

# LM311

*+5 to -15 Volts DC Converter*



Literature Number: SNOA851

# +5 to -15 Volts DC Converter

National Semiconductor  
Linear Brief 18  
July 1972



## Introduction

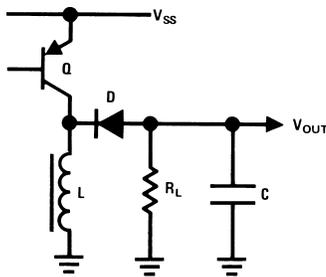
It is frequently necessary to convert a DC voltage to another higher or lower DC-voltage while maximizing efficiency. Conventional switching regulators are capable of converting from a high input DC voltage to a lower output voltage and satisfying the efficiency criteria. The problem is a little more 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

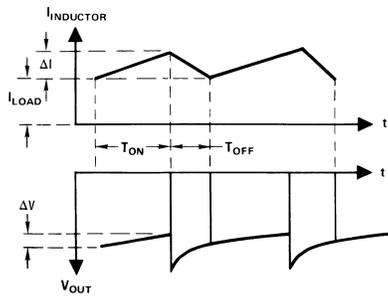
an application as a power supply for MOS memories in a logic system where only +5 volts is available. However, the principle used can be applied for almost any input output combination.

## 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:



00846701



00846702

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:

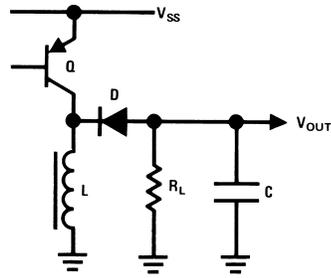
$$\Delta I = \frac{V_{OUT} - V_D}{L} \times T_{OFF} \approx \frac{V_{OUT}}{L} \times T_{OFF} \quad (2)$$

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  $R_L$ .

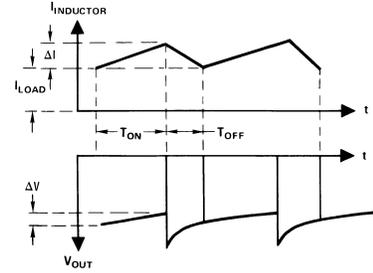
Drop in capacitor voltage:

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

Operation (Continued)



00846701



00846702

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:

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

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

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

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:

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

which yields:

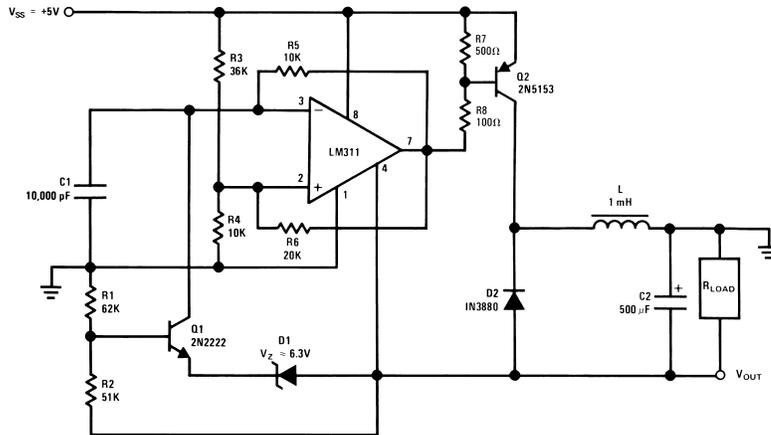
$$T_{ON} = \frac{2 \times L \times I_{LOAD} \times V_{OUT}}{V_{SS}^2} \tag{8}$$

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  $\mu$ s from Equation (4) and the oscillator frequency to:

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



00846703

FIGURE 3. Switching Regulator for Voltage Conversion

## Operation (Continued)

$$\eta = \frac{P_{OUT}}{P_{IN}} \approx 75\%$$

$$F = 6 \text{ kHz } 80\% \text{ DUTY}$$

$$V_{RIPPLE} = 100 \text{ mV @ } 200 \text{ mA OUT}$$

$$I_L = 200 \text{ mA MAX}$$

$$V_{OUT} = -15\text{V}$$

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

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<sub>2</sub>. The duty cycle is given by the voltage divider R<sub>3</sub> and R<sub>4</sub> and the frequency of C<sub>1</sub> in conjunction with R<sub>5</sub>.

