Regulated, 125mA-Output, Charge-Pump DC-DC Inverter

General Description
The MAX1673 charge-pump inverter provides a low-cost, compact means of generating a regulated negative output from a positive input at up to 125mA. It requires only three small capacitors, and only two resistors to set its output voltage. The input range is 2V to 5.5V. The regulated output can be set from 0V to -VIN in Skip regulation mode or -1.5V to -VIN in Linear (LIN) regulation mode.

In Skip mode, the MAX1673 regulates by varying its switching frequency as a function of load current. This On-Demand™ switching gives the MAX1673 two advantages: very small capacitors and very low quiescent supply current. At heavy loads, it transfers energy from the input to the output by switching at up to 350kHz. It switches more slowly at light loads, using only 35µA quiescent supply current.

In Linear mode, the MAX1673 switches at a constant 350kHz at all loads and regulates by controlling the current-path resistance. This provides constant-frequency ripple, which is easily filtered for low-noise applications.

This device also features a 1µA logic-controlled shutdown mode and is available in a standard 8-pin SO package. For a device that delivers about 10mA and fits in a smaller package, refer to the MAX868.

Features
- Regulated Negative Output Voltage (up to -1 x VIN)
- 125mA Output Current
- 35µA Quiescent Supply Current (Skip-mode regulation)
- 350kHz Fixed-Frequency, Low-Noise Output (Linear-mode regulation)
- 2V to 5.5V Input Range
- 1µA Logic-Controlled Shutdown

Ordering Information

<table>
<thead>
<tr>
<th>PART</th>
<th>TEMP. RANGE</th>
<th>PIN-PACKAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>MAX1673ESA</td>
<td>-40°C to +85°C</td>
<td>8 SO</td>
</tr>
</tbody>
</table>

Applications
- Hard Disk Drives
- Measurement Instruments
- Camcorders
- Modems
- Analog Signal-Processing
- Digital Cameras
- Applications

Typical Operating Circuit

On-Demand™ is a trademark of Maxim Integrated Products.

For free samples & the latest literature: http://www.maxim-ic.com, or phone 1-800-998-8800. For small orders, phone 408-737-7600 ext. 3468.
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ABSOLUTE MAXIMUM RATINGS

IN .................................................................-0.3V to +6V  Continuous Power Dissipation (TA = +70°C)
CAP+, FB, LIN/SKIP ......................................-0.3V to (VIN + 0.3V)  (derate 5.88mW/°C above +70°C) ..............450mW
SHDN ............................................................-0.3V to +6V  Operating Temperature Range ......................-40°C to +85°C
OUT, CAP ...............................................-6V to +0.3V  Junction Temperature ..............................+150°C
Continuous Output Current ...........................135mA  Storage Temperature Range ......................-65°C to +160°C
Output Short-Circuit Duration to GND (Note 1) ...........1sec  Lead Temperature (soldering, 10sec) .................+300°C

Note 1: Shorting OUT to IN may damage the device and should be avoided.

Stresses beyond those listed under “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

ELECTRICAL CHARACTERISTICS

(VIN = VSHDN = +5V, CIN = 10µF, COUT = 22µF, CFLY = 2.2µF, TA = -40°C to +85°C, unless otherwise noted. Typical values are at TA = +25°C.) (Note 2)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage Range</td>
<td>VIN</td>
<td>LIN/SKIP = GND (Skip mode)</td>
<td>2.0</td>
<td>5.5</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Minimum Output Voltage</td>
<td>VOUT</td>
<td>LIN/SKIP = GND</td>
<td>0</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Output Current</td>
<td>IOUT(MAX)</td>
<td>-2.90</td>
<td>-3.02</td>
<td>-3.15</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>Output Voltage</td>
<td>VOUT</td>
<td>LIN/SKIP = IN (LIN mode)</td>
<td>-2.92</td>
<td>-3.02</td>
<td>-3.12</td>
<td>V</td>
</tr>
<tr>
<td>Quiescent Current (IIN Current)</td>
<td>IQ</td>
<td>VFB = -100mV, VOUT = -3V, LIN/SKIP = IN (LIN mode)</td>
<td>8</td>
<td>16</td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>Shutdown Current (IIN Current)</td>
<td>ISHDN</td>
<td>VSHDN = GND</td>
<td>0.1</td>
<td>1</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>Line Regulation</td>
<td>ΔVLNR</td>
<td>VIN = 4.5V to 5.5V, Figure 4, VREF = VIN</td>
<td>0.01</td>
<td>%/V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load Regulation</td>
<td>ΔVLDR</td>
<td>IOUT = 25mA to 125mA, Figure 1</td>
<td>0.01</td>
<td>%/mA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Open-Loop Output Resistance (Dropout)</td>
<td>PO</td>
<td>3.5</td>
<td>10</td>
<td>Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Resistance to Ground in Shutdown Mode</td>
<td>SHDN = GND</td>
<td>1</td>
<td>5</td>
<td>Ω</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Regulated, 125mA-Output, Charge-Pump DC-DC Inverter

