

+ 5 to - 15 Volts DC Converter

National Semiconductor
Linear Brief 18
July 1972



+ 5 to - 15 Volts DC Converter

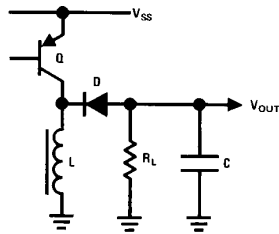
INTRODUCTION

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.

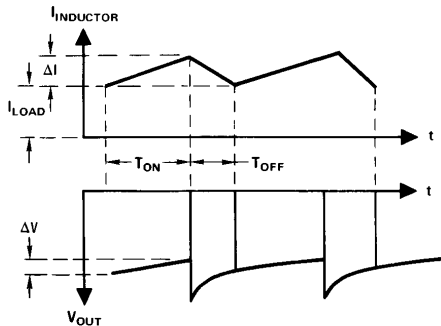
This brief demonstrates the use of the switching regulator idea for a +5 volts to -15 volts converter. The converter has an application as a power supply for MOS memories in a logic system where only +5 volts is available. However, the principle used can be applied for almost any input output combination.

OPERATION

The method by which the regulator generates the opposite polarity is explained in *Figure 1*. 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



TL/H/8467-1



TL/H/8467-2

FIGURE 1. Switching Circuit for Voltage Conversion
supply voltage minus V_{SAT} . The current change in the inductor is given by:

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

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:

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

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 1*. 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 2*. 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 μ s from equation 4 and the oscillator frequency to:

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

LB-18

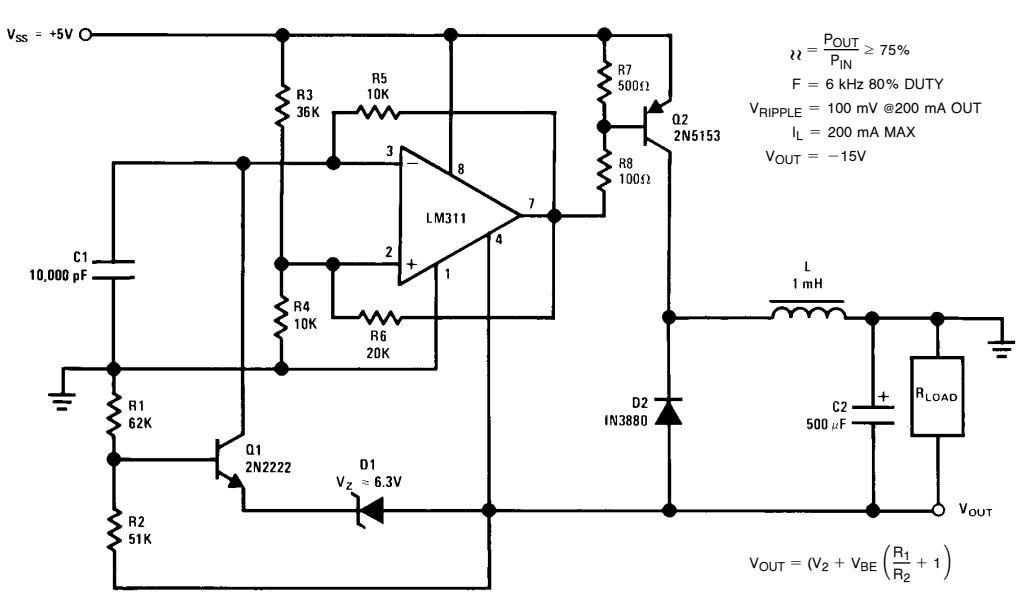


FIGURE 2. Switching Regulator for Voltage Conversion

TL/H/8467-3

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 Q₂. The duty cycle is given by the voltage divider R₃ and R₄ and the frequency of C₁ in conjunction with R₅.

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 Q₁ 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:

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


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

LIFE SUPPORT POLICY

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform, when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

 <p>National Semiconductor Corporation 1111 West Bardin Road Arlington, TX 76017 Tel: (800) 272-9959 Fax: (800) 737-7018</p>	<p>National Semiconductor Europe Fax: (+49) 0-180-530 85 86 Email: onjwge@tevm2.nsc.com Deutsch Tel: (+49) 0-180-530 85 85 English Tel: (+49) 0-180-532 78 32 Français Tel: (+49) 0-180-532 93 58 Italiano Tel: (+49) 0-180-534 16 80</p>	<p>National Semiconductor Hong Kong Ltd. 19th Floor, Straight Block, Ocean Centre, 5 Canton Rd. Tsimshatsui, Kowloon Hong Kong Tel: (852) 2737-1600 Fax: (852) 2736-9960</p>	<p>National Semiconductor Japan Ltd. Tel: 81-043-299-2309 Fax: 81-043-299-2408</p>
--	--	---	---

National does not assume any responsibility for use of any circuitry described, no circuit patent licenses are implied and National reserves the right at any time without notice to change said circuitry and specifications.