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<sub>1</sub> 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 <sub>IN</sub>	= 5 volts
V <sub>OUT</sub>	= -15 volts
I <sub>OUT</sub>	= max 200 mA
Efficiency	≈ 75%
Frequency	≈ 6 kHz 80% duty cycle
V <sub>RIPPLE</sub>	≈ 100 mV @ 200 mA load
Line regulation:	V <sub>IN</sub> = 5V to 10V < 3% V <sub>OUT</sub>
	I <sub>LOAD</sub> = 200 mA
Load regulation:	V <sub>IN</sub> = 5V < 3% V <sub>OUT</sub>
	I <sub>LOAD</sub> = 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 AND GENERAL COUNSEL 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.



**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

## IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, modifications, enhancements, improvements, and other changes to its products and services at any time and to discontinue any product or service without notice. Customers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All products are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its hardware products to the specifications applicable at the time of sale in accordance with TI's standard warranty. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by government requirements, testing of all parameters of each product is not necessarily performed.

TI assumes no liability for applications assistance or customer product design. Customers are responsible for their products and applications using TI components. To minimize the risks associated with customer products and applications, customers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any TI patent right, copyright, mask work right, or other TI intellectual property right relating to any combination, machine, or process in which TI products or services are used. Information published by TI regarding third-party products or services does not constitute a license from TI to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. Reproduction of this information with alteration is an unfair and deceptive business practice. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI products or services with statements different from or beyond the parameters stated by TI for that product or service voids all express and any implied warranties for the associated TI product or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

TI products are not authorized for use in safety-critical applications (such as life support) where a failure of the TI product would reasonably be expected to cause severe personal injury or death, unless officers of the parties have executed an agreement specifically governing such use. Buyers represent that they have all necessary expertise in the safety and regulatory ramifications of their applications, and acknowledge and agree that they are solely responsible for all legal, regulatory and safety-related requirements concerning their products and any use of TI products in such safety-critical applications, notwithstanding any applications-related information or support that may be provided by TI. Further, Buyers must fully indemnify TI and its representatives against any damages arising out of the use of TI products in such safety-critical applications.

TI products are neither designed nor intended for use in military/aerospace applications or environments unless the TI products are specifically designated by TI as military-grade or "enhanced plastic." Only products designated by TI as military-grade meet military specifications. Buyers acknowledge and agree that any such use of TI products which TI has not designated as military-grade is solely at the Buyer's risk, and that they are solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI products are neither designed nor intended for use in automotive applications or environments unless the specific TI products are designated by TI as compliant with ISO/TS 16949 requirements. Buyers acknowledge and agree that, if they use any non-designated products in automotive applications, TI will not be responsible for any failure to meet such requirements.

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

### Products

Audio	<a href="http://www.ti.com/audio">www.ti.com/audio</a>
Amplifiers	<a href="http://amplifier.ti.com">amplifier.ti.com</a>
Data Converters	<a href="http://dataconverter.ti.com">dataconverter.ti.com</a>
DLP® Products	<a href="http://www.dlp.com">www.dlp.com</a>
DSP	<a href="http://dsp.ti.com">dsp.ti.com</a>
Clocks and Timers	<a href="http://www.ti.com/clocks">www.ti.com/clocks</a>
Interface	<a href="http://interface.ti.com">interface.ti.com</a>
Logic	<a href="http://logic.ti.com">logic.ti.com</a>
Power Mgmt	<a href="http://power.ti.com">power.ti.com</a>
Microcontrollers	<a href="http://microcontroller.ti.com">microcontroller.ti.com</a>
RFID	<a href="http://www.ti-rfid.com">www.ti-rfid.com</a>
OMAP Mobile Processors	<a href="http://www.ti.com/omap">www.ti.com/omap</a>
Wireless Connectivity	<a href="http://www.ti.com/wirelessconnectivity">www.ti.com/wirelessconnectivity</a>

### Applications

Communications and Telecom	<a href="http://www.ti.com/communications">www.ti.com/communications</a>
Computers and Peripherals	<a href="http://www.ti.com/computers">www.ti.com/computers</a>
Consumer Electronics	<a href="http://www.ti.com/consumer-apps">www.ti.com/consumer-apps</a>
Energy and Lighting	<a href="http://www.ti.com/energy">www.ti.com/energy</a>
Industrial	<a href="http://www.ti.com/industrial">www.ti.com/industrial</a>
Medical	<a href="http://www.ti.com/medical">www.ti.com/medical</a>
Security	<a href="http://www.ti.com/security">www.ti.com/security</a>
Space, Avionics and Defense	<a href="http://www.ti.com/space-avionics-defense">www.ti.com/space-avionics-defense</a>
Transportation and Automotive	<a href="http://www.ti.com/automotive">www.ti.com/automotive</a>
Video and Imaging	<a href="http://www.ti.com/video">www.ti.com/video</a>

TI E2E Community Home Page

[e2e.ti.com](http://e2e.ti.com)

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265  
Copyright © 2011, Texas Instruments Incorporated