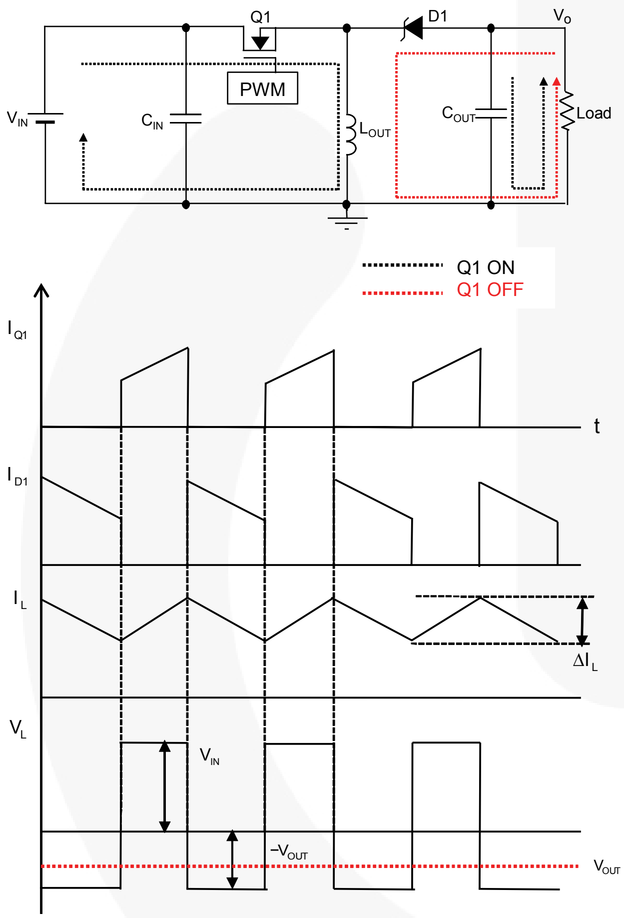

Figure 2. Buck-Boost Topology

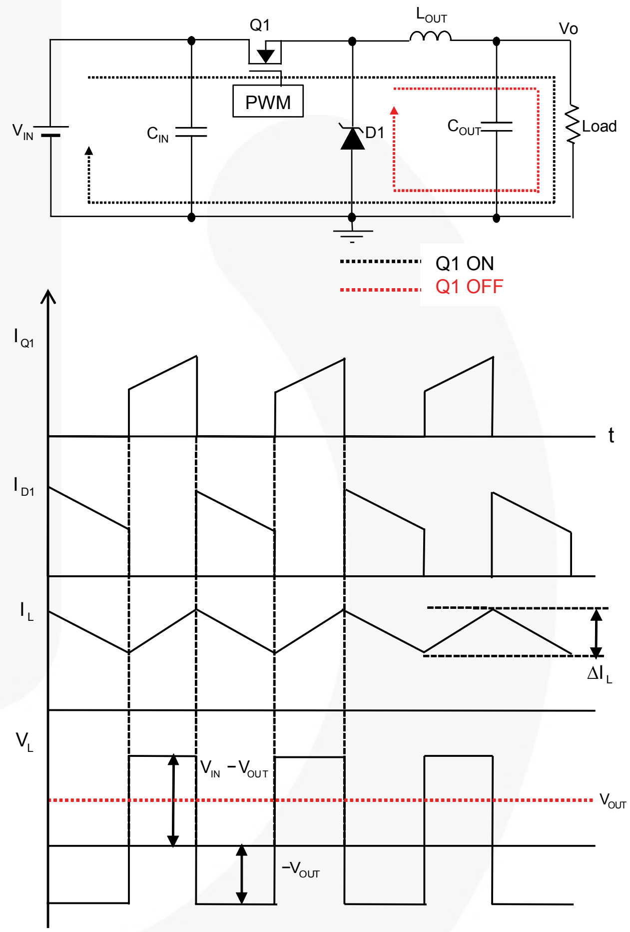

Figure 3. Buck Topology

Table 1. Buck and Buck-Boost Design Parameters

Topology	I_L (Average)	Maximum V_{SW}	Duty Cycles
Buck-Boost	$\frac{I_{OUT}}{1-D}$	$V_{IN}+\lvert V_{OUT}\rvert$	$\frac{\lvert V_{OUT}\rvert}{V_{IN}+\lvert V_{OUT}\rvert}$
Buck	I_{OUT}	V_{IN}	$\frac{V_{OUT}}{V_{IN}}$

