

# LM2687

*LM2687 Low Noise Regulated Switched Capacitor Voltage Inverter*



Literature Number: SNVS060D

# 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 or LLP package.

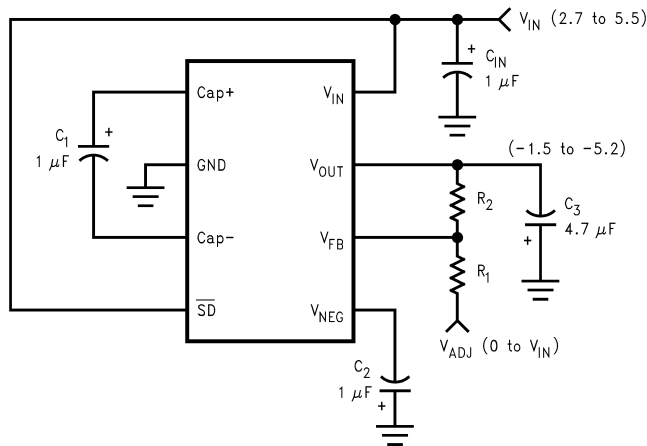
### Features

- Inverts and regulates the input supply voltage
- Small MSOP-8 or LLP-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

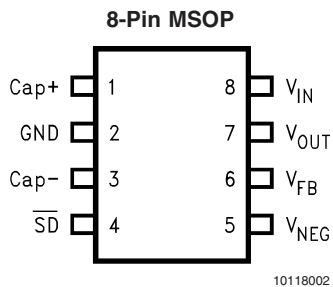
- Wireless Communication Systems
- Cellular Phone Power Amplifier Biasing
- Interface Power Supplies
- Handheld Instrumentation
- Laptop Computers and PDA's

### Typical Application Circuit

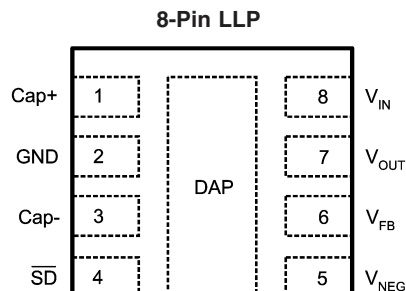


10118001

### Connection Diagrams



10118002



10118025

## Ordering Information for MSOP Package

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)

## Ordering Information for LLP Package

Device Order Number	Package Number	Package Marking*	Supplies As
LM2687LD	LDA08A	L050B	Tape and Reel (1000 units/reel)
LM2687LDX	LDA08A	L050B	Tape and Reel (3500 units/reel)

**Note:** \* The small physical sizes of the MSOP-8 and LLP-8 packages do 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 $C_1$ .
2	GND	Ground.
3	Cap-	Negative terminal for $C_1$ .
4	$\overline{SD}$	Active low, logic-level shutdown input.
5	$V_{NEG}$	Negative unregulated output voltage.
6	$V_{FB}$	Feedback input. Connect $V_{FB}$ to an external resistor divider between $V_{OUT}$ and a positive adjust voltage $V_{ADJ}$ ( $0 \leq V_{ADJ} \leq V_{IN}$ ). <b>DO NOT</b> leave unconnected.
7	$V_{OUT}$	Regulated negative output voltage.
8	$V_{IN}$	Positive power supply input.
DAP	Die Attach Pad	LLP package only. Connect this pad to $V_{NEG}$ .

## 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.

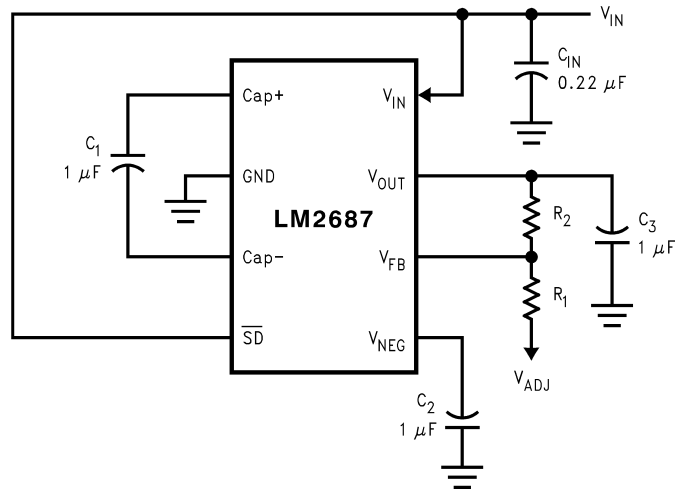
**Note 5:** The output switches operate at one half the oscillator frequency,  $f_{OSC} = 2f_{SW}$ .

