

# LMC7660

*LMC7660 Switched Capacitor Voltage Converter*



Literature Number: SNOSBZ9B

# LMC7660

## Switched Capacitor Voltage Converter

### General Description

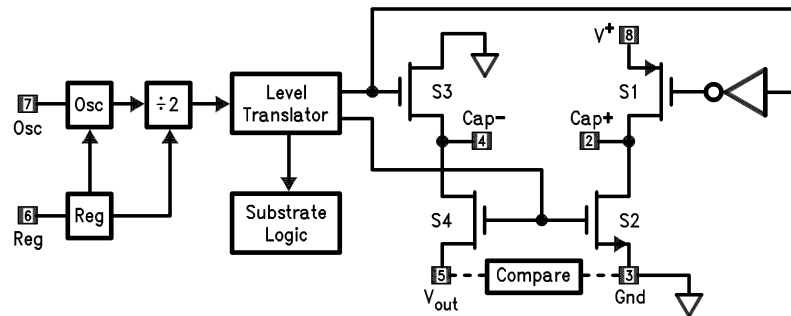
The LMC7660 is a CMOS voltage converter capable of converting a positive voltage in the range of +1.5V to +10V to the corresponding negative voltage of -1.5V to -10V. The LMC7660 is a pin-for-pin replacement for the industry-standard 7660. The converter features: operation over full temperature and voltage range without need for an external diode, low quiescent current, and high power efficiency.

The LMC7660 uses its built-in oscillator to switch 4 power MOS switches and charge two inexpensive electrolytic capacitors.

### Features

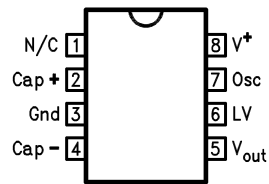
- Operation over full temperature and voltage range without an external diode
- Low supply current, 200  $\mu$ A max
- Pin-for-pin replacement for the 7660
- Wide operating range 1.5V to 10V
- 97% Voltage Conversion Efficiency
- 95% Power Conversion Efficiency
- Easy to use, only 2 external components
- Extended temperature range
- Narrow SO-8 Package

### Block Diagram



00913601

### Pin Configuration



00913602

### Ordering Information

Package	Temperature Range	NSC Drawing
	Industrial -40°C to +85°C	
8-Lead Molded DIP	LMC7660IN	N08E
8-Lead Molded Small Outline	LMC7660IM	M08A

**Absolute Maximum Ratings** (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage	10.5V
Input Voltage on Pin 6, 7 (Note 2)	-0.3V to ( $V^+ + 0.3V$ ) for $V^+ < 5.5V$ ( $V^+ - 5.5V$ ) to ( $V^+ + 0.3V$ ) for $V^+ > 5.5V$
Current into Pin 6 (Note 2)	20 $\mu A$
Output Short Circuit Duration ( $V^+ \leq 5.5V$ )	Continuous

## Power Dissipation (Note 3)

Dual-In-Line Package	1.4W
Surface-Mount Package	0.6W
$T_J$ Max (Note 3)	150°C
$\theta_{JA}$ (Note 3)	
Dual-In-Line Package	90°C/W
Surface-Mount Package	160°C/W
Storage Temp. Range	$-65^\circ C \leq T \leq 150^\circ C$
Lead Temperature (Soldering, 5 sec.)	260°C
ESD Tolerance (Note 7)	$\pm 2000V$

**Electrical Characteristics** (Note 4)

Symbol	Parameter	Conditions	Typ	LMC7660IN/ LMC7660IM	Units Limits
				Limit (Note 5)	
$I_s$	Supply Current	$R_L = \infty$	120	200 <b>400</b>	$\mu A$ max
$V^+H$	Supply Voltage Range High (Note 6)	$R_L = 10\text{ k}\Omega$ , Pin 6 Open Voltage Efficiency $\geq 90\%$	3 to 10	3 to 10 <b>3 to 10</b>	V
$V^+L$	Supply Voltage Range Low	$R_L = 10\text{ k}\Omega$ , Pin 6 to Gnd. Voltage Efficiency $\geq 90\%$	1.5 to 3.5	1.5 to 3.5 <b>1.5 to 3.5</b>	V
$R_{out}$	Output Source Resistance	$I_L = 20\text{ mA}$	55	100 <b>120</b>	$\Omega$ max
		$V = 2V$ , $I_L = 3\text{ mA}$ Pin 6 Short to Gnd.	110	200 <b>300</b>	$\Omega$ max
$F_{osc}$	Oscillator Frequency		10		kHz
$P_{eff}$	Power Efficiency	$R_L = 5\text{ k}\Omega$	97	95 <b>90</b>	% min
$V_{o\text{ eff}}$	Voltage Conversion Efficiency	$R_L = \infty$	99.9	97 <b>95</b>	% min
$I_{osc}$	Oscillator Sink or Source Current	Pin 7 = Gnd. or $V^+$	3		$\mu A$

**Note 1:** Absolute Maximum ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications do not apply when operating the device beyond its rated operating conditions. See Note 4 for conditions.

