+5 to −15 Volts DC Converter

National Semiconductor
Linear Brief 18
July 1972

Introduction

It is frequently necessary to convert a DC voltage to another higher or lower DC-voltage while maximizing efficiency. Conventional switching regulators are capable of converting from a high input DC voltage to a lower output voltage and satisfying the efficiency criteria. The problem is a little more troublesome if a higher output voltage than the input voltage is desired. Particularly, generating DC voltage with opposite polarity to the input voltage usually involves a complicated design.

This brief demonstrates the use of the switching regulator idea for a +5 volts to −15 volts converter. The converter has an application as a power supply for MOS memories in a logic system where only +5 volts is available. However, the principle used can be amplied for almost any input output combination.

Operation

The method by which the regulator generates the opposite polarity is explained in *Figure 2*. The transistor Q is turned ON and OFF with a given duty cycle. If the base drive is sufficient the voltage across the inductor is equal to the supply voltage minus V_{SAT}. The current change in the inductor is given by:

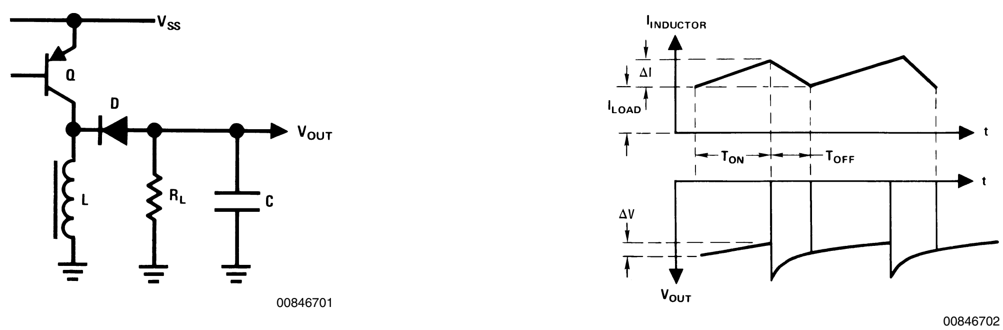

FIGURE 1. Switching Circuit for Voltage Conversion

$$\Delta I = \frac{V_{SS} - V_{SAT}}{L} \times T_{ON} \approx \frac{V_{SS}}{L} T_{ON} \quad (1)$$

Turning OFF the transistor the inductor current has a path through the catch diode and this in turn builds up a negative voltage across R_L.

The figure also shows the current and voltage levels versus time. A capacitor in parallel to the resistor will prevent the voltage from dropping to zero during the transistor ON time.

Assuming a large capacitor, we can also write the current change as:

$$\Delta I = \frac{V_{OUT} - V_D}{L} \times T_{OFF} \approx \frac{V_{OUT}}{L} \times T_{OFF} \quad (2)$$

In order to get a general idea of the operation for certain input output conditions, we will develop a set of equations.

During the transistor ON time, energy is loaded into the inductor. In the same time interval, the capacitor is drained due to the load resistor R_L.

Drop in capacitor voltage:

$$\Delta V = \frac{I_{LOAD} \times T_{ON}}{C} \quad (3)$$

Operation (Continued)

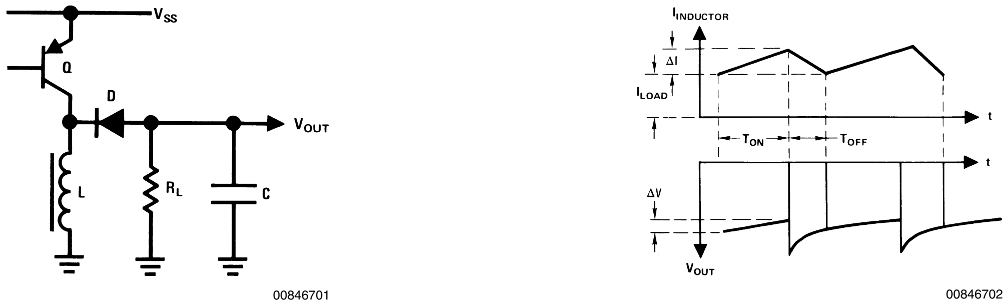

FIGURE 2. Switching Circuit for Voltage Conversion

During the T_{OFF} time the stored energy in the inductor is transferred to the load and capacitor. A rough estimate of T_{OFF} can be expressed as:

$$T_{OFF} = \frac{V_{SS}}{V_{OUT}} \times T_{ON} \quad (4)$$

The capacitor voltage will be restored with a average current given by:

$$I_C = \frac{\Delta V \times C}{T_{OFF}} = \frac{I_{LOAD} \times V_{OUT}}{V_{SS}} \quad (5)$$