**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.

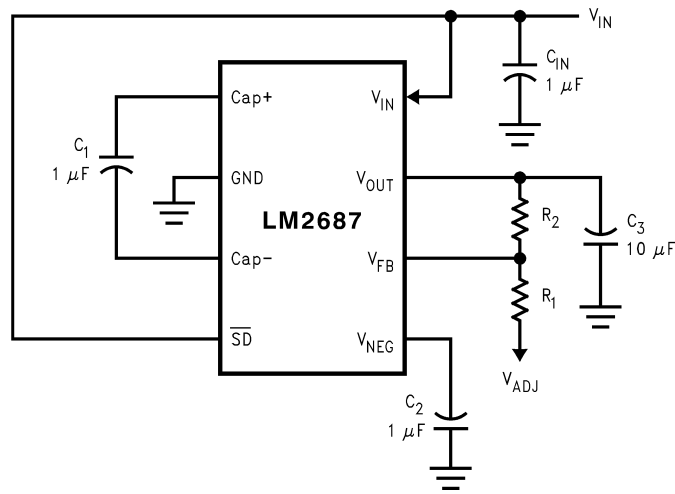
**Note 8:** In the test circuit, capacitors  $C_1$  and  $C_2$  are 1 $\mu\text{F}$ ,  $C_3 = 10\mu\text{F}$ , 0.30 $\Omega$  maximum ESR capacitors. Capacitors with higher ESR will increase output resistance, increase output voltage ripple, and reduce efficiency.

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



10118021

FIGURE 1. Standard Application Circuit for Minimum Capacitance Values

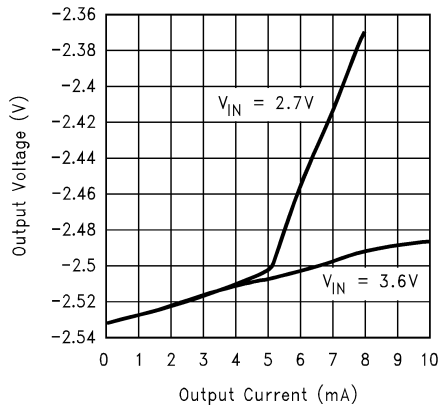


10118022

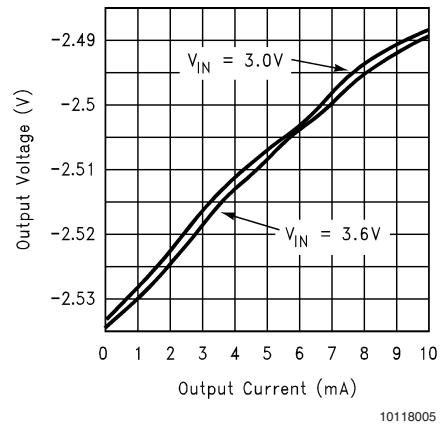
FIGURE 2. Standard Application Circuit for Low Output Noise

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

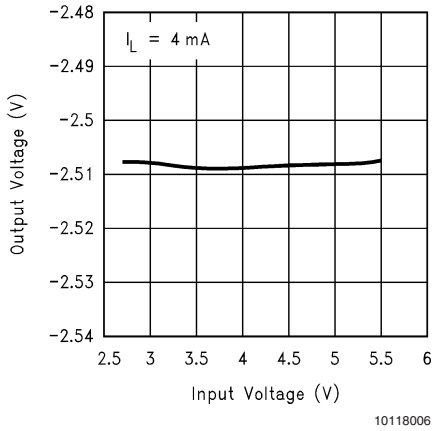
**Output Voltage vs. Output Current**  
**Figure 2**