**Note 2:** Connecting any input terminal to voltages greater than  $V^+$  or less than ground may cause destructive latchup. It is recommended that no inputs from sources operating from external supplies be applied prior to "power-up" of the LMC7660.

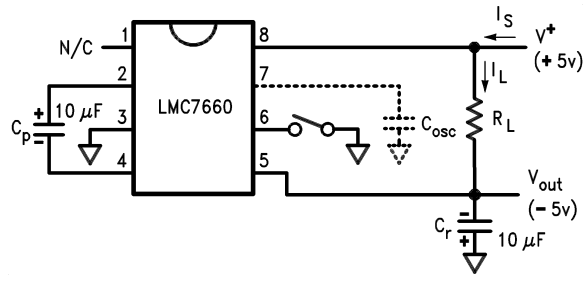
**Note 3:** For operation at elevated temperature, these devices must be derated based on a thermal resistance of  $\theta_{ja}$  and  $T_J$  max,  $T_J = T_A + \theta_{ja} P_D$ .

**Note 4:** Boldface numbers apply at temperature extremes. All other numbers apply at  $T_A = 25^\circ C$ ,  $V^+ = 5V$ ,  $C_{osc} = 0$ , and apply for the LMC7660 unless otherwise specified. Test circuit is shown in Figure 1.

**Note 5:** Limits at room temperature are guaranteed and 100% production tested. Limits in **boldface** are guaranteed over the operating temperature range (but not 100% tested), and are not used to calculate outgoing quality levels.

**Note 6:** The LMC7660 can operate without an external diode over the full temperature and voltage range. The LMC7660 can also be used with the external diode Dx, when replacing previous 7660 designs.

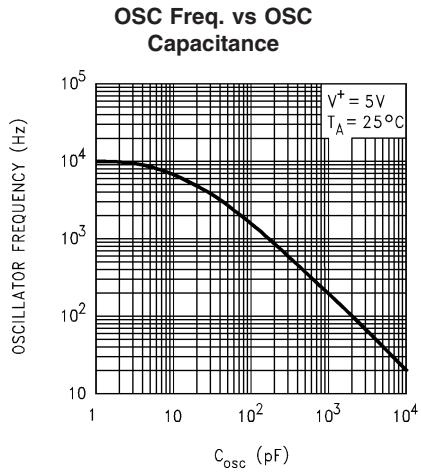
**Note 7:** The test circuit consists of the human body model of 100 pF in series with 1500 $\Omega$ .



