

# LM2687

## Low Noise Regulated Switched Capacitor Voltage Inverter

### General Description

The LM2687 CMOS Negative Regulated Switched Capacitor Voltage Inverter delivers a very low noise adjustable output for an input voltage in the range of +2.7V to +5.5V. Four low cost capacitors are used in this circuit to provide up to 10mA of output current. The regulated output for the LM2687 is adjustable between -1.5V and -5.2V. The LM2687 operates at 100 kHz (typical) switching frequency to reduce output resistance and voltage ripple. With an operating current of only 500  $\mu$ A (charge pump power efficiency greater than 90% with most loads) and 0.05  $\mu$ A typical shutdown current, the LM2687 provides ideal performance for cellular phone power amplifier bias and other low current, low noise negative voltage needs. The device comes in a small 8-pin MSOP package.

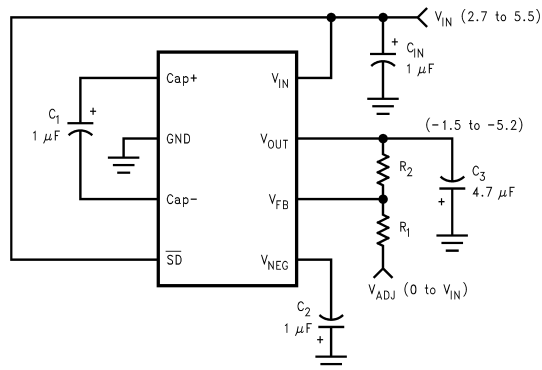
### Features

- Inverts and regulates the input supply voltage
- Small MSOP-8 package
- 91% typical charge pump power efficiency at 10mA
- Low output ripple (1mV typical)
- Shutdown lowers Quiescent current to 0.05  $\mu$ A (typical)

### Applications

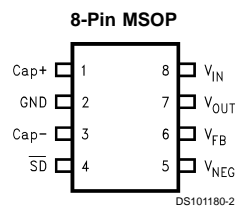
- Wireless Communication Systems
- Cellular Phone Power Amplifier Biasing
- Interface Power Supplies
- Handheld Instrumentation
- Laptop Computers and PDA's

### Typical Application Circuit



DS101180-1

### Connection Diagram



## Ordering Information

Device Order Number	Package Number	Package Marking*	Supplies As
LM2687MM	MUA08A	S12A	Tape and Reel (1000 units/reel)
LM2687MMX	MUA08A	S12A	Tape and Reel (3500 units/reel)

**Note:** \* The small physical size of the MSOP-8 package does not allow for the full part number marking. Devices will be marked with the designation shown in the column Package Marking.

## Pin Description

Pin No.	Name	Function
1	Cap+	Positive terminal for C <sub>1</sub> .
2	GND	Ground.
3	Cap-	Negative terminal for C <sub>1</sub> .
4	$\overline{SD}$	Active low, logic-level shutdown input.
5	V <sub>NEG</sub>	Negative unregulated output voltage.
6	V <sub>FB</sub>	Feedback input. Connect V <sub>FB</sub> to an external resistor divider between V <sub>OUT</sub> and a positive adjust voltage V <sub>ADJ</sub> ( $0 \leq V_{ADJ} \leq V_{IN}$ ). <b>DO NOT</b> leave unconnected.
7	V <sub>OUT</sub>	Regulated negative output voltage.
8	V <sub>IN</sub>	Positive power supply input.

## 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 ( $V_{IN}$ to GND or GND to OUT)	+ 5.8V
$\overline{SD}$	(GND - 0.3V) to ( $V_{IN} + 0.3V$ )
$V_{NEG}$ and $V_{OUT}$ Continuous Output Current	10mA
$V_{OUT}$ Short-Circuit Duration to GND (Note 2)	1 sec.
Continuous Power Dissipation ( $T_A = 25^\circ\text{C}$ ) (Note 3)	600mW

$T_{JMAX}$ (Note 3)	150°C
$\theta_{JA}$ (Note 3)	250°C/W
Operating Input Voltage Range	2.7V to 5.5V
Operating Output Current Range	0mA to 10mA
Operating Ambient Temp. Range	-40°C to 85°C
Operating Junction Temp. Range	-40°C to 110°C
Storage Temperature	-65°C to 150°C
Lead Temp. (Soldering, 10 sec.)	300°C
ESD Rating (Note 4)	2kV

## Electrical Characteristics

Limits with standard typeface apply for  $T_J = 25^\circ\text{C}$ , and limits in **boldface type** apply over the full temperature range. Unless otherwise specified  $V_{IN} = 3.6V$ ,  $C_1 = C_2 = 1\mu\text{F}$ ,  $C_3 = 10\mu\text{F}$ .