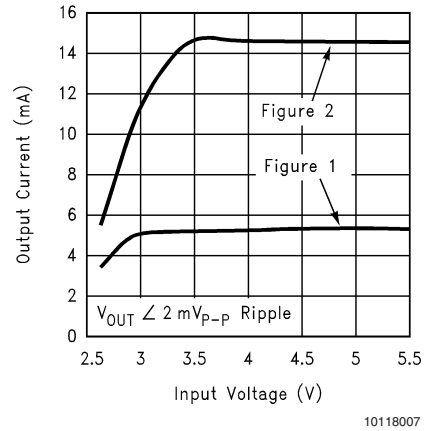
**Output Voltage vs. Output Current**  
**Figure 1**



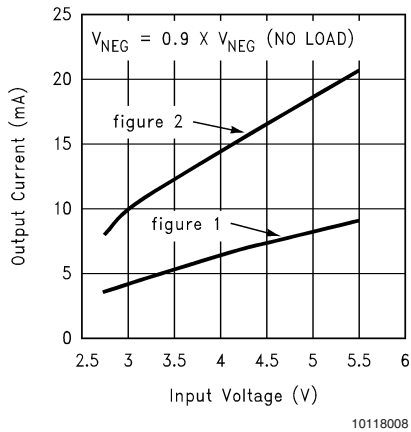
**Output Voltage vs. Input Voltage**



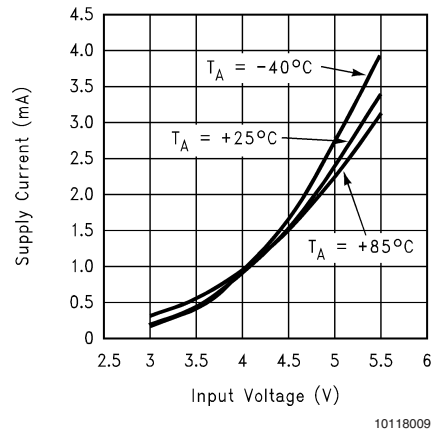
**Maximum Output Current vs. Input Voltage**



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



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

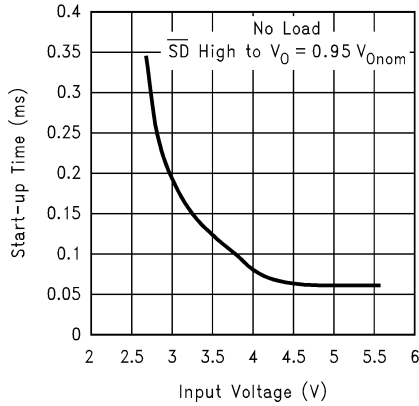


# Typical Performance Characteristics

Unless otherwise specified,  $T_A = 25^\circ\text{C}$ ,

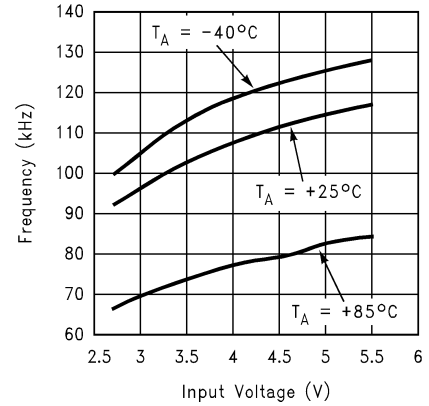
$V_{OUT} = -2.5\text{V}$ . (Continued)

