LM2787
Low Noise Regulated Switched Capacitor Voltage Inverter in micro SMD

General Description
The LM2787 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 LM2787 is adjustable between −1.5V and −5.2V. The LM2787 operates at 260 kHz (typical) switching frequency to reduce output resistance and voltage ripple. With an operating current of only 400 µA (charge pump power efficiency greater than 90% with most loads) and 0.05 µA typical shutdown current, the LM2787 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-Bump micro SMD package.

Features
- Inverts and regulates the input supply voltage
- Small 8-Bump micro SMD package
- 91% typical charge pump power efficiency at 10mA
- Low output ripple
- 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
### Ordering Information

<table>
<thead>
<tr>
<th>Device Order Number</th>
<th>Package Number</th>
<th>Package Marking</th>
<th>Supplies As</th>
</tr>
</thead>
<tbody>
<tr>
<td>LM2787BP</td>
<td>BPA08CCB</td>
<td>S8</td>
<td>Tape and Reel (250 units/reel)</td>
</tr>
<tr>
<td>LM2787BPX</td>
<td>BPA08CCB</td>
<td>S8</td>
<td>Tape and Reel (3000 units/reel)</td>
</tr>
</tbody>
</table>

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

### Pin Descriptions

<table>
<thead>
<tr>
<th>Pin No.</th>
<th>Name</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Cap+</td>
<td>Positive terminal for ( C_1 ).</td>
</tr>
<tr>
<td>B1</td>
<td>V_IN</td>
<td>Positive power supply input.</td>
</tr>
<tr>
<td>C1</td>
<td>V_OUT</td>
<td>Regulated negative output voltage.</td>
</tr>
<tr>
<td>C2</td>
<td>V_FB</td>
<td>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) ). <strong>DO NOT</strong> leave unconnected.</td>
</tr>
<tr>
<td>C3</td>
<td>SD</td>
<td>Active low, logic-level shutdown input.</td>
</tr>
<tr>
<td>B3</td>
<td>V_NEG</td>
<td>Negative unregulated output voltage.</td>
</tr>
<tr>
<td>A3</td>
<td>Cap−</td>
<td>Negative terminal for ( C_1 ).</td>
</tr>
<tr>
<td>A2</td>
<td>GND</td>
<td>Ground.</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 (VIN to GND or GND to OUT) + 5.8V (GND – 0.3V) to (VIN + 0.3V)

VNEG and VOUT Continuous Output Current 10mA

VOUT Short-Circuit Duration to GND (Note 2) 1 sec.

Continuous Power Dissipation (TA = 25˚C) (Note 3) 600mW

TJMAX (Note 3) 150˚C

θJA (Note 3) 220˚C/W

Operating Input Voltage Range 2.7V to 5.5V

Operating Output Current Range 0mA to 10mA

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 TJ = 25˚C, and limits in boldface type apply over the full temperature range. Unless otherwise specified VIN = 3.6V, C1 = C2 = C3 = 1µF.

<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>
</thead>
<tbody>
<tr>
<td>IQ</td>
<td>Supply Current</td>
<td>Open Circuit, No Load</td>
<td>400</td>
<td>950</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>ISD</td>
<td>Shutdown Supply Current</td>
<td></td>
<td>0.05</td>
<td>1</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>FSW</td>
<td>Switching Frequency</td>
<td>V_IN = 3.6V (Note 5)</td>
<td>140</td>
<td>260</td>
<td>450</td>
<td>kHz</td>
</tr>
<tr>
<td>ηPOWER</td>
<td>Power Efficiency at VNEG</td>
<td>IL = 3.6mA</td>
<td></td>
<td></td>
<td>94</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>IL = 10mA</td>
<td>91</td>
<td>91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSTART</td>
<td>Start Up time</td>
<td></td>
<td>120</td>
<td>600</td>
<td>µs</td>
<td></td>
</tr>
<tr>
<td>RNEG</td>
<td>Output Resistance to VNEG</td>
<td></td>
<td>30</td>
<td></td>
<td>Ω</td>
<td></td>
</tr>
<tr>
<td>VR</td>
<td>Output Voltage Ripple</td>
<td>IL = 2.5mA, VOUT = −2.7V</td>
<td>1</td>
<td>1</td>
<td>mV</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(Note 7)</td>
<td>IL = 10mA, VOUT = −3.8V</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VF</td>
<td>Feedback Pin Reference Voltage</td>
<td>IL = 2.5mA (Note 8)</td>
<td>−1.25</td>
<td>−1.20</td>
<td>−1.15</td>
<td>V</td>
</tr>
<tr>
<td>VOUT</td>
<td>Adjustable Output Voltage</td>
<td>5.5V ≥ VIN ≥ 2.7V, 2.5mA ≥ IL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>5.5V ≥ VIN ≥ 3.0V, 10mA ≥ IL ≥ 0mA</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>−(VIN −0.3V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>−(VIN −1.2V)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Load Regulation</td>
<td>0 to 10mA, VOUT = −2.4V</td>
<td>5</td>
<td></td>
<td>mV/mA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Line Regulation</td>
<td>5.5V ≥ VIN ≥ 2.7V, IL = 2.5mA</td>
<td>1</td>
<td></td>
<td>mV/V</td>
<td></td>
</tr>
<tr>
<td>VIH</td>
<td>Shutdown Pin Input Voltage High</td>
<td>5.5V ≥ VIN ≥ 2.7V</td>
<td>2.4</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>VIL</td>
<td>Shutdown Pin Input Voltage Low</td>
<td>5.5V ≥ VIN ≥ 2.7V</td>
<td>0.8</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 VIN may damage the device and must be avoided. Also, for temperatures above TA = 85˚C, OUT must not be shorted to GND or VNEG or device may be damaged.