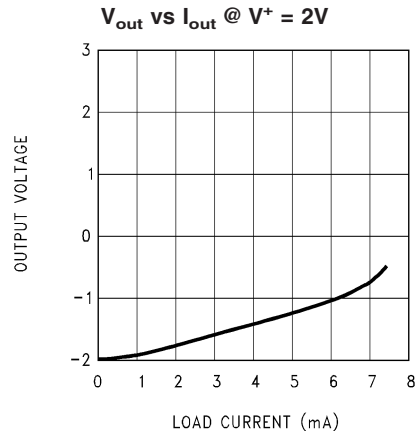
00913605

FIGURE 1. LMC7660 Test Circuit

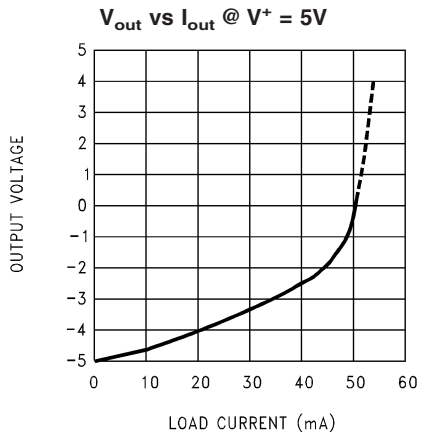
## Typical Performance Characteristics



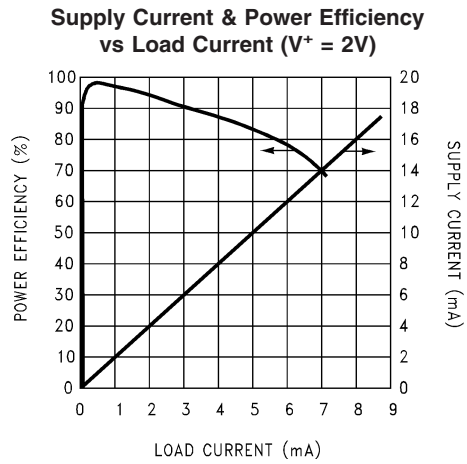
00913618



00913619



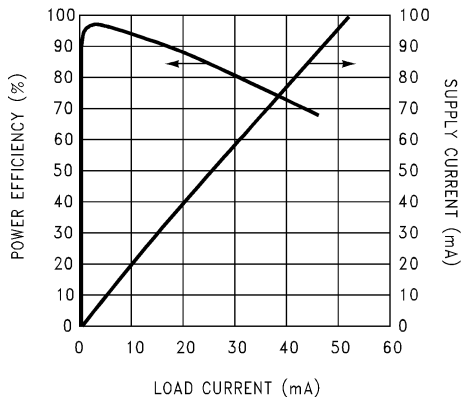
00913620



00913621

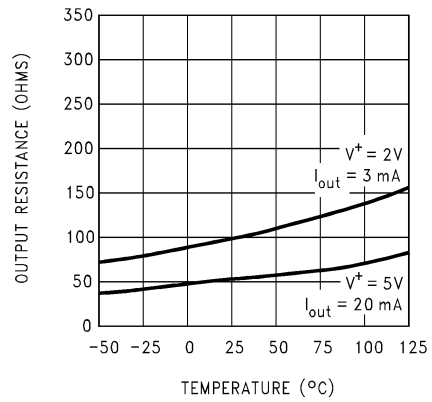
# Typical Performance Characteristics (Continued)

**Supply Current & Power Efficiency vs Load Current ( $V^+ = 5V$ )**



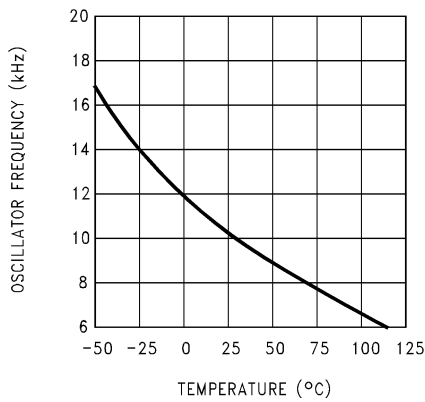
00913622

**Output Source Resistance as a Function of Temperature**



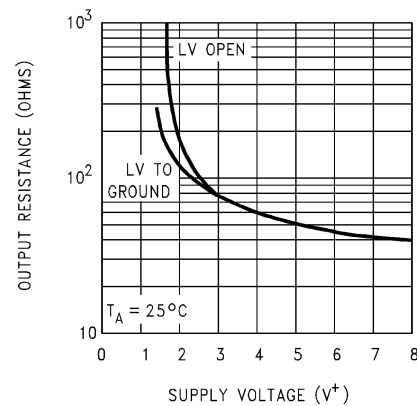
00913623

**Unloaded Oscillator Frequency as a Function of Temperature**



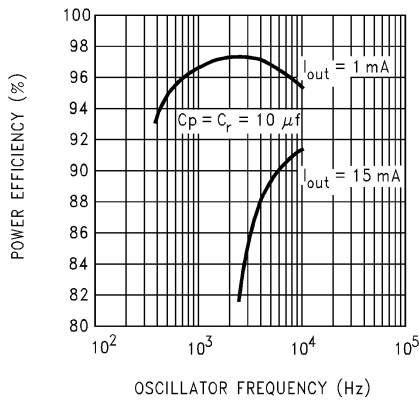
00913624

**Output R vs Supply Voltage**



00913625

**$P_{eff}$  vs OSC Freq. @  $V^+ = 5V$**



00913626

## Application Information

### CIRCUIT DESCRIPTION

The LMC7660 contains four large CMOS switches which are switched in a sequence to provide supply inversion  $V_{out} = -V_{in}$ . Energy transfer and storage are provided by two inexpensive electrolytic capacitors. Figure 2 shows how the LMC7660 can be used to generate  $-V^+$  from  $V^+$ . When

switches S1 and S3 are closed,  $C_p$  charges to the supply voltage  $V^+$ . During this time interval, switches S2 and S4 are open. After  $C_p$  charges to  $V^+$ , S1 and S3 are opened, S2 and S4 are then closed. By connecting S2 to ground,  $C_p$  develops a voltage  $-V^+/2$  on  $C_r$ . After a number of cycles  $C_r$  will be pumped to exactly  $-V^+$ . This transfer will be exact assuming no load on  $C_r$ , and no loss in the switches.

