# High Voltage, Low Quiescent Current Inverting Charge Pump

## FEATURES

- **4.5V to 32V $V_{IN}$ Range**
- **Inverting Charge Pump Generates $–V_{IN}$**
- **60µA Quiescent Current in Burst Mode® Operation**
- **Charge Pump Output Current Up to 100mA**
- **50kHz to 500kHz Programmable Oscillator Frequency**
- Short-Circuit/Thermal Protection
- Low Profile Thermally Enhanced 12-Pin MSOP Package

## APPLICATIONS

- Bipolar/Inverting Supplies
- Industrial/Instrumentation Bias Generators
- Portable Medical Equipment
- Portable Instruments

## DESCRIPTION

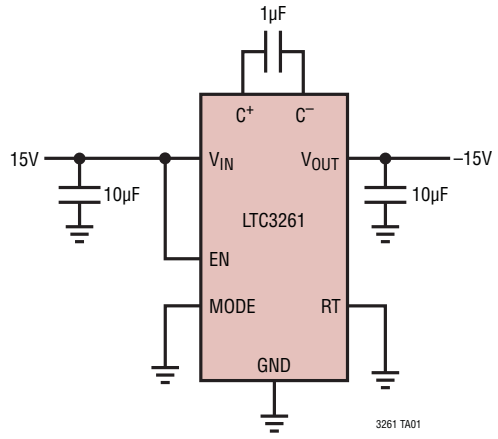
The LTC®3261 is a high voltage inverting charge pump that operates over a wide 4.5V to 32V input range and is capable of delivering up to 100mA of output current.

The charge pump employs either low quiescent current Burst Mode operation or low noise constant frequency mode. In Burst Mode operation the charge pump $V_{OUT}$ regulates to $–0.94 • V_{IN}$ and the LTC3261 draws only 60µA of quiescent current. In constant frequency mode the charge pump produces an output equal to $–V_{IN}$ and operates at a fixed 500kHz or to a programmed frequency between 50kHz to 500kHz using an external resistor. The LTC3261 is available in a thermally enhanced 12-pin MSOP package.

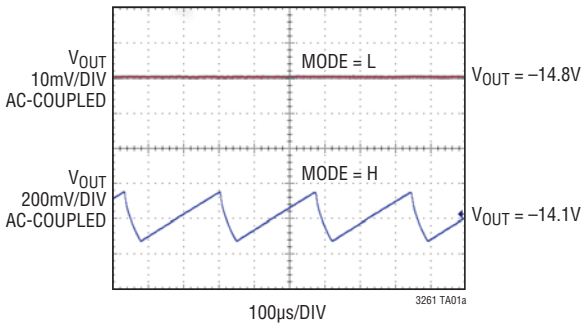
LT, LTC, LTM, Burst Mode, Linear Technology and the Linear logo are registered trademarks and ThinSOT is a trademark of Linear Technology Corporation. All other trademarks are the property of their respective owners.

## TYPICAL APPLICATION

**15V to –15V Inverter**




**$V_{OUT}$ Ripple**



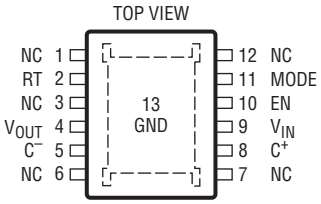

$V_{IN}$ = 15V
$f_{OSC}$ = 500kHz
$I_{OUT}$ = 5mA

## ABSOLUTE MAXIMUM RATINGS

**(Notes 1, 3)**

$V_{IN}$, EN, MODE.. ..... –0.3V to 36V
$V_{OUT}$ ..... –36V to 0.3V
RT ..... –0.3V to 6V
$V_{OUT}$ Short-Circuit Duration ..... Indefinite
Operating Junction Temperature Range
(Note 2) ..... –40°C to 125°C
Storage Temperature Range ..... –65°C to 150°C
Lead Temperature (Soldering, 10 sec) ..... 300°C

## PIN CONFIGURATION




MSE PACKAGE
12-LEAD PLASTIC MSOP
$T_{JMAX}$ = 150°C, $\theta_{JA}$ = 40°C/W
EXPOSED PAD (PIN 13) IS GND, MUST BE SOLDERED TO PCB

## ORDER INFORMATION

| LEAD FREE FINISH | TAPE AND REEL | PART MARKING* | PACKAGE DESCRIPTION | TEMPERATURE RANGE |
|---|---|---|---|---|
| LTC3261EMSE#PBF | LTC3261EMSE#TRPBF | 3261 | 12-Lead Plastic MSOP | –40°C to 125°C |
| LTC3261IMSE#PBF | LTC3261IMSE#TRPBF | 3261 | 12-Lead Plastic MSOP | –40°C to 125°C |

Consult LTC Marketing for parts specified with wider operating temperature ranges. *The temperature grade is identified by a label on the shipping container.
Consult LTC Marketing for information on non-standard lead based finish parts.

