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 µA (charge pump power efficiency greater than 90% with most loads) and 0.05 µA 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 µA (typical)

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

Typical Application Circuit

Connection Diagrams

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Ordering Information for MSOP Package

<table>
<thead>
<tr>
<th>Device Order Number</th>
<th>Package Number</th>
<th>Package Marking*</th>
<th>Supplies As</th>
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<tbody>
<tr>
<td>LM2687MM</td>
<td>MUA08A</td>
<td>S12A</td>
<td>Tape and Reel (1000 units/reel)</td>
</tr>
<tr>
<td>LM2687MMX</td>
<td>MUA08A</td>
<td>S12A</td>
<td>Tape and Reel (3500 units/reel)</td>
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Ordering Information for LLP Package

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<td>LM2687LD</td>
<td>LDA08A</td>
<td>L050B</td>
<td>Tape and Reel (1000 units/reel)</td>
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<tr>
<td>LM2687LDX</td>
<td>LDA08A</td>
<td>L050B</td>
<td>Tape and Reel (3500 units/reel)</td>
</tr>
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</table>

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

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Cap+</td>
<td>Positive terminal for C&lt;sub&gt;1&lt;/sub&gt;.</td>
</tr>
<tr>
<td>2</td>
<td>GND</td>
<td>Ground.</td>
</tr>
<tr>
<td>3</td>
<td>Cap−</td>
<td>Negative terminal for C&lt;sub&gt;1&lt;/sub&gt;.</td>
</tr>
<tr>
<td>4</td>
<td>SD</td>
<td>Active low, logic-level shutdown input.</td>
</tr>
<tr>
<td>5</td>
<td>V&lt;sub&gt;NEG&lt;/sub&gt;</td>
<td>Negative unregulated output voltage.</td>
</tr>
<tr>
<td>6</td>
<td>V&lt;sub&gt;FB&lt;/sub&gt;</td>
<td>Feedback input. Connect V&lt;sub&gt;FB&lt;/sub&gt; to an external resistor divider between V&lt;sub&gt;OUT&lt;/sub&gt; and a positive adjust voltage V&lt;sub&gt;ADJ&lt;/sub&gt; (0≤V&lt;sub&gt;ADJ&lt;/sub&gt;≤V&lt;sub&gt;IN&lt;/sub&gt;). <strong>DO NOT</strong> leave unconnected.</td>
</tr>
<tr>
<td>7</td>
<td>V&lt;sub&gt;OUT&lt;/sub&gt;</td>
<td>Regulated negative output voltage.</td>
</tr>
<tr>
<td>8</td>
<td>V&lt;sub&gt;IN&lt;/sub&gt;</td>
<td>Positive power supply input.</td>
</tr>
<tr>
<td></td>
<td>DAP</td>
<td>Die Attach Pad LLP package only. Connect this pad to V&lt;sub&gt;NEG&lt;/sub&gt;.</td>
</tr>
</tbody>
</table>
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\text{IN} to GND or GND to OUT) + 5.8V

SD (GND − 0.3V) to (V\text{IN} + 0.3V)

V\text{NEG} and V\text{OUT} Continuous Output Current 10mA

V\text{OUT} Short-Circuit Duration to GND (Note 2) 1 sec.