Symbol	Parameter	Conditions	Min	Typ	Max	Units
$I_Q$	Supply Current	Open Circuit, No Load		500	<b>950</b>	$\mu\text{A}$
$I_{SD}$	Shutdown Supply Current			0.05	1	$\mu\text{A}$
$F_{SW}$	Switching Frequency (Note 5)	$2.7V \leq V_{IN} \leq 5.5V$ $V_{IN} = 3.6V$	<b>50</b> <b>60</b>	110 105	<b>180</b> <b>170</b>	kHz
$\eta_{POWER}$	Power Efficiency at $V_{NEG}$	$I_L = 3.6\text{mA}$ $I_L = 10\text{mA}$		94 91		%
$T_{START}$	Start Up time	(Note 6)		120	600	$\mu\text{s}$
$R_{NEG}$	Output Resistance to $V_{NEG}$	(Note 7)		30		$\Omega$
$V_R$	Output Voltage Ripple (Note 8)	$I_L = 2.5\text{mA}$ , $V_{OUT} = -2.7V$ $I_L = 10\text{mA}$ , $V_{OUT} = -3.8V$		1 2		mV
$V_{FB}$	Feedback Pin Reference Voltage	$I_L = 2.5\text{mA}$ (Note 9)	<b>-1.25</b>	-1.20	<b>-1.15</b>	V
$V_{OUT}$	Adjustable Output Voltage	$5.5V \geq V_{IN} \geq 2.7V$ , $2.5\text{mA} \geq I_L$ $5.5V \geq V_{IN} \geq 3.0V$ , $10\text{mA} \geq I_L \geq 0\text{mA}$	<b>-(<math>V_{IN} - 0.3V</math>)</b> <b>-(<math>V_{IN} - 1.2V</math>)</b>			V
	Load Regulation	0 to 10mA, $V_{OUT} = -2.4V$		5		mV/mA
	Line Regulation	$5.5V \geq V_{IN} \geq 2.7V$ , $I_L = 2.5\text{mA}$		1		mV/V
$V_{IH}$	Shutdown Pin Input Voltage High	$5.5V \geq V_{IN} \geq 2.7V$	<b>2.2</b>			V
$V_{IL}$	Shutdown Pin Input Voltage Low	$5.5V \geq V_{IN} \geq 2.7V$			<b>0.5</b>	V

**Note 1:** Absolute Maximum Ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its rated operating conditions.

**Note 2:** OUT may be shorted to GND for one second without damage. However, shorting OUT to  $V_{IN}$  may damage the device and must be avoided. Also, for temperatures above  $T_A = 85^\circ\text{C}$ , OUT must not be shorted to GND or  $V_{IN}$  or device may be damaged.

**Note 3:** The maximum power dissipation must be de-rated at elevated temperatures and is limited by  $T_{JMAX}$  (maximum junction temperature),  $T_A$  (ambient temperature) and  $\theta_{JA}$  (junction-to-ambient thermal resistance). The maximum power dissipation at any temperature is:

$$PD_{Diss_{MAX}} = (T_{JMAX} - T_A) / \theta_{JA} \text{ up to the value listed in the Absolute Maximum Ratings.}$$

**Note 4:** Rating is for the human body model, a 100pF capacitor discharged through a 1.5 k $\Omega$  resistor into each pin.

**Note 5:** The output switches operate at one half the oscillator frequency,  $f_{OSC} = 2f_{SW}$ .

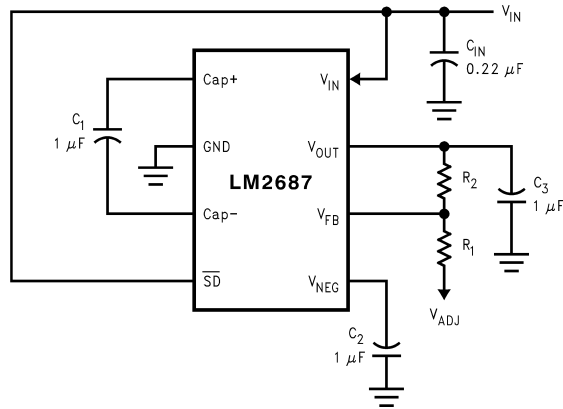
**Note 6:** All capacitors are 1 $\mu\text{F}$ .