For more information on lead free part marking, go to: http://www.linear.com/leadfree/
For more information on tape and reel specifications, go to: http://www.linear.com/tapeandreel/

## ELECTRICAL CHARACTERISTICS

**The ● denotes the specifications which apply over the full operating temperature range, otherwise specifications are at $T_A$ = 25°C (Note 2). $V_{IN}$ = EN = 12V, MODE = 0V, RT = 200kΩ.**

| SYMBOL | PARAMETER | CONDITIONS | | MIN | TYP | MAX | UNITS |
|---|---|---|---|---|---|---|---|
| **Charge Pump** | | | | | | | |
| $V_{IN}$ | Input Voltage Range | | ● | 4.5 | | 32 | V |
| $V_{UVLO}$ | $V_{IN}$ Undervoltage Lockout Threshold | $V_{IN}$ Rising<br>$V_{IN}$ Falling | ●<br>● | <br>3.4 | 3.8<br>3.6 | 4 | V<br>V |
| $I_{VIN}$ | $V_{IN}$ Quiescent Current | Shutdown, = EN = 0V<br>MODE = $V_{IN}$, $I_{VOUT}$ = 0mA<br>MODE = 0V, $I_{VOUT}$ = 0mA | | | 2<br>60<br>3.5 | 5<br>120<br>5.5 | µA<br>µA<br>mA |
| $V_{RT}$ | RT Regulation Voltage | | | | 1.200 | | V |
| $V_{OUT}$ | $V_{OUT}$ Regulation Voltage | MODE = 12V<br>MODE = 0V | | | –0.94 • $V_{IN}$<br>–$V_{IN}$ | | V<br>V |
| $f_{OSC}$ | Oscillator Frequency | RT = GND | | 450 | 500 | 550 | KHz |
| $R_{OUT}$ | Charge Pump Output Impedance | MODE = 0V, RT = GND | | | 32 | | Ω |
| $I_{SHORT_CKT}$ | Max $I_{VOUT}$ Short-Circuit Current | $V_{OUT}$ = GND, RT = GND | ● | 100 | 160 | 250 | mA |
| $V_{MODE(H)}$ | MODE Threshold Rising | | ● | | 1.1 | 2 | V |
| $V_{MODE(L)}$ | MODE Threshold Falling | | ● | 0.4 | 1.0 | | V |
| $I_{MODE}$ | MODE Pin Internal Pull-Down Current | $V_{IN}$ = MODE = 32V | | | 0.7 | | µA |
| $V_{EN(H)}$ | EN Threshold Rising | | ● | | 1.1 | 2 | V |
| $V_{EN(L)}$ | EN Threshold Falling | | ● | 0.4 | 1.0 | | V |
| $I_{EN}$ | EN Pin Internal Pull-Down Current | $V_{IN}$ = EN = 32V | | | 0.7 | | µA |

**Note 1:** Stresses beyond those listed under Absolute Maximum Ratings may cause permanent damage to the device. Exposure to any Absolute Maximum Rating condition for extended periods may affect device reliability and lifetime.

**Note 2:** The LTC3261 is tested under pulsed load conditions such that $T_J \approx T_A$. The LTC3261E is guaranteed to meet specifications from 0°C to 85°C junction temperature. Specifications over the –40°C to 125°C operating junction temperature range are assured by design, characterization and correlation with statistical process controls. The LTC3261I is guaranteed over the –40°C to 125°C operating junction temperature range. High junction temperatures degrade operating lifetimes; operating lifetime is derated for junction temperatures greater than 125°C. Note that the maximum ambient temperature consistent with these specifications is determined by specific operating conditions in conjunction with board layout, the rated package thermal impedance and other environmental factors.