First of all, inductor current is limited by (1–*D*); so attention is needed to see that the maximum output current of buck regulator is be always lower than the maximum current in buck-boost circuit. Second, the switch node is a sum of input voltage and output voltage in buck-boost. It also needs to be limited to the maximum switch node voltage of buck regulator. Since buck-boost is very noisy on input and output compared to buck circuit, it requires good-quality MLCC as input and output filters.

Design Considerations

Inductor Selection

When choosing inductor, the main concerns are inductance value, RMS current rating, and DCR. Inductance value is usually adopted higher than the minimum inductance to operate Continuous Current Mode (CCM). RMS current should be higher than the inductor current to prevent inductor saturation without core loss. A low-DCR inductor is usually adopted when a power system needs high efficiency.

To operate in continuous current mode, critical minimum inductance is calculated by:

$$L = \frac{V_{IN} \times D}{f_{SW} \times \Delta I_L} \tag{1}$$

where:

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

f_{SW} = Switching frequency; and

ΔI_L = Ripple current to maintain continuous current mode (typically 20%~30% of I_L).

Output Capacitor

An output capacitor is needed to satisfy the output voltage ripple requirement and to maintain constant output voltage during dynamic load condition. Ripple voltage depends on ESR, output capacitance, and ESL. To obtain the desired output ripple, the below equation for required minimum capacitance is useful:

$$C_{MIN} = \frac{I_{OUTMAX} \times D_{MAX}}{f_{SW} \times \Delta V_{OUT}} \tag{2}$$

where:

D_{MAX} = Maximum Duty Cycle;

I_{OUTMAX} = Maximum Output Current; and

ΔV_{OUT} = Desired Output Voltage Ripple.

The equation for required ESR is:

$$ESR = \frac{\Delta V_{OUT}}{I_{LMAX}} \tag{3}$$

Input Capacitor

The input capacitor should handle the maximum input RMS current, so use the equations below for calculation. Good estimation is given by 10µF or 22µF per amp with MLCC.

Maximum RMS input current:

$$I_{RMS\_MAX} = I_{OUTMAX} \times \sqrt{(D \times (1 - D))} \tag{4}$$

Required minimum capacitance:

$$C_{MIN} = (I_{RMS} \times D)/(f_{SW} \times \Delta V_{IN}) \tag{5}$$

where ΔV_{IN} is desired input voltage ripple.

Freewheeling Diode

The freewheeling diode acts as a inductor current path when the switch is turned off. Breakdown voltage, lower forward drop voltage, and the maximum current rating are considered for low power dissipation. A Schottky diode is preferred, which has low forward voltage drop.

Required diode current rating:

$$> I_{LMAX} \tag{6}$$

where I_{LMAX} is maximum inductor current.

Required breakdown voltage:

$$> V_{IN} + |V_{OUT}| \tag{7}$$

Design Example

A design example with test conditions V_{IN} =12V, V_{OUT} = -5V, I_{OUT} = 1A, and f_{SW} =370 kHz (fixed) is shown below. The first step is to set the critical design parameters, such as inductor ripple current (ΔI_L) and desired output ripple voltage (ΔV_{OUT}). The second step is calculation of duty cycle. To achieve accurate value, consider the forward voltage drop of diode and MOSFET switch on drop voltage.

Fairchild FAN8303, non-synchronous buck regulator has integrated 0.22Ω N-channel MOSFET, so on drop voltage is about 0.4V. Forward voltage of the Schottky diode (40V_{RRM}/ 2A I_{OUT}) is 0.45V. When it comes to the inductor, a higher value than calculated is recommended and a low DCR inductor is preferred:

Table 2. Design Example Calculations

Duty Cycle:	$= (\lvert V_{OUT}\rvert + V_F) / (V_{IN} + \lvert V_{OUT}\rvert + V_F - V_{Q1})$	0.33
Inductance:	$= (V_{IN} \times D) / (f_{SW} \times \Delta I_L)$	35.6µH (desired ΔI_L = 20%)
Output Capacitance:	$= (I_{OUT} \times D) / (f_{SW} \times \Delta V_{OUT})$	86.8µF (desired ΔV_{OUT} = 10mV)
Input Capacitance:	$I_{RMS} = I_{OUT} \times \sqrt{D \times (1-D)}$	0.47A
	$C_{IN} = I_{RMS} \times D / (\Delta V_{IN} \times f_{SW})$	4.05µF
Diode Current Rating:	$I_{DIODE\_MAX} = I_{AVG} + \Delta I_L/2$ where I_{AVG} = Average Inductor Current	1.77A

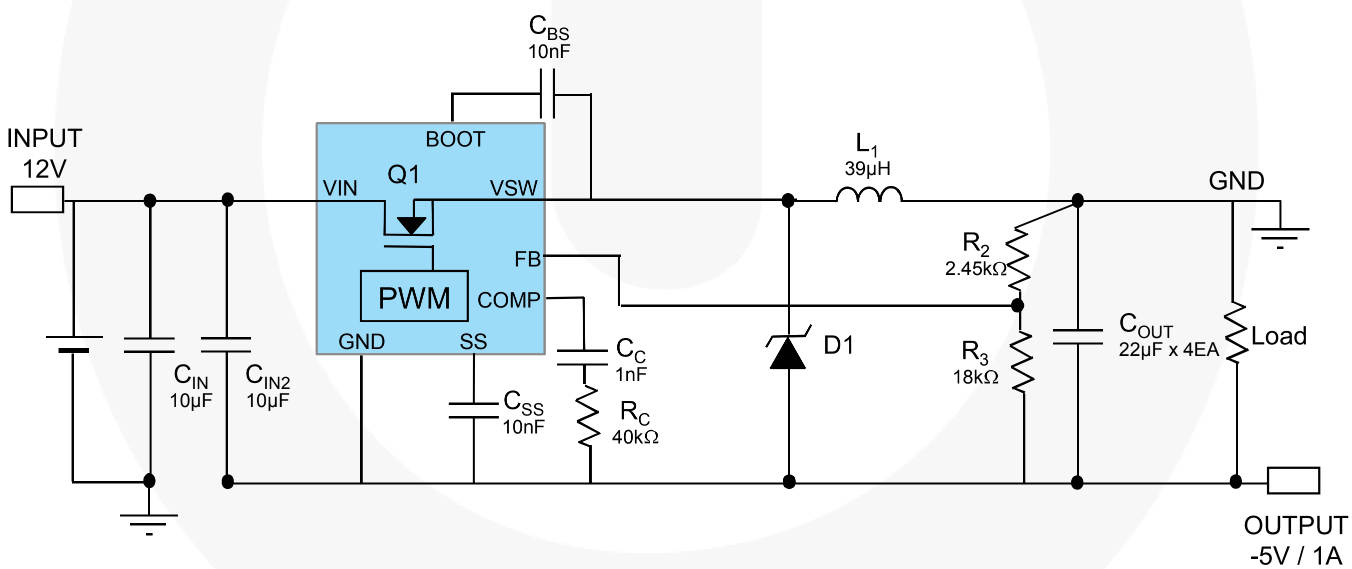

Figure 4. Buck-Boost Schematic Using FAN8303

Typical Waveforms & Graphs

Figure 5 and Figure 6 show the typical waveforms of the FAN8303 output ripple voltage. To achieve low ripple voltage, lower than 10mΩ MLCC is used.

Figure 7 shows FAN8303 efficiency and power-loss graph. It indicates a maximum of 87% efficiency with 0.31W at 400mA load condition.