**Note 7:** Current drawn from  $V_{NEG}$  pin decreases power efficiency and will increase output voltage ripple.

**Note 8:** In the test circuit, capacitors  $C_1$  and  $C_2$  are 1 $\mu\text{F}$ ,  $C_3 = 10\mu\text{F}$ , 0.30 $\Omega$  maximum ESR capacitors. Capacitors with higher ESR will increase output resistance, increase output voltage ripple, and reduce efficiency.

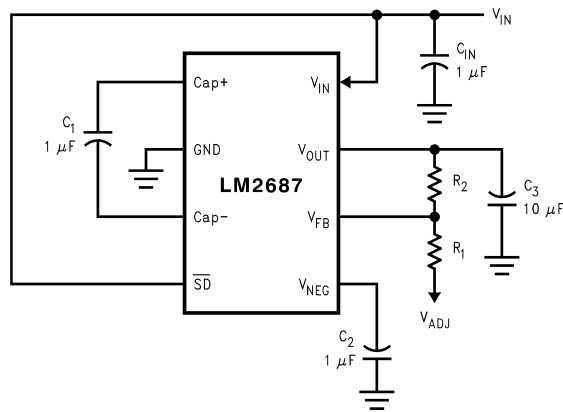
**Note 9:** The feedback resistors R1 and R2 are 200k $\Omega$  resistors.

## Electrical Characteristics (Continued)



DS101180-21

FIGURE 1. Standard Application Circuit for Minimum Capacitance Values

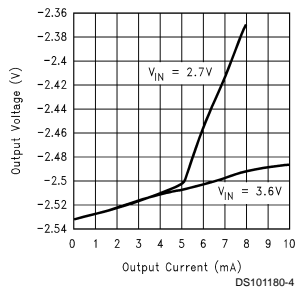


DS101180-22

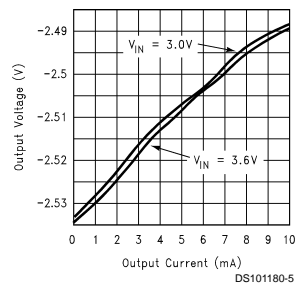
FIGURE 2. Standard Application Circuit for Low Output Noise

## Typical Performance Characteristics Unless otherwise specified, $T_A = 25^\circ\text{C}$ , $V_{\text{OUT}} = -2.5\text{V}$ .

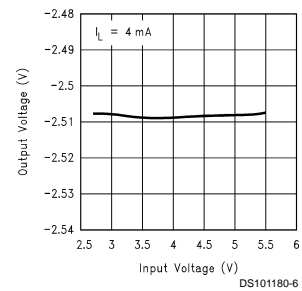
Output Voltage vs. Output Current  
Figure 2



Output Voltage vs. Output Current  
Figure 1

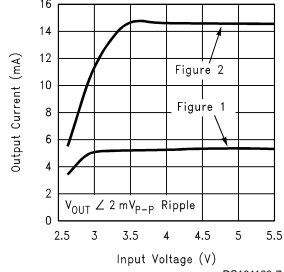


Output Voltage vs. Input Voltage

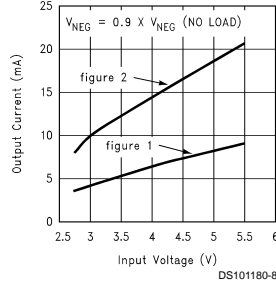


**Typical Performance Characteristics** Unless otherwise specified,  $T_A = 25^\circ\text{C}$ ,  $V_{\text{OUT}} = -2.5\text{V}$ . (Continued)

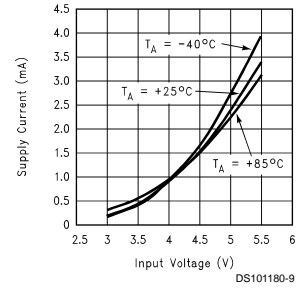
**Maximum Output Current vs. Input Voltage**



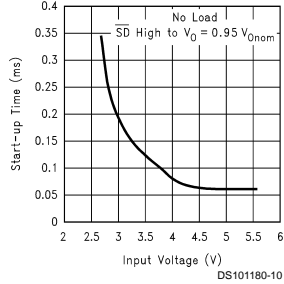
**Maximum  $V_{\text{NEG}}$  Current vs. Input Voltage**