Continuous Power Dissipation (T\text{A} = 25˚C) (Note 3) 600mW

T\text{JMAX} (Note 3) 150˚C

θ\text{JA} (Note 3) 250˚C/W

Operating Input Voltage Range 2.7V to 5.5V

Operating Output Current Range 0mA to 10mA

Operating Ambient −40˚C to 85˚C

Temp. Range

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\text{J} = 25˚C, and limits in boldface type apply over the full temperature range. Unless otherwise specified V\text{IN} = 3.6V, C\text{1} = C\text{2} = 1µF, C\text{3} = 10µF.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
</tr>
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<tbody>
<tr>
<td>I\text{Q}</td>
<td>Supply Current</td>
<td>Open Circuit, No Load</td>
<td>500</td>
<td>950</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>I\text{SD}</td>
<td>Shutdown Supply Current</td>
<td></td>
<td>0.05</td>
<td>1</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>F\text{SW}</td>
<td>Switching Frequency</td>
<td>2.7V ≤ V\text{IN} ≤ 5.5V</td>
<td>50</td>
<td>110</td>
<td>180</td>
<td>kHz</td>
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<tr>
<td>η\text{POWER}</td>
<td>Power Efficiency at V\text{NEG}</td>
<td>IL = 3.6mA</td>
<td>94</td>
<td>91</td>
<td>%</td>
<td></td>
</tr>
<tr>
<td>η\text{POWER}</td>
<td>Power Efficiency at V\text{NEG}</td>
<td>IL = 10mA</td>
<td>60</td>
<td>105</td>
<td>170</td>
<td>kHz</td>
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<td>T\text{START}</td>
<td>Start Up time</td>
<td>V\text{NEG}</td>
<td>120</td>
<td>600</td>
<td>µs</td>
<td></td>
</tr>
<tr>
<td>R\text{NEG}</td>
<td>Output Resistance to V\text{NEG}</td>
<td>(Note 7)</td>
<td>30</td>
<td></td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td>V\text{FB}</td>
<td>Feedback Pin Reference Voltage</td>
<td>IL = 2.5mA</td>
<td>−1.25</td>
<td>−1.20</td>
<td>−1.15</td>
<td>V</td>
</tr>
<tr>
<td>V\text{OUT}</td>
<td>Adjustable Output Voltage</td>
<td>5.5V ≥ V\text{IN} ≥ 2.7V, 2.5mA ≥ IL ≥ 0mA</td>
<td>(V\text{IN} −0.3V)</td>
<td>(V\text{IN} −1.2V)</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.5V ≥ V\text{IN} ≥ 3.0V, 10mA ≥ IL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(Note 8)</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V\text{IH}</td>
<td>Shutdown Pin Input Voltage High</td>
<td>5.5V ≥ V\text{IN} ≥ 2.7V</td>
<td>2.2</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>V\text{IL}</td>
<td>Shutdown Pin Input Voltage Low</td>
<td>5.5V ≥ V\text{IN} ≥ 2.7V</td>
<td>0.5</td>
<td></td>
<td>V</td>
<td></td>
</tr>
</tbody>
</table>

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\text{IN} may damage the device and must be avoided. Also, for temperatures above T\text{A} = 85˚C, OUT must not be shorted to GND or V\text{IN} or device may be damaged.

Note 3: The maximum power dissipation must be de-rated at elevated temperatures and is limited by T\text{JMAX} (maximum junction temperature), T\text{A} (ambient temperature) and θ\text{JA} (junction-to-ambient thermal resistance). The maximum power dissipation at any temperature is:

\[ P_{\text{Diss,MAX}} = \left( T_{\text{JMAX}} - T_{\text{A}} \right) / \theta_{\text{JA}} \]

Note 4: Rating is for the human body model, a 100pF capacitor discharged through a 1.5 kΩ resistor into each pin.

Note 5: The output switches operate at one half the oscillator frequency, f\text{OSC} = 2f\text{SW}.

Note 6: All capacitors are 1µF.

Note 7: Current drawn from V\text{NEG} pin decreases power efficiency and will increase output voltage ripple.

Note 8: In the test circuit, capacitors C\text{1} and C\text{2} are 1µF, C\text{3} = 10µF, 0.30Ω maximum ESR capacitors. Capacitors with higher ESR will increase output resistance, increase output voltage ripple, and reduce efficiency.

Note 9: The feedback resistors R\text{1} and R\text{2} are 200kΩ resistors.
FIGURE 1. Standard Application Circuit for Minimum Capacitance Values

FIGURE 2. Standard Application Circuit for Low Output Noise
Typical Performance Characteristics  
Unless otherwise specified, $T_A = 25^\circ C$, $V_{OUT} = -2.5V$. 

Output Voltage vs. Output Current

**Figure 2**

- $V_{IN} = 2.7V$
- $V_{IN} = 3.6V$

Output Voltage vs. Input Voltage

**Figure 2**

- $I_o = 4 \text{ mA}$

Maximum $V_{NEG}$ Current vs. Input Voltage

**Figure 2**

- $V_{NEG} = 0.9 \times V_{NEG}$ (NO LOAD)

No Load Supply Current vs. Input Voltage

**Figure 2**

- $T_A = -40^\circ C$
- $T_A = +25^\circ C$
- $T_A = +85^\circ C$

Maximum Output Current vs. Input Voltage

**Figure 2**

- $V_{OUT} \leq 2 \text{ mVp-p}$ Ripple

Output Current vs. Input Voltage

**Figure 2**
Typical Performance Characteristics

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

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

**Load Transient Response**

![Load Transient Response](image1)

**Output Noise Spectrum**

*Figure 1*

![Output Noise Spectrum](image2)

**Output Noise Spectrum**

*Figure 2*

![Output Noise Spectrum](image3)

**FIGURE 3. Functional Block Diagram**

![Functional Block Diagram](image4)
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 \(-1.5\)V to \(-5.2\)V 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 1mVP-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 0.05µA (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 \(-1.2\)V. 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 500kΩ 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 10Ω. 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 10Ω. When the circuit is in regulation, the overall output voltage 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 1µF minimum with less than 0.3Ω 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
Telephone: 1-800-272-9959

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