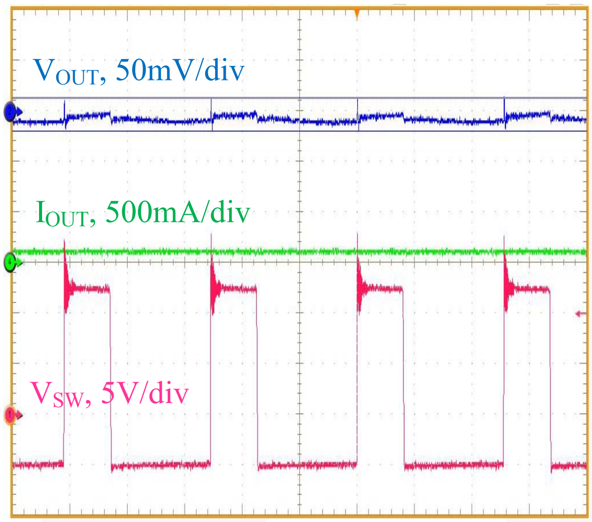

Figure 5. V_{OUT} Ripple (1µs/div), 33mV at 100mA

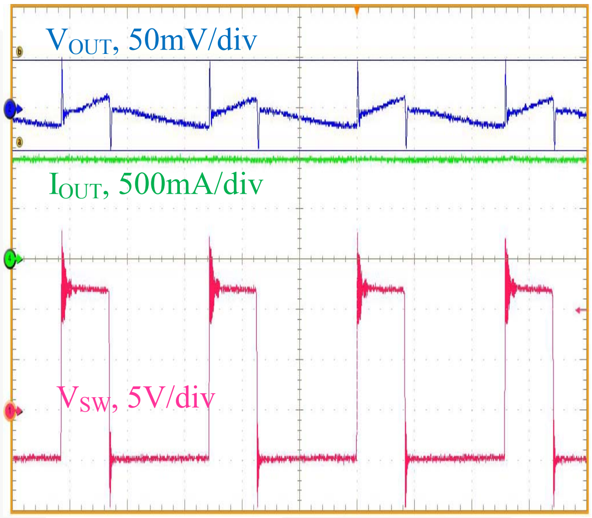

Figure 6. V_{OUT} Ripple (1µs/div), 89mV at 1A

Note:

1. Test conditions: V_{IN} =12V, V_{OUT} = -5V, f_{SW} = fixed 370 kHz, and I_{OUT} = 0~1A.

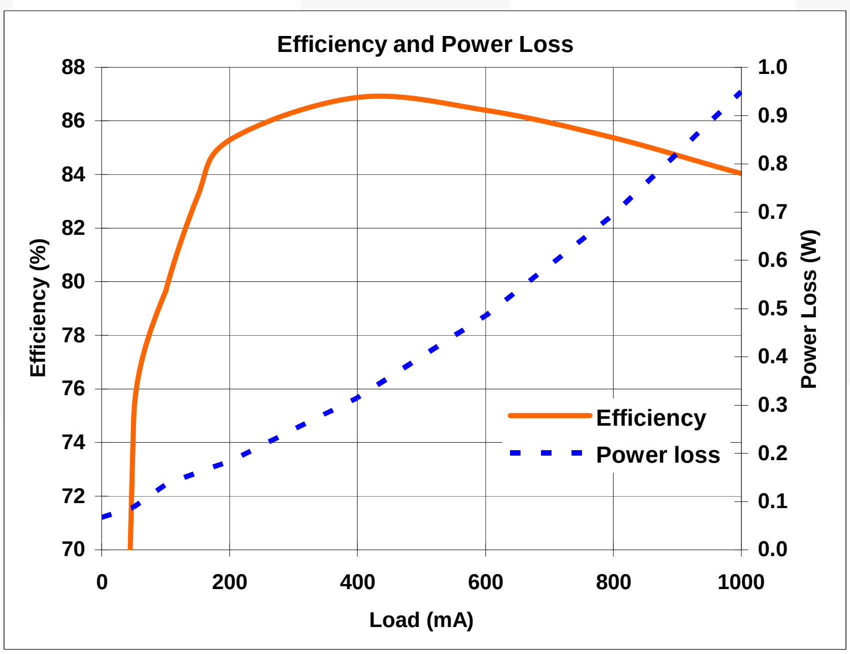

Figure 7. Efficiency and Power Loss

Conclusion

Fairchild 2A monolithic and non-synchronous buck regulator, FAN8303, has wide input range (~23V) with excellent load and line regulation. In spite of buck regulator, FAN8303 also can be utilized for buck-boost circuit to generate negative output voltage with simple changes of passive element.

Author

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Related Datasheets

FAN8303 — 2A 23V Non-Synchronous Step-Down DC/DC Regulator