## Application Information (Continued)

In the circuit of *Figure 2*, S1 is a P-channel device and S2, S3, and S4 are N-channel devices. Because the output is biased below ground, it is important that the p<sup>-</sup> wells of S3 and S4 never become forward biased with respect to either their sources or drains. A substrate logic circuit guarantees that these p<sup>-</sup> wells are always held at the proper voltage. Under all conditions S4 p<sup>-</sup> well must be at the lowest potential in the circuit. To switch off S4, a level translator generates  $V_{GS4} = 0V$ , and this is accomplished by biasing the level translator from the S4 p<sup>-</sup> well.

An internal RC oscillator and ÷ 2 circuit provide timing signals to the level translator. The built-in regulator biases the oscillator and divider to reduce power dissipation on high supply voltage. The regulator becomes active at about  $V^+ = 6.5V$ . Low voltage operation can be improved if the LV pin is shorted to ground for  $V^+ \leq 3.5V$ . For  $V^+ \geq 3.5V$ , the LV pin must be left open to prevent damage to the part.

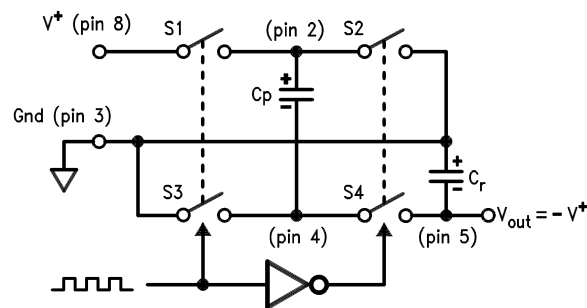
### POWER EFFICIENCY AND RIPPLE

It is theoretically possible to approach 100% efficiency if the following conditions are met:

1. The drive circuitry consumes little power.
2. The power switches are matched and have low  $R_{on}$ .
3. The impedance of the reservoir and pump capacitors are negligibly small at the pumping frequency.

The LMC7660 closely approaches 1 and 2 above. By using a large pump capacitor  $C_p$ , the charge removed while supplying the reservoir capacitor is small compared to  $C_p$ 's total charge. Small removed charge means small changes in the pump capacitor voltage, and thus small energy loss and high efficiency. The energy loss by  $C_p$  is:

$$E = \frac{1}{2}C_p (V_1^2 - V_2^2)$$



00913606

FIGURE 2. Idealized Voltage Converter

## Typical Applications

### CHANGING OSCILLATOR FREQUENCY

It is possible to dramatically reduce the quiescent operating current of the LMC7660 by lowering the oscillator frequency. The oscillator frequency can be lowered from a nominal 10 kHz to several hundred hertz, by adding a slow-down capacitor  $C_{osc}$  (*Figure 3*). As shown in the Typical Performance Curves the supply current can be lowered to the 10  $\mu A$  range. This low current drain can be extremely useful when used in  $\mu$ Power and battery back-up equipment. It must be

understood that the lower operating frequency and supply current cause an increased impedance of  $C_r$  and  $C_p$ . The increased impedance, due to a lower switching rate, can be offset by raising  $C_r$  and  $C_p$  until ripple and load current requirements are met.

$$I_s = C_r \frac{dv}{dt}$$

$$\sim C_r \times \frac{V_{\text{ripple p-p}}}{4/F_{\text{osc}}} \quad C_r = \frac{0.5 \text{ mA}}{0.5V/ms} = 10 \mu F$$

### PRECAUTIONS

1. Do not exceed the maximum supply voltage or junction temperature.
2. Do not short pin 6 (LV terminal) to ground for supply voltages greater than 3.5V.
3. Do not short circuit the output to  $V^+$ .
4. External electrolytic capacitors  $C_r$  and  $C_p$  should have their polarities connected as shown in *Figure 1*.

### REPLACING PREVIOUS 7660 DESIGNS

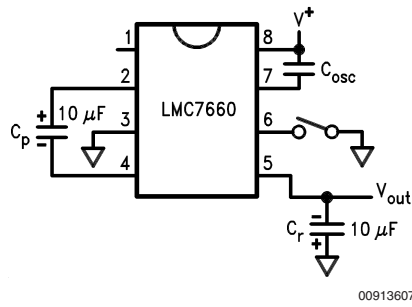
To prevent destructive latchup, previous 7660 designs require a diode in series with the output when operated at elevated temperature or supply voltage. Although this prevented the latchup problem of these designs, it lowered the available output voltage and increased the output series resistance.