The junction temperature ($T_J$, in °C) is calculated from the ambient temperature ($T_A$, in °C) and power dissipation ($P_D$, in Watts) according to the formula:

$$T_J = T_A + (P_D \bullet \theta_{JA}),$$

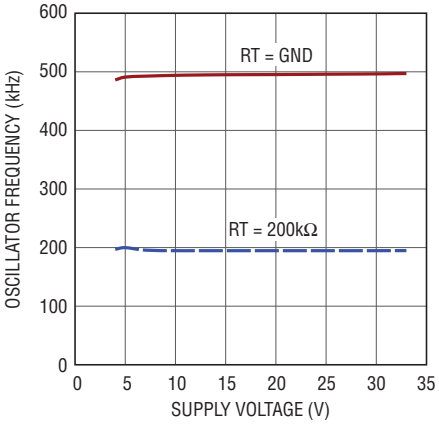
where $\theta_{JA}$ = 40°C/W is the package thermal impedance.

**Note 3:** This IC includes overtemperature protection that is intended to protect the device during momentary overload conditions. Junction temperatures will exceed 150°C when overtemperature protection is active. Continuous operation above the specified maximum operating junction temperature may result in device degradation or failure.

# TYPICAL PERFORMANCE CHARACTERISTICS

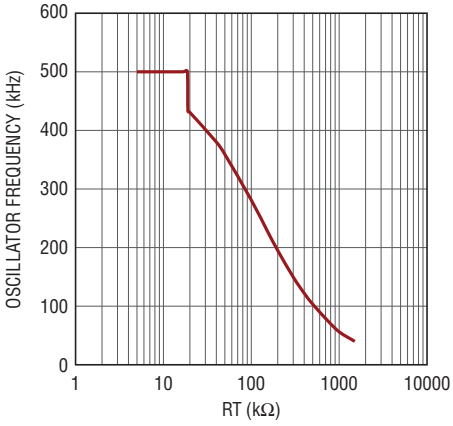
**($T_A$ = 25°C, $C_{FLY}$ = 1µF, $C_{IN}$ = $C_{OUT}$ = 10µF unless otherwise noted)**