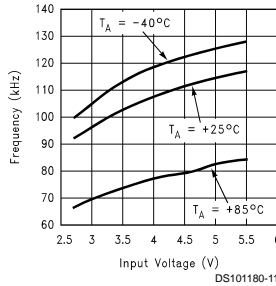
**No Load Supply Current vs. Input Voltage**



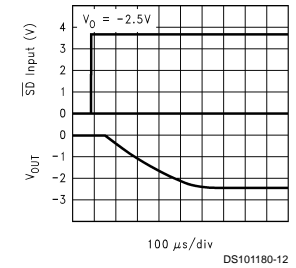
**Start-Up Time vs. Input Voltage**  
Figure 1



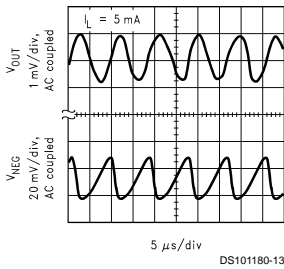
**Switching Frequency vs. Input Voltage**



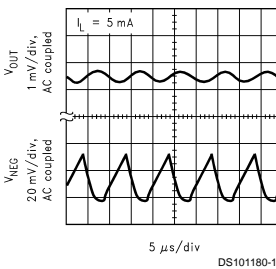
**Start-Up from Shutdown (no load)**  
Figure 2



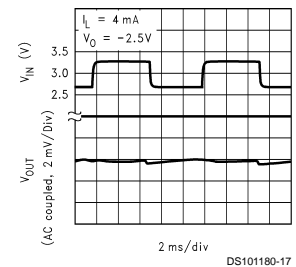
**Output Ripple**  
Figure 1



**Output Ripple**  
Figure 2

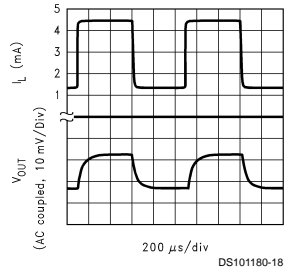


**Line Transient Response**

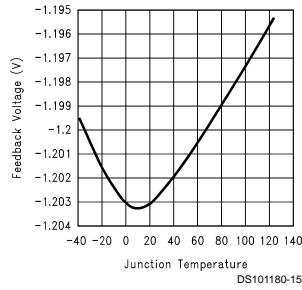


**Typical Performance Characteristics** Unless otherwise specified,  $T_A = 25^\circ\text{C}$ ,  $V_{OUT} = -2.5\text{V}$ . (Continued)

**Load Transient Response**

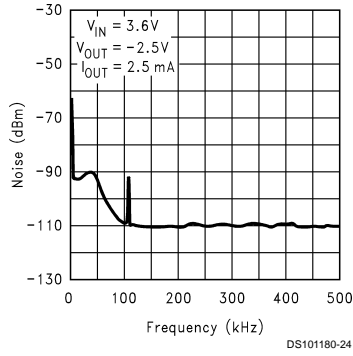


**$V_{FB}$  vs. Temperature**



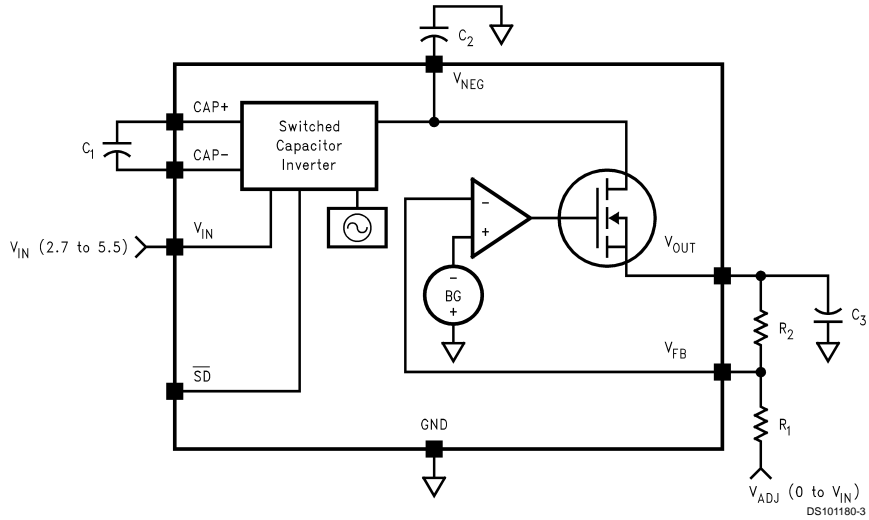
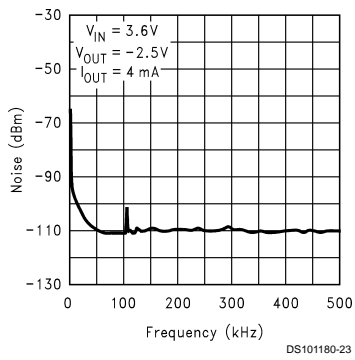
**Output Noise Spectrum**