The total inductor current during the OFF time can be written as:

$$I_{INDUCTOR} = I_{LOAD} + I_C \quad (6)$$

Inspecting *Figure 2*. We find:

$$I_C = \frac{\Delta I}{2} = \frac{V_{SS} \times T_{ON}}{2 \times L} \quad (7)$$

which yields:

$$T_{ON} = \frac{2 \times L \times I_{LOAD} \times V_{OUT}}{V_{SS}^2} \quad (8)$$

Taking into account that the efficiency is in the order of 75% the final expression is:

$$T_{ON} = \frac{1.5 \times L \times I_{LOAD} \times V_{OUT}}{V_{SS}^2} \quad (9)$$

The above equations will be applied to the regulator shown at *Figure 3*. The regulator must deliver −15 volts at 200 mA from a +5 volt supply. Using a 1 mH inductor the T_{ON} time for Q_2 is 0.18 ms from *Equation (9)*. T_{OFF} is 60 µs from *Equation (4)* and the oscillator frequency to:

$$F = \frac{1}{T_{ON} + T_{OFF}} \approx 4 \text{ kHz}$$

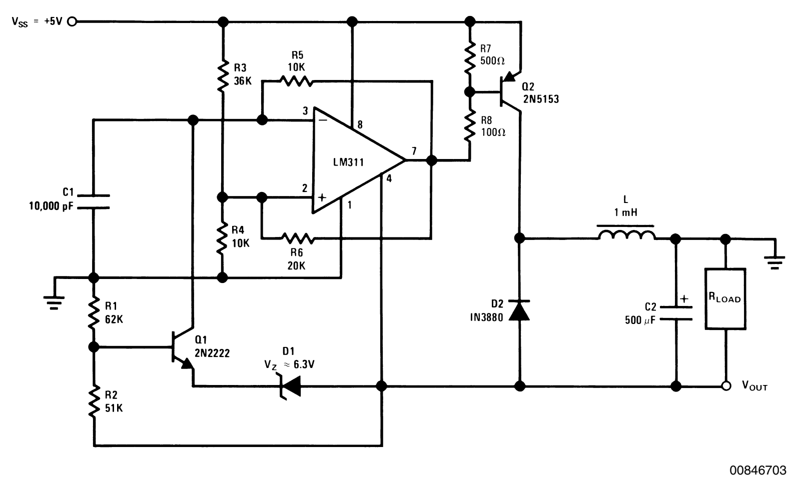

FIGURE 3. Switching Regulator for Voltage Conversion

Operation (Continued)

$$\eta = \frac{P_{OUT}}{P_{IN}} \geq 75\%$$
$$F = 6\ \text{kHz}\ 80\%\ \text{DUTY}$$
$$V_{RIPPLE} = 100\ \text{mV @200 mA OUT}$$
$$I_L = 200\ \text{mA MAX}$$
$$V_{OUT} = -15V$$
$$V_{OUT} = (V_Z + V_{BE}\left(\frac{R_1}{R_2} + 1\right))$$

The LM311 performs like a free running multivibrator with high duty cycle. The IC is designed to operate from a standard single 5 volt supply and has a high output current capability for driving the switching transistor Q_2. The duty cycle is given by the voltage divider R_3 and R_4 and the frequency of C_1 in conjunction with R_5.

By setting the duty cycle higher than first calculated, the output voltage will tend to increase above the desired output voltage of 15 volts. However, an extra loop performed by Q_1 and the zener diode in conjunction with the resistor network will modify the oscillator duty cycle until the desired output level is obtained.

The output voltage is given by:

$$V_{OUT} = \left(V_Z + V_{BE}\right)\left(\frac{R_1}{R_2} + 1\right)$$

Data and results obtained with the design:

V_{IN}	= 5 volts
V_{OUT}	= –15 volts
I_{OUT}	= max 200 mA
Efficiency	≃ 75%
Frequency	≃ 6 kHz 80% duty cycle
V_{RIPPLE}	≃ 100 mV @ 200 mA load
Line regulation:	V_{IN} = 5V to 10V < 3% V_{OUT}
	I_{LOAD} = 200 mA
Load regulation:	V_{IN} = 5V < 3% V_{OUT}
	I_{LOAD} = 0 – 100 mA

National Semiconductor Corporation
Americas
Email: support@nsc.com

www.national.com

National Semiconductor Europe
Fax: +49 (0) 180-530 85 86
Email: europe.support@nsc.com
Deutsch Tel: +49 (0) 69 9508 6208
English Tel: +44 (0) 870 24 0 2171
Français Tel: +33 (0) 1 41 91 8790

National Semiconductor Asia Pacific Customer Response Group
Tel: 65-2544466
Fax: 65-2504466
Email: ap.support@nsc.com

National Semiconductor Japan Ltd.
Tel: 81-3-5639-7560
Fax: 81-3-5639-7507