### Oscillator Frequency vs Supply Voltage



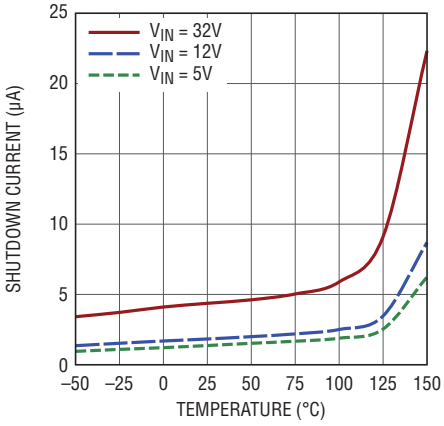

3261 G01

### Oscillator Frequency vs RT



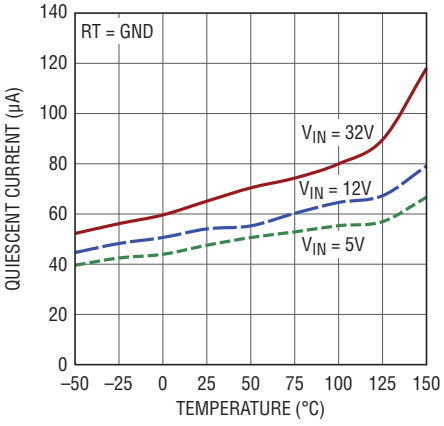

3261 G02

### Shutdown Current vs Temperature



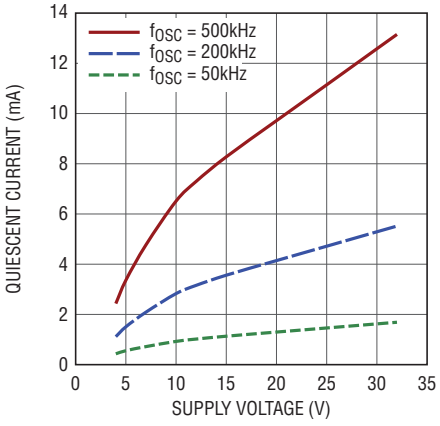

3261 G03

### Quiescent Current vs Temperature (Burst Mode Operation)



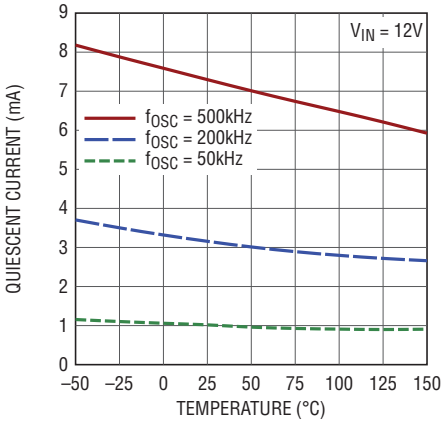

3261 G04

### Quiescent Current vs Supply Voltage (Constant Frequency Mode)



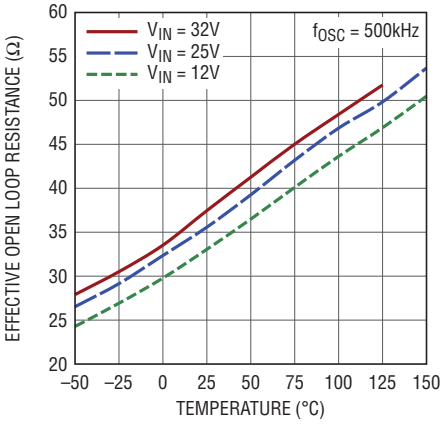

3261 G05

### Quiescent Current vs Temperature (Constant Frequency Mode)



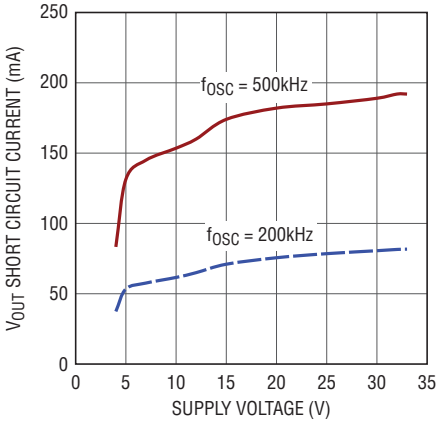

3261 G06

### Effective Open-Loop Resistance vs Temperature



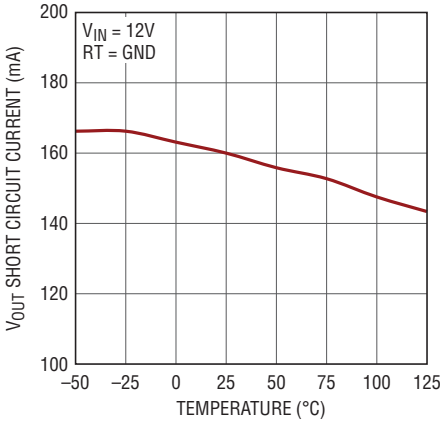

3261 G07

### $V_{OUT}$ Short-Circuit Current vs Supply Voltage




3261 G08

### $V_{OUT}$ Short Circuit Current vs Temperature

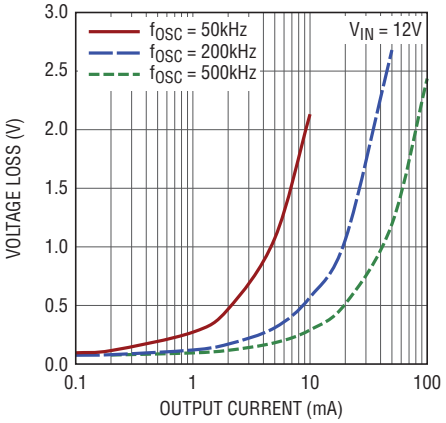



3261 G8b

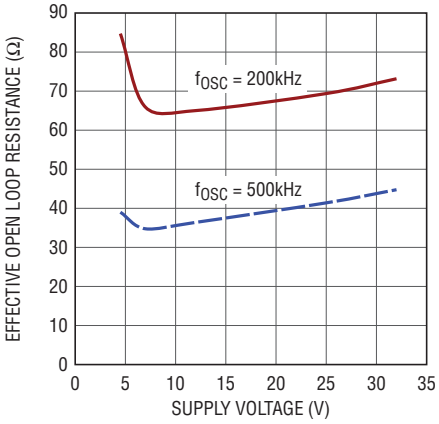
# TYPICAL PERFORMANCE CHARACTERISTICS

**($T_A$ = 25°C, $C_{FLY}$ = 1µF, $C_{IN}$ = $C_{OUT}$ = 10µF unless otherwise noted)**

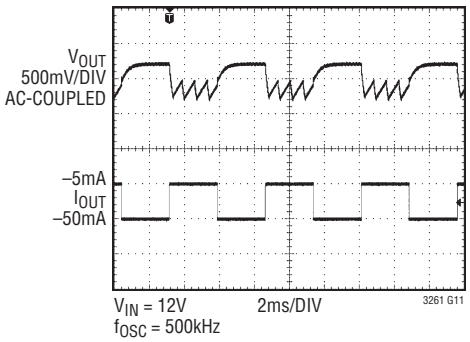
### Voltage Loss ($V_{IN}$ – $|V_{OUT}|$) vs Output Current (Constant Frequency Mode)



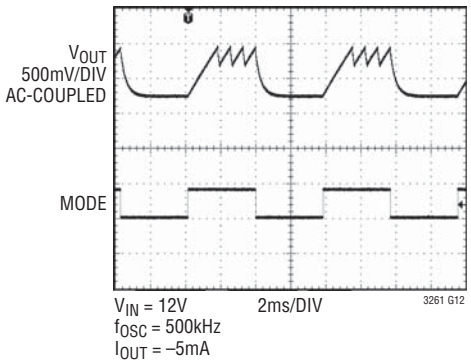