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



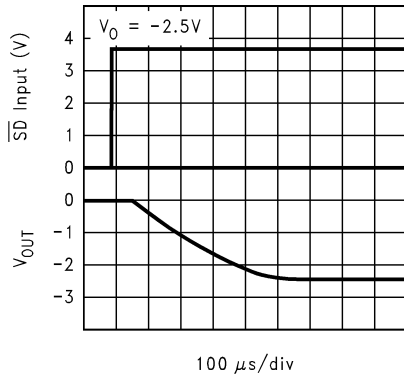
10118010

**Switching Frequency vs. Input Voltage**



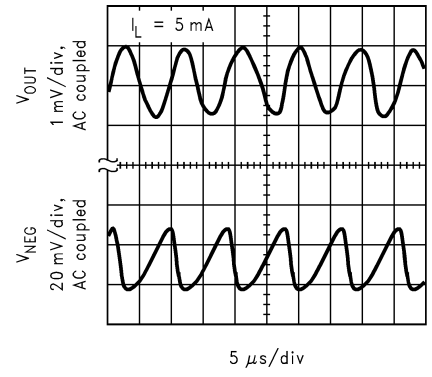
10118011

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



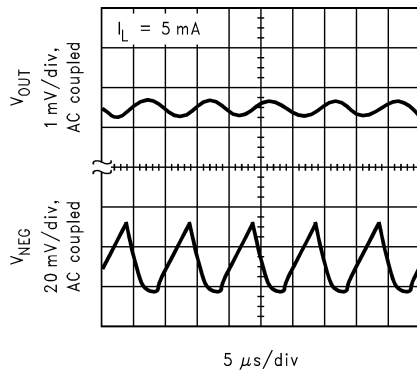
10118012

**Output Ripple**  
Figure 1



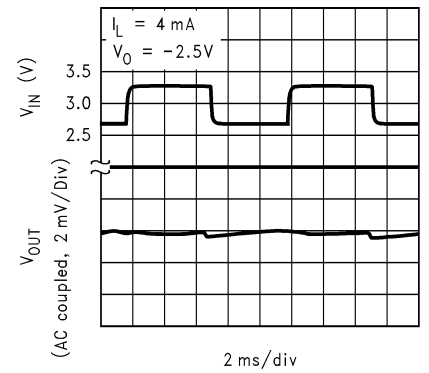
10118013

**Output Ripple**  
Figure 2



10118014

**Line Transient Response**

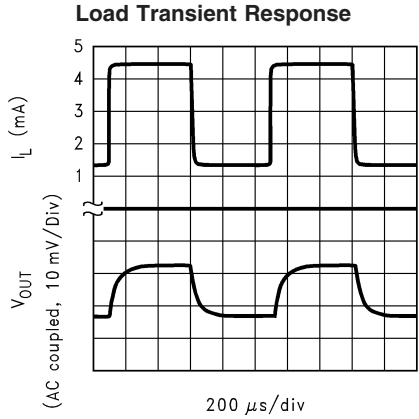


10118017

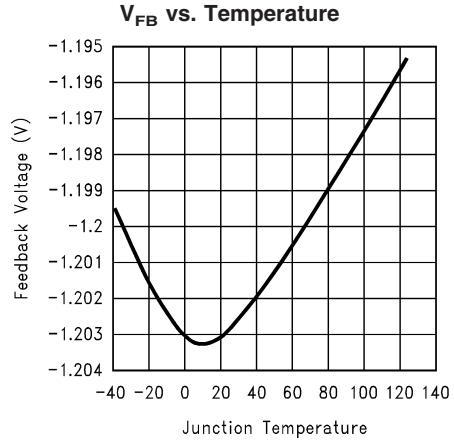
# Typical Performance Characteristics

Unless otherwise specified,  $T_A = 25^\circ\text{C}$ ,

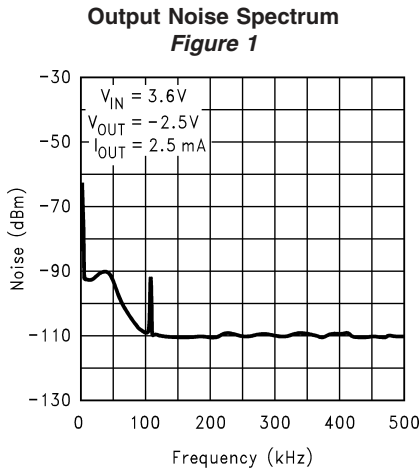
$V_{OUT} = -2.5\text{V}$ . (Continued)