The National LMC7660 has been designed to solve the inherent latch problem. The LCM7660 can operate over the entire supply voltage and temperature range without the need for an output diode. When replacing existing designs, the LMC7660 can be operated with diode Dx.

**Typical Applications** (Continued)

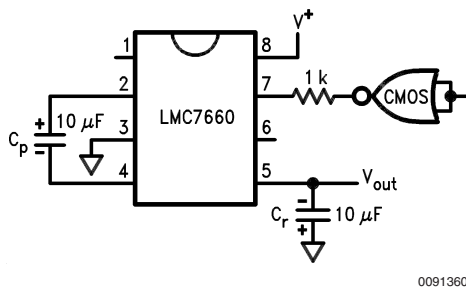
interference. The external clock still passes through the  $\pm 2$

circuit in the 7660, so the pumping frequency will be  $\frac{1}{2}$  the external clock frequency.



00913607

**FIGURE 3. Reduce Supply Current by Lowering Oscillator Frequency**



00913608

**FIGURE 4. Synchronizing to an External Clock**

**LOWERING OUTPUT IMPEDANCE**

Paralleling two or more LMC7660's lowers output impedance. Each device must have its own pumping capacitor  $C_p$ , but the reservoir capacitor  $C_r$  is shared as depicted in Figure 5. The composite output resistance is:

$$R_{out} = \frac{R_{out} \text{ of one LMC7660}}{\text{Number of devices}}$$

## Typical Applications (Continued)

### INCREASING OUTPUT VOLTAGE

Stacking the LMC7660s is an easy way to produce a greater negative voltage. It should be noted that the input current required for each stage is twice the load current on that stage as shown in *Figure 6*. The effective output resistance

is approximately the sum of the individual  $R_{out}$  values, and so only a few levels of multiplication can be used.

It is possible to generate  $-15V$  from  $+5V$  by connecting the second 7660's pin 8 to  $+5V$  instead of ground as shown in *Figure 7*. Note that the second 7660 sees a full  $20V$  and the input supply should not be increased beyond  $+5V$ .