### ELECTRICAL CHARACTERISTICS (continued)

(VIN = VSHDN = +5V, Cin = 10µF, Cout = 22µF, CFLY = 2.2µF, TA = -40°C to +85°C, unless otherwise noted. Typical values are at TA = +25°C.) (Note 2)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SYMBOL</th>
<th>CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switching Frequency (LIN Mode)</td>
<td>fOSC</td>
<td>TA = +25°C</td>
<td>250</td>
<td>350</td>
<td>460</td>
<td>kHz</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TA = -40°C to +85°C</td>
<td>205</td>
<td>515</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FB Threshold</td>
<td>VFB</td>
<td>LIN/SKIP = GND (Skip mode)</td>
<td>-25</td>
<td>0</td>
<td>25</td>
<td>mV</td>
</tr>
<tr>
<td>FB Input Bias Current</td>
<td>IFB</td>
<td>LIN/SKIP = IN (LIN mode)</td>
<td></td>
<td></td>
<td></td>
<td>nA</td>
</tr>
<tr>
<td></td>
<td></td>
<td>LIN/SKIP = GND (Skip mode)</td>
<td>150</td>
<td>600</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Input Bias Current (SHDN, LIN/SKIP)</td>
<td></td>
<td>LIN/SKIP = GND (Skip mode)</td>
<td>1</td>
<td></td>
<td></td>
<td>µA</td>
</tr>
<tr>
<td>Logic High Input (SHDN, LIN/SKIP)</td>
<td>VIL</td>
<td>2V ≤ VIN ≤ 5.5V</td>
<td>0.7 x VIN</td>
<td></td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Logic Low Input (SHDN, LIN/SKIP)</td>
<td>VIL</td>
<td>2V ≤ VIN ≤ 5.5V</td>
<td>0.3 x VIN</td>
<td></td>
<td>V</td>
<td></td>
</tr>
</tbody>
</table>

**Note 2:** Specifications to -40°C are guaranteed by design, not production tested.
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Typical Operating Characteristics (continued)

(Circuit of Figure 1, V_{IN} = +5V, C_{FLY} = 2.2\mu F, C_{OUT} = 22\mu F, T_{A} = +25^\circ C, unless otherwise noted.)
Regulated, 125mA-Output, Charge-Pump DC-DC Inverter

Detailed Description

The MAX1673 new-generation, high-output-current, regulated charge-pump DC-DC inverter provides up to 125mA. Designed specifically for compact applications, a complete regulating circuit requires only three small capacitors and two resistors. The MAX1673 employs On-Demand™ regulation circuitry, providing output regulation modes optimized for either lowest output noise or lowest supply current. In addition, the MAX1673 includes shutdown control.

In Linear (LIN) mode or when heavily loaded in Skip mode, the charge pump runs continuously at 350kHz. During one-half of the oscillator period, switches S1 and S2 close (Figure 2), charging the transfer capacitor (CFLY) to the input voltage (CAP- = GND, and CAP+ = IN). During the other half cycle, switches S3 and S4 close (Figure 3), transferring the charge on CFLY to the output capacitor (CAP+ = GND, CAP- = OUT).