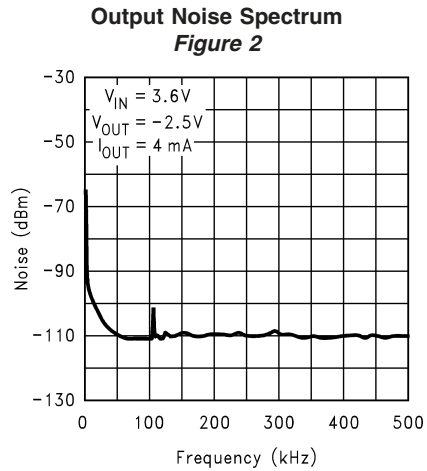
10118018



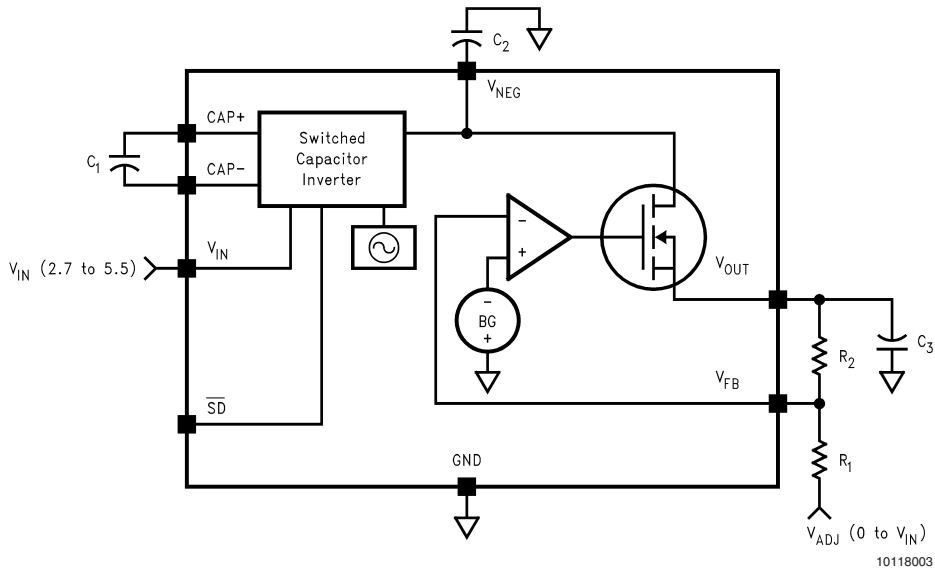
10118015



10118024



10118023



10118003



## 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.

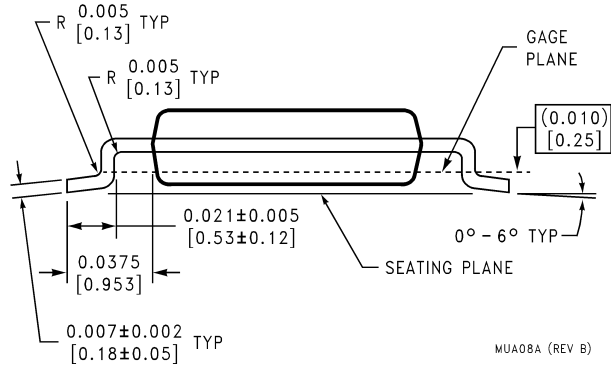
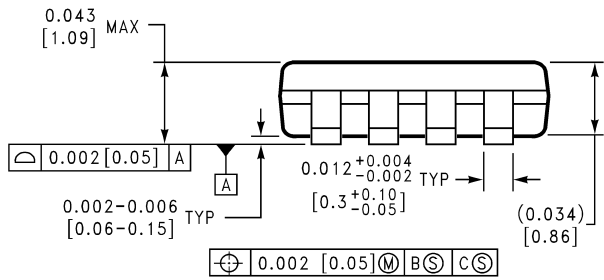
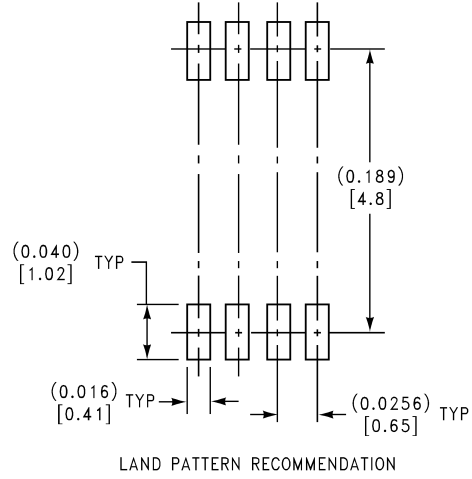
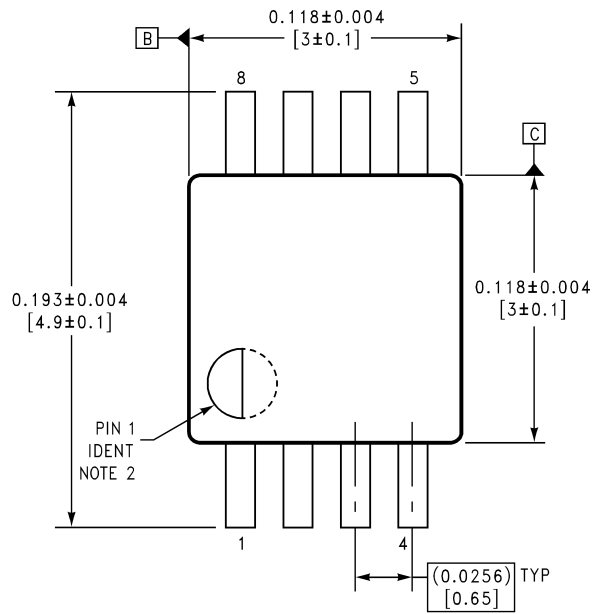
The Low Dropout Linear Regulator uses an N-channel FET device which behaves similarly to an NPN device. Because of this and the internal compensation there are no strict ESR requirements for the output capacitor to maintain stability. Using the minimum recommended values will ensure stability under all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