### Effective Open-Loop Resistance vs Supply Voltage



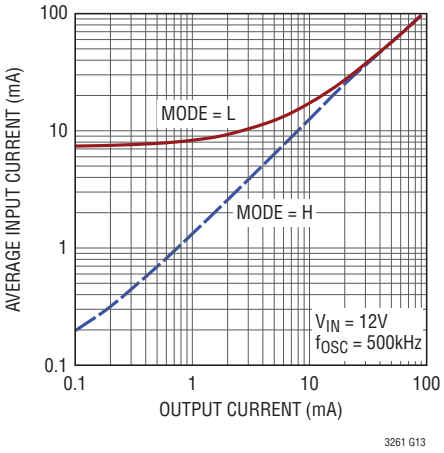

### $V_{OUT}$ Load Transient Burst Mode Operation (MODE = H)



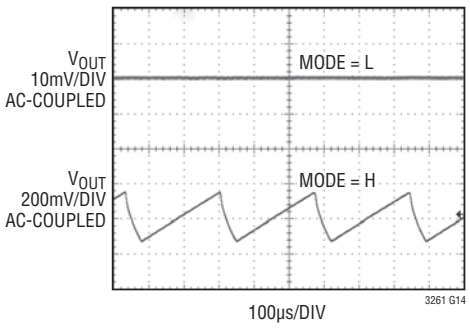

### $V_{OUT}$ Transient (MODE = Low to High)




### Average Input Current vs Output Current




### $V_{OUT}$ Ripple




VIN = 15V
fOSC = 500kHz
IOUT = 5mA

## PIN FUNCTIONS

**NC (Pins 1, 3, 6, 7,12):** No Connect Pins. These pins are not connected to the LTC3261 die. These pins should be left floating or connected to ground. Pins 6 and 7 can also be shorted to adjacent pins.

**RT (Pin 2):** Input Connection for Programming the Switching Frequency. The RT pin servos to a fixed 1.2V when the EN pin is driven to a logic "high". A resistor from RT to GND sets the charge pump switching frequency. If the RT pin is tied to GND, the switching frequency defaults to a fixed 500kHz.

**$V_{OUT}$ (Pin 4):** Charge Pump Output Voltage. In constant frequency mode (MODE = low) this pin is driven to $–V_{IN}$. In Burst Mode operation, (MODE = high) this pin voltage is regulated to $–0.94 • V_{IN}$ using an internal burst comparator with hysteretic control.

