LM311

+5 to -15 Volts DC Converter

Literature Number: SNOA851
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 amplified 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

\[ \Delta I = \frac{V_{SS} - V_{SAT}}{L} \times T_{ON} \approx \frac{V_{SS}}{L} \times T_{ON} \]  

(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:

\[ \Delta I = \frac{V_{OUT} - V_D}{L} \times T_{OFF} \approx \frac{V_{OUT}}{L} \times T_{OFF} \]  

(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:

\[ \Delta V = \frac{I_{LOAD} \times T_{ON}}{C} \]  

(3)
Operation (Continued)

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:

$$T_{OFF} = \frac{V_{SS}}{V_{OUT}} \cdot T_{ON} \tag{4}$$

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

$$I_C = \Delta V \times C \times \frac{T_{OFF}}{T_{ON}} \cdot \frac{I_{LOAD} \times V_{OUT}}{V_{SS}} \tag{5}$$

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

$$I_{INDUCTOR} = I_{LOAD} + I_C \tag{6}$$

Inspecting Figure 2. We find:

$$I_C = \frac{\Delta V}{2} \cdot \frac{V_{SS} \times T_{ON}}{2 \times L} \tag{7}$$

which yields:

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

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

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

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:

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

FIGURE 2. Switching Circuit for Voltage Conversion

FIGURE 3. Switching Regulator for Voltage Conversion
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:

\[ V_{OUT} = \left( V_2 + V_{BE} \right) \left( \frac{R_1}{R_2} + 1 \right) \]

Data and results obtained with the design:

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

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