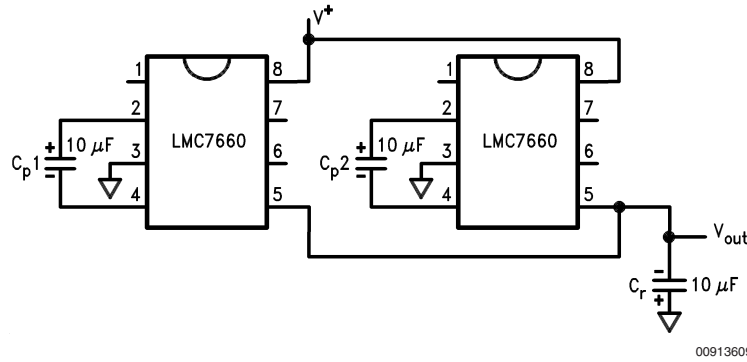


FIGURE 5. Lowering Output Resistance by Paralleling Devices

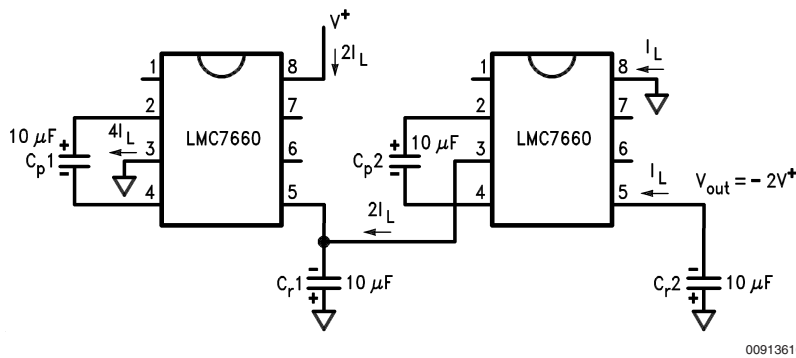


FIGURE 6. Higher Voltage by Cascade

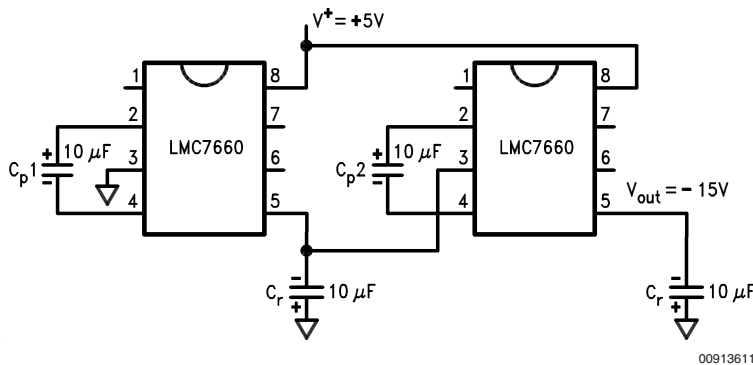


FIGURE 7. Getting  $-15V$  from  $+5V$

### SPLIT $V^+$ IN HALF

*Figure 8* is one of the more interesting applications for the LMC7660. The circuit can be used as a precision voltage divider (for very light loads), alternately it is used to generate a  $\frac{1}{2}$  supply point in battery applications. In the  $\frac{1}{2}$  cycle when

S1 and S3 are closed, the supply voltage divides across the capacitors in a conventional way proportional to their value. In the  $\frac{1}{2}$  cycle when S2 and S4 are closed, the capacitors switch from a series connection to a parallel connection. This forces the capacitors to have the same voltage; the charge



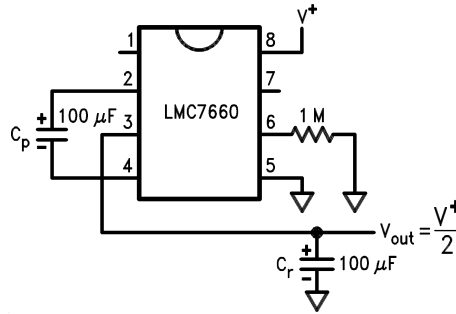
## Typical Applications (Continued)

redistributes to maintain precisely  $V^+/2$ , across  $C_p$  and  $C_r$ . In this application all devices are only  $V^+/2$ , and the supply voltage can be raised to 20V giving exactly 10V at  $V_{out}$ .

### GETTING UP ... AND DOWN

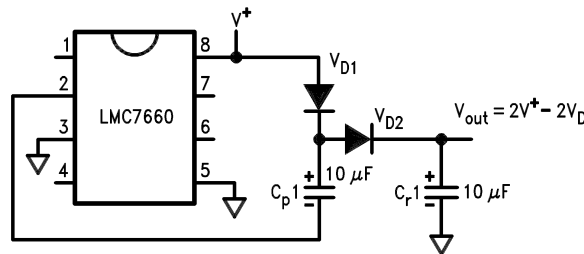
The LMC7660 can also be used as a positive voltage multiplier. This application, shown in *Figure 9*, requires 2 additional diodes. During the first  $\frac{1}{2}$  cycle S2 charges  $C_p1$  through D1; D2 is reverse biased. In the next  $\frac{1}{2}$  cycle S2 is

open and S1 is closed. Since  $C_p1$  is charged to  $V^+ - V_{D1}$  and is referenced to  $V^+$  through S1, the junction of D1 and D2 is at  $V^+ + (V^+ - V_{D1})$ . D1 is reverse biased in this interval. This application uses only two of the four switches in the 7660. The other two switches can be put to use in performing a negative conversion at the same time as shown in *Figure 10*. In the  $\frac{1}{2}$  cycle that D1 is charging  $C_p1$ ,  $C_p2$  is connected from ground to  $-V_{out}$  via S2 and S4, and  $C_r2$  is storing  $C_p2$ 's charge. In the interval that S1 and S3 are closed,  $C_p1$  pumps the junction of D1 and D2 above  $V^+$ , while  $C_p2$  is refreshed from  $V^+$ .