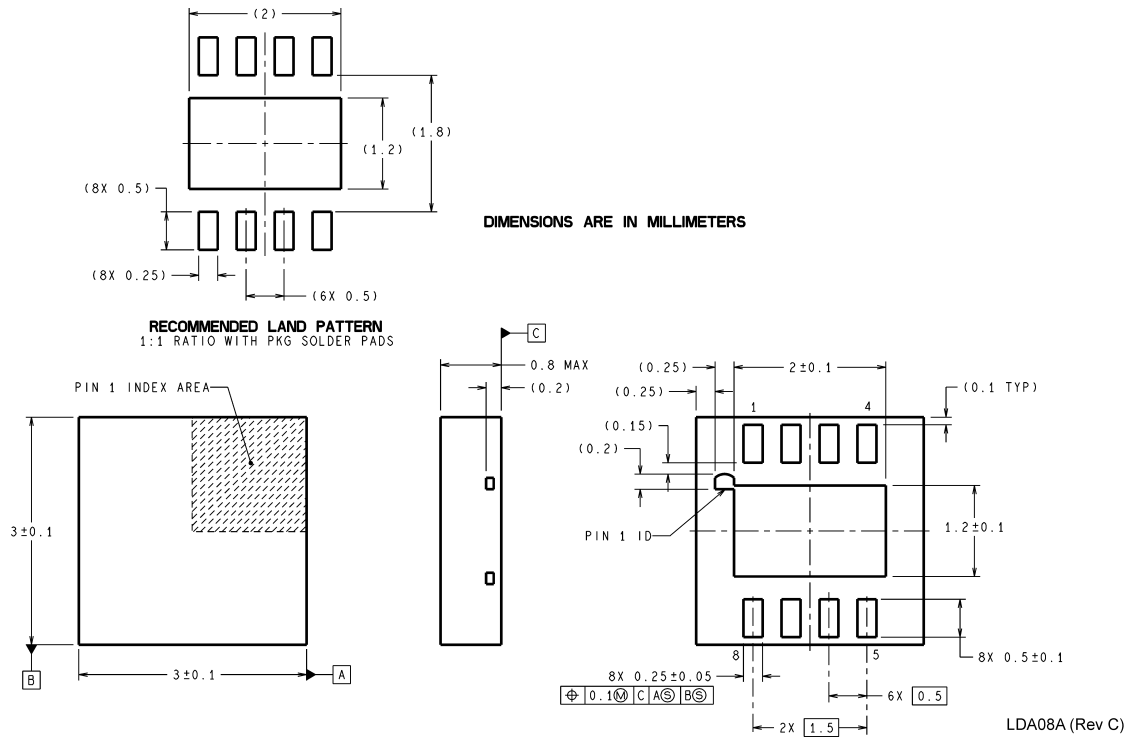
**Physical Dimensions** inches (millimeters) unless otherwise noted



MUA08A (REV B)

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

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



**LLP-8 Package**  
**8-Lead Leadless Leadframe Package (LD)**  
For Ordering, Refer to Ordering Information Table  
NS Package Number LDA08A

**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**  
Americas Customer  
Support Center  
Email: new.feedback@nsc.com  
Tel: 1-800-272-9959

www.national.com

**National Semiconductor**  
Europe Customer Support Center  
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  
Support Center  
Fax: +65-6250 4466  
Email: ap.support@nsc.com  
Tel: +65-6254 4466

**National Semiconductor**  
Japan Customer Support Center  
Fax: 81-3-5639-7507  
Email: 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