**Figure 1**



**Output Noise Spectrum**

**Figure 2**



**FIGURE 3. Functional Block Diagram**

## Device Description

The LM2687 is an inverting, regulated charge-pump power converter. It features low noise, small physical size, and is simple to use. It is an ideal solution for biasing GaAsFET devices such as power amplifier modules found in portable devices and cellular phones.

A switched capacitor charge-pump circuit is used to invert the input voltage  $V_{IN}$  to its corresponding negative value which is seen at  $V_{NEG}$ . This voltage is regulated by a low dropout linear regulator at  $V_{OUT}$  (Figure 3). The output voltage can be regulated anywhere from  $-1.5V$  to  $-5.2V$  and is determined by a pair of feedback resistors (see Setting the Output Voltage). The PSRR of the linear regulator reduces the output voltage ripple produced by the charge-pump inverter to  $1mV_{P-P}$  (typical) at the output  $V_{OUT}$ . The regulator also attenuates noise from the incoming supply due to its high PSRR.

## Shutdown

The LM2687 features a logic-level shutdown feature. The function is active-low and will reduce the supply current to  $0.05\mu A$  (typical) when engaged. When shutdown is active  $V_{OUT}$  and  $V_{NEG}$  are switched to ground.

## Application Information

### Setting the Output Voltage

The output voltage on the LM2687 is set by using a resistor divider between the output, the feedback pin, and an arbitrary voltage  $V_{ADJ}$  (Figure 3).  $V_{ADJ}$  can range from GND to any positive voltage up to  $V_{IN}$ .  $V_{ADJ}$  is usually chosen to be GND and should not be connected to a different voltage unless it is well regulated so the output will stay constant. The feedback pin is held at a constant voltage  $V_{FB}$  which equals  $-1.2V$ . The output voltage can be selected using the equation:

$$V_{OUT} = \frac{R_2}{R_1} (V_{FB} - V_{ADJ}) + V_{FB}$$

The current into the feedback pin  $I_{FB}$  is in the range of  $10nA$  to  $100nA$ . Therefore using a value of  $500k\Omega$  or smaller for  $R_1$  should make this current of little concern when setting the output voltage. For best accuracy, use resistors with 1% or better tolerance.

### Capacitor Selection

Selecting the right capacitors for your circuit is important. The capacitors affect the output resistance of the charge-pump, the output voltage ripple, and the overall dropout voltage ( $V_{IN}-|V_{OUT}|$ ) of the circuit. The output resistance of the charge-pump inverter is:

$$R_{NEG} = R_{SW} + 4ESR_{C1} + ESR_{C2} + \frac{1}{f_{SW} \times C1}$$

The switching frequency is fixed at  $100kHz$  and  $R_{SW}$  (the combined resistance of the internal switches) is typically  $10\Omega$ . It is clear from this equation that low ESR capacitors are desirable and that larger values of  $C_1$  will further reduce the output resistance. The output resistance of the entire circuit (in dropout) is:

$$R_{OUT} = R_{NEG} + R_{regulator}$$

$R_{regulator}$  (the output impedance of the linear regulator) is approximately  $10\Omega$ . When the circuit is in regulation, the overall output resistance is equal to the linear regulator load regulation ( $5mV/mA$ ). The dropout voltage is therefore affected by the capacitors used since it is simply defined as  $I_{OUT} \times R_{OUT}$ . A larger value of capacitor and lower ESR for  $C_2$  will lower the output voltage ripple of the charge-pump. This ripple will then be subject to the PSRR of the linear regulator and reduced at  $V_{OUT}$ . A larger value and lower ESR for  $C_3$  will further reduce this ripple.