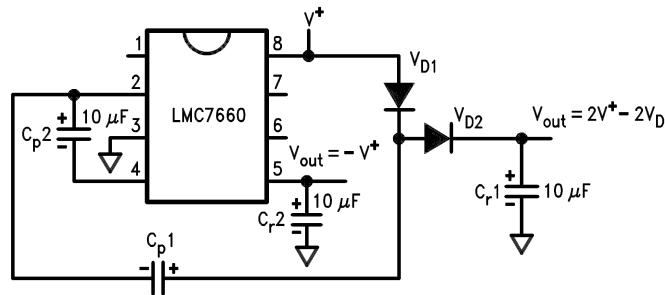
00913612

FIGURE 8. Split  $V^+$  in Half



00913613

FIGURE 9. Positive Voltage Multiplier



00913614

FIGURE 10. Combined Negative Converter and Positive Multiplier

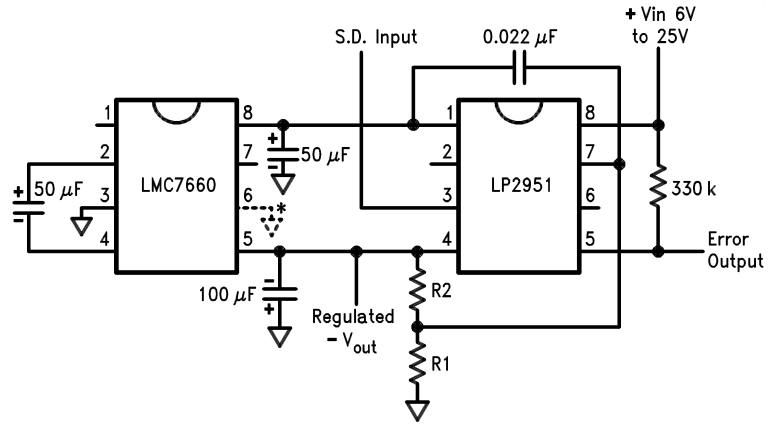
### THERMOMETER SPANS 180°C

Using the combined negative and positive multiplier of *Figure 11* with an LM35 it is possible to make a  $\mu$ Power thermometer that spans a 180°C temperature range. The LM35 temperature sensor has an output sensitivity of 10 mV/°C, while drawing only 50  $\mu$ A of quiescent current. In order for

the LM35 to measure negative temperatures, a pull down to a negative voltage is required. *Figure 11* shows a thermometer circuit for measuring temperatures from  $-55^\circ\text{C}$  to  $+125^\circ\text{C}$  and requiring only two 1.5V cells. End of battery life can be extended by replacing the up converter diodes with Schottky's.



Typical Applications (Continued)



00913617

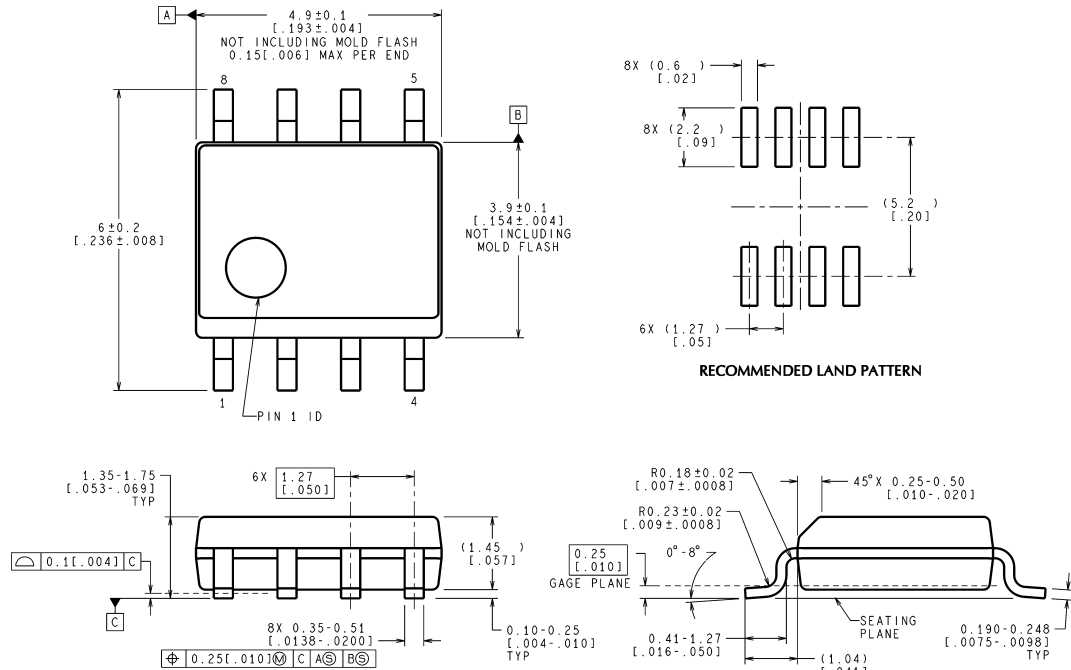
$$V_{out} = V_{ref} \left( 1 + \frac{R1}{R2} \right)$$