Note 3: The maximum power dissipation must be de-rated at elevated temperatures and is limited by TJMAX (maximum junction temperature), TA (ambient temperature) and θJA (junction-to-ambient thermal resistance). The maximum power dissipation at any temperature is:

\[ PD_{\text{MAX}} = \left( \frac{T_{\text{JMAX}} - T_A}{\theta_{\text{JA}}} \right) \]

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, fOSC = 2fSW.

Note 6: Current drawn from VNEG pin decreases power efficiency and will increase output voltage ripple.

Note 7: In the test circuit, capacitors C1, C2, and C3 are 1µF, 0.30Ω maximum ESR capacitors. Capacitors with higher ESR will increase output resistance, increase output voltage ripple, and reduce efficiency.

Note 8: The feedback resistors R1 and R2 are 200kΩ resistors.
Typical Performance Characteristics  Unless otherwise specified, $T_A = 25^\circ$C, $V_{OUT} = -2.5V$.

**FIGURE 1. Standard Application Circuit**

**Output Voltage vs. Output Current**

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

**Output Voltage vs. Input Voltage**

- $I = 4$ mA

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

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

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

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

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

Switching Frequency vs. Input Voltage

- $T_A = -40°C$
- $T_A = +25°C$
- $T_A = +85°C$

Start-up Time vs. Input Voltage

Start-up from Shutdown (no load)

Output Ripple

Output Noise Spectrum

$V_{IN} = 3.6V$
$V_{OUT} = -2.5V$
$V_{OUT} = 2.5mA$

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Typical Performance Characteristics

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

**FIGURE 2. Functional Block Diagram**
Device Description
The LM2787 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 \( V_{OUT} \). 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 at the output \( V_{OUT} \). The regulator also attenuates noise from the incoming supply due to its high PSRR.

Shutdown
The LM2787 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 LM2787 is set by using a resistor divider between the output, the feedback pin, and an arbitrary voltage \( V_{ADJ} \) (Figure 2). \( V_{ADJ} \) 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 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:

\[
R_{NEG} = \frac{1}{f_{SW} \times C_1} + 4 \times ESR_{C1} + ESR_{C2} + \frac{1}{f_{SW} \times C_1} \]

The switching frequency is fixed at 260kHz 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 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 \( V_{OUT} \).

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 1.0µF 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 LM2787. Because they are small, the noise and ripple can be hard to measure accurately. Ground loop error between the circuit and the oscilloscope causes 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 output ground. This should give the most accurate reading of the actual output waveform.

Micro SMD Mounting
The micro SMD package requires specific mounting techniques which are detailed in National Semiconductor Application Note # 1112. Referring to the section Surface Mount Technology (SMT) Assembly Considerations, it should be noted that the pad style which must be used with the 8-pin package is the NSMD (non-solder mask defined) type. For best results during assembly, alignment ordinals on the PC board may be used to facilitate placement of the micro SMD device.

Micro SMD Light Sensitivity
Exposing the micro SMD device to direct sunlight may cause misoperation of the device. Light sources such as Halogen lamps can also affect electrical performance if brought near the device.

The wavelengths which have the most detrimental effect are reds and infra-reds. The fluorescent lighting used inside of most buildings has very little effect on performance.
**Physical Dimensions**
inches (millimeters)

unless otherwise noted

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