Figure 1. Standard Application Circuit

Figure 2. Charging CFLY

Figure 3. Transferring Charge on CFLY to COUT

Regulated, 125mA-Output, Charge-Pump DC-DC Inverter

Pin Description

<table>
<thead>
<tr>
<th>PIN</th>
<th>NAME</th>
<th>FUNCTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>LIN/SKIP</td>
<td>Regulation-Mode Select Input. Driving LIN/SKIP high or connecting it to IN selects LIN mode, with regulation accomplished by modulating switch resistance. Driving LIN/SKIP low or connecting it to GND selects Skip mode, where the device regulates by skipping charge-pump pulses.</td>
</tr>
<tr>
<td>2</td>
<td>CAP+</td>
<td>Positive Terminal of Flying Capacitor</td>
</tr>
<tr>
<td>3</td>
<td>CAP-</td>
<td>Negative Terminal of Flying Capacitor</td>
</tr>
<tr>
<td>4</td>
<td>SHDN</td>
<td>Shutdown Control Input. Drive SHDN low to shut down the MAX1673. Connect SHDN to IN for normal operation. OUT connects to GND through a 1Ω (typical) resistor in shutdown mode.</td>
</tr>
<tr>
<td>5</td>
<td>OUT</td>
<td>Inverting Charge-Pump Output</td>
</tr>
<tr>
<td>6</td>
<td>FB</td>
<td>Feedback Input. Connect FB to a resistor-divider from IN (or other reference source) to OUT for regulated output voltages (Figures 1 and 4).</td>
</tr>
<tr>
<td>7</td>
<td>GND</td>
<td>Ground</td>
</tr>
<tr>
<td>8</td>
<td>IN</td>
<td>Power-Supply Positive Voltage Input</td>
</tr>
</tbody>
</table>

In Linear (LIN) mode or when heavily loaded in Skip mode, the charge pump runs continuously at 350kHz. During one-half of the oscillator period, switches S1 and S2 close (Figure 2), charging the transfer capacitor (CFLY) to the input voltage (CAP- = GND, and CAP+ = IN). During the other half cycle, switches S3 and S4 close (Figure 3), transferring the charge on CFLY to the output capacitor (CAP+ = GND, CAP- = OUT).
Linear Mode (Constant-Frequency Mode)

In LIN mode (LIN/SKIP = IN), the charge pump runs continuously at 350kHz. The MAX1673 controls the charge on CFLY by varying the gate drive on S1 (Figure 2). When the output voltage falls, CFLY charges faster due to increased gate drive. Since the device switches continuously, the regulation scheme minimizes output ripple, the output noise contains well-defined frequency components, and the circuit requires much smaller external capacitors than in Skip mode for a given output ripple.* However, LIN mode is less efficient than Skip mode due to higher operating current (8mA typical).

Skip Mode

In Skip mode (LIN/SKIP = GND), the device switches only as needed to maintain regulation on FB. Switching cycles are skipped until the voltage on FB rises above GND. Skip mode has higher output noise than LIN mode, but minimizes operating current.

Shutdown Mode

When SHDN (a CMOS-compatible input) is driven low, the MAX1673 enters low-power shutdown mode. Charge-pump switching action halts and an internal 1Ω switch pulls VOUT to ground. Connect SHDN to IN or drive high for normal operation.

*See Output Ripple vs. Load Current in Typical Operating Characteristics.

Applications Information

Resistor Selection (Output Voltage Selection)

The accuracy of VOUT depends on the accuracy of the voltage biasing the voltage-divider network (R1, R2). Use a separate reference voltage if VIN is an unregulated voltage or if greater accuracy is desired (Figure 4). Adjust the output voltage from -1.5V to -VIN in LIN mode or 0V to -VIN in Skip mode with external resistors R1 and R2 as shown in Figures 1 and 4. In either regulating mode (LIN or Skip), FB servos to 0V. Use the following equations to select R1 and R2 for the desired output voltage:

\[ V_{OUT} = -V_{REF} \frac{R2}{R1} \]

where VREF can be either VIN or some other positive reference source.

Typically, choose a voltage-divider current of 50µA to minimize the effect of FB input current:

\[ R1 = V_{REF} / 50\mu A \]
\[ R2 = -V_{OUT} / 50\mu A \]

Capacitor Selection

A CFLY value of 1µF or more is sufficient to supply the specified load current. However, for minimum ripple in Skip mode, this value may need to be increased. Maxim recommends 2.2µF.

Surface-mount ceramic capacitors are preferred for CFLY, due to their small size, low cost, and low equivalent series resistance (ESR). To ensure proper operation over the entire temperature range, choose ceramic capacitors with X7R (or equivalent) low-temperature-coefficient (tempco) dielectrics. See Table 1 for a list of suggested capacitor suppliers.

The output capacitor stores the charge transferred from the flying capacitor and services the load between oscillator cycles. A good general rule is to make the output capacitance at least ten times greater than that of the flying capacitor.