$V_{ref} = 1.235V$   
 \*Low voltage operation

FIGURE 13. LMC7660 and LP2951 Make a Negative Adjustable Regulator

**Physical Dimensions** inches (millimeters)

unless otherwise noted

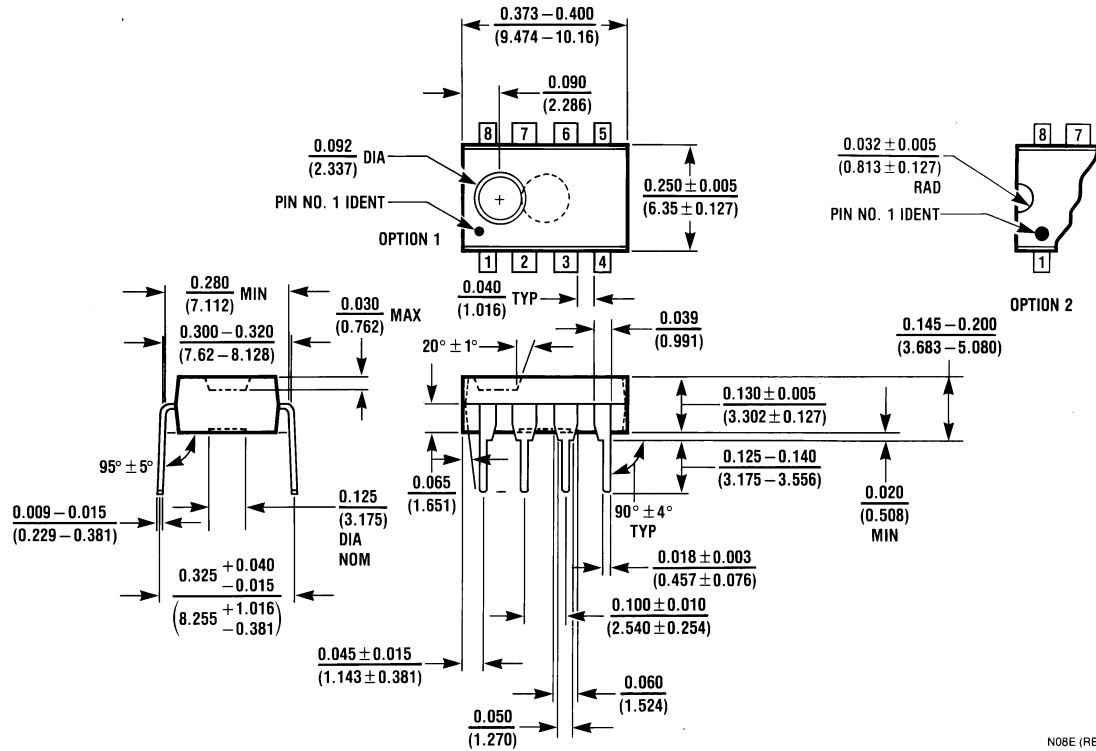


CONTROLLING DIMENSION IS MILLIMETER  
 VALUES IN [ ] ARE INCHES  
 DIMENSIONS IN ( ) FOR REFERENCE ONLY

M08A (Rev K)

**Molded Small Outline Package (M)**  
**Order Number LMC7660IM**  
**NS Package Number M08A**

**Physical Dimensions** inches (millimeters) unless otherwise noted (Continued)



**Molded Dual-In-Line Package (N)**  
**Order Number LMC7660IN**  
**NS Package Number N08E**

N08E (REV F)

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.

For the most current product information visit us at [www.national.com](http://www.national.com).


**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.

**BANNED SUBSTANCE COMPLIANCE**

National Semiconductor manufactures products and uses packing materials that meet the provisions of the Customer Products Stewardship Specification (CSP-9-111C2) and the Banned Substances and Materials of Interest Specification (CSP-9-111S2) and contain no "Banned Substances" as defined in CSP-9-111S2.

 **National Semiconductor**  
**Americas Customer Support Center**  
 Email: [new.feedback@nsc.com](mailto:new.feedback@nsc.com)  
 Tel: 1-800-272-9959

**National Semiconductor**  
**Europe Customer Support Center**  
 Fax: +49 (0) 180-530 85 86  
 Email: [europe.support@nsc.com](mailto: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 Support Center**  
 Email: [ap.support@nsc.com](mailto:ap.support@nsc.com)

**National Semiconductor**  
**Japan Customer Support Center**  
 Fax: 81-3-5639-7507  
 Email: [jpn.feedback@nsc.com](mailto:jpn.feedback@nsc.com)  
 Tel: 81-3-5639-7560

## 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