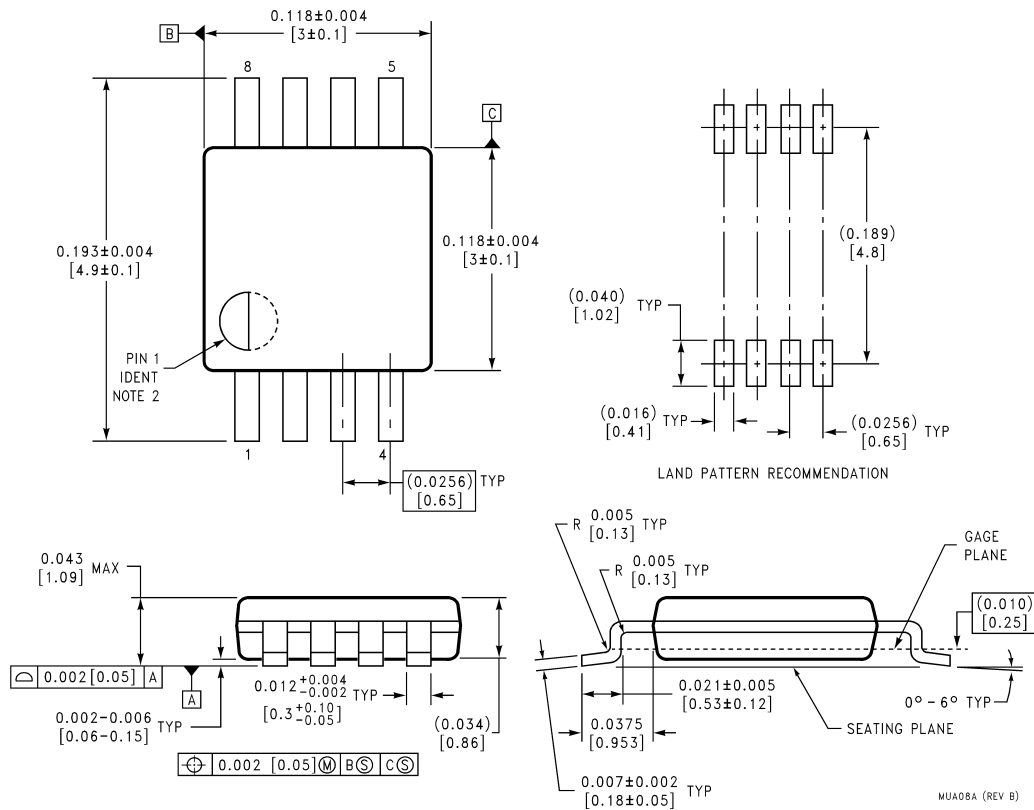
The Low Dropout Linear Regulator uses an N-channel FET device which behaves similarly to an NPN device. Because of this and the internal compensation there are no strict ESR requirements for the output capacitor to maintain stability. Using the minimum recommended values will ensure stability under all conditions.

In summation, larger value capacitors with lower ESR will give the lowest output noise and ripple.  $C_1$ ,  $C_2$ , and  $C_3$  should be  $1.0\mu F$  minimum with less than  $0.3\Omega$  ESR. Larger values may be used for any or all capacitors. All capacitors should be either ceramic, surface-mount chip tantalum, or polymer electrolytic.

### Output Noise and Ripple

Low output noise and output voltage ripple are two of the attractive features of the LM2687. Because they are small, the noise and ripple ( $1mV$  typ.) can be hard to measure accurately. Ground loop error between the circuit and the oscilloscope caused by the switching of the charge-pump produces ground currents in the probe wires. This causes sharp voltage spikes on the oscilloscope waveform. To reduce this error measure, the output directly at the output capacitor ( $C_3$ ) and use the shortest wires possible. Also, do not use the ground lead on the probe. Take the tip cover off of the probe and touch the grounding ring of the probe directly to the ground terminal of  $C_3$ . This should give the most accurate reading of the actual output waveform.

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



**MSOP-8 Package**  
**8-Lead Mini SO-8 (MM)**  
 For Ordering, Refer to Ordering Information Table  
 NS Package Number MUA08A

**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  
 Tel: 1-800-272-9959  
 Fax: 1-800-737-7018  
 Email: support@nsc.com  
 www.national.com

**National Semiconductor Europe**  
 Fax: +49 (0) 1 80-530 85 86  
 Email: europe.support@nsc.com  
 Deutsch Tel: +49 (0) 1 80-530 85 85  
 English Tel: +49 (0) 1 80-532 78 32  
 Français Tel: +49 (0) 1 80-532 93 58  
 Italiano Tel: +49 (0) 1 80-534 16 80

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

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