When in Skip mode, output ripple depends mostly on two parameters: charge transfer between the capacitance values of CFLY and COUT, and the ESR of COUT. The ESR ripple contribution occurs as COUT charges. The charging current creates a negative voltage pulse across the capacitor’s ESR that recedes as COUT charges. At equilibrium, when the voltage on CFLY approaches that on COUT, no charging current flows. Secondly, the ripple contribution due to charge transfer between capacitors creates a pulse as charge flows to COUT. Adding the two terms does not determine peak-to-peak ripple because their peaks do not occur at the same time. It is best to use only the dominant term. The expression for the ripple component predominantly due to COUT ESR is:
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\[
V_{\text{RIPPLE(ESR)}} = 2 \left( \frac{V_{\text{IN}} - V_{\text{OUT}}}{f_{\text{OSC}}} \right) \left( \frac{1}{R_{\text{OUT}} C_{\text{OUT}} + C_{\text{FLY}}} \right)
\]

The expression for the ripple component predominantly due to charge transfer is:

\[
V_{\text{RIPPLE(ESR)}} = 2 \left( \frac{V_{\text{IN}} - V_{\text{OUT}}}{f_{\text{OSC}}} \right) \left( \frac{1}{R_{\text{OUT}} C_{\text{OUT}} + C_{\text{FLY}}} \right)
\]

where \( C_{\text{FLY}} \) and \( C_{\text{OUT}} \) are their respective capacitance values, \( ESR_{\text{OUT}} \) is the equivalent series resistance of \( C_{\text{OUT}} \), \( R_{\text{OUT}} \) is the MAX1673 open-loop output impedance (typically 3.5Ω), and \( f_{\text{OSC}} \) is the MAX1673 switching frequency (typically 350kHz). If \( ESR_{\text{OUT}} \) is very small, as is likely when ceramic capacitors are used, \( VRIPPLE \) (TRANSFER) dominates. If \( ESR \) is relatively large, as with low-cost tantalum capacitors, then \( VRIPPLE \) (ESR) dominates.

When operating in LIN mode, use the following equation to approximate peak-to-peak output voltage ripple:

\[
V_{\text{RIPPLE}} = \frac{I_{\text{OUT}}}{2 f_{\text{OSC}} C_{\text{OUT}}} + 2 I_{\text{OUT}} ESR_{\text{OUT}}
\]

where \( C_{\text{OUT}} \) is the output capacitor value, \( ESR_{\text{OUT}} \) is the output capacitor’s ESR, and \( f_{\text{OSC}} \) is the MAX1673 oscillator frequency (typically 350kHz).

To ensure LIN mode stability over the entire temperature range, choose a low-ESR (no more than 100mΩ) output capacitance using the following equation:

\[
C_{\text{OUT}} = 75 \times 10^{-6} \left( \frac{R_{1}}{R_{1} + R_{2}} \right) V_{\text{OUT}}
\]

where \( C_{\text{OUT}} \) is the output capacitor value, and \( f_{\text{MIN}} \) is the minimum oscillator frequency (250kHz). See Table 1 for a list of suggested capacitor suppliers.

**Layout Considerations**

The MAX1673’s high oscillator frequency requires good layout technique, which ensures stability and helps maintain the output voltage under heavy loads. Take the following steps to ensure good layout:

- Mount all components as close together as possible.
- Place the feedback resistors R1 and R2 close to the FB pin, and minimize the PC trace length at the FB circuit node.
- Keep traces short to minimize parasitic inductance and capacitance.
- Use a ground plane.

### Table 1. Partial Listing of Capacitor Vendors

<table>
<thead>
<tr>
<th>PRODUCTION METHOD</th>
<th>MANUFACTURER</th>
<th>SERIES</th>
<th>PHONE</th>
<th>FAX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface-Mount Tantalum</td>
<td>AVX</td>
<td>TPS</td>
<td>(803) 946-0690</td>
<td>(803) 448-2170</td>
</tr>
<tr>
<td></td>
<td>Matsuo</td>
<td>267</td>
<td>(714) 969-2491</td>
<td>(714) 960-6492</td>
</tr>
<tr>
<td></td>
<td>Sprague</td>
<td>593D, 595D</td>
<td>(603) 224-1961</td>
<td>(603) 224-1430</td>
</tr>
<tr>
<td>Surface-Mount Ceramic</td>
<td>AVX</td>
<td>X7R</td>
<td>(803) 946-0590</td>
<td>(803) 626-3123</td>
</tr>
<tr>
<td></td>
<td>Matsuo</td>
<td>X7R</td>
<td>(714) 969-2491</td>
<td>(714) 960-6492</td>
</tr>
</tbody>
</table>

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