**$C^–$ (Pin 5):** Flying Capacitor Negative Connection.

**$C^+$ (Pin 8):** Flying Capacitor Positive Connection.

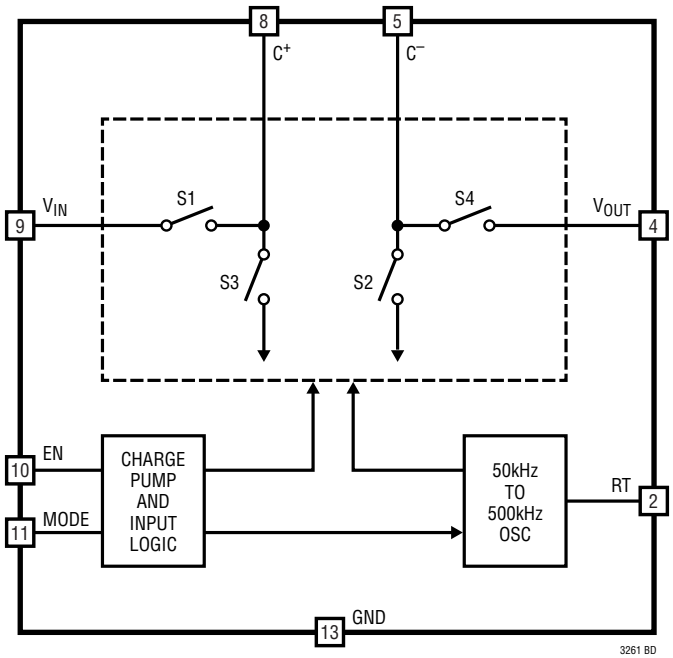
**$V_{IN}$ (Pin 9):** Input Voltage for the Charge Pump. $V_{IN}$ should be bypassed with a low impedance ceramic capacitor.

**EN (Pin 10):** Logic Input. A logic "high" on the EN pin enables the inverting charge pump.

**MODE (Pin 12):** Logic Input. The MODE pin determines the charge pump operating mode. A logic "high" on the MODE pin forces the charge pump into Burst Mode operation regulating $V_{OUT}$ to approximately $–0.94 • V_{IN}$ with hysteretic control. A logic "low" on the MODE pin forces the charge pump to operate as an open-loop inverter with a constant switching frequency. The switching frequency in both modes is determined by an external resistor from the RT pin to GND. In Burst Mode, this represents the frequency of the burst cycles before the part enters the low quiescent current sleep state.

**GND (Exposed Pad Pin 13):** Ground. The exposed package pad is ground and must be soldered to the PC board ground plane for proper functionality and for rated thermal performance.

## BLOCK DIAGRAM



## OPERATION (Refer to the Block Diagram)

The LTC3261 is a high voltage inverting charge pump. It supports a wide input power supply range from 4.5V to 32V.

### Shutdown Mode

In shutdown mode, all circuitry except the internal bias is turned off. The LTC3261 is in shutdown when a logic low is applied to the enable input (EN). The LTC3261 only draws 2µA (typical) from the $V_{IN}$ supply in shutdown.

### Constant Frequency Operation

The LTC3261 provides low noise constant frequency operation when a logic low is applied to the MODE pin. The charge pump and oscillator circuit are enabled using the EN pin. At the beginning of a clock cycle, switches S1 and S2 are closed. The external flying capacitor across the $C^+$ and $C^-$ pins is charged to the $V_{IN}$ supply. In the second phase of the clock cycle, switches S1 and S2 are opened, while switches S3 and S4 are closed. In this configuration the $C^+$ side of the flying capacitor is grounded and charge is delivered through the $C^-$ pin to $V_{OUT}$. In steady state the $V_{OUT}$ pin regulates at $-V_{IN}$ less any voltage drop due to the load current on $V_{OUT}$.

The charge transfer frequency can be adjusted between 50kHz and 500kHz using an external resistor on the RT pin. At slower frequencies the effective open-loop output resistance ($R_{OL}$) of the charge pump is larger and it is able to provide smaller average output current. Figure 1 can be used to determine a suitable value of RT to achieve a required oscillator frequency. If the RT pin is grounded, the part operates at a constant frequency of 500kHz.

### Burst Mode Operation

The LTC3261 provides low power Burst Mode operation when a logic high is applied to the MODE pin. In Burst Mode operation, the charge pump charges the $V_{OUT}$ pin to $-0.94 \bullet V_{IN}$ (typical). The part then shuts down the internal oscillator to reduce switching losses and goes into a low current state. This state is referred to as the sleep state in which the IC consumes only about 60µA. When the output voltage droops enough to overcome the burst comparator hysteresis, the part wakes up and commences charge pump cycles until output voltage exceeds $-0.94 \bullet V_{IN}$ (typical). This mode provides lower operating current at the cost of higher output ripple and is ideal for light load operation.

The frequency of charging cycles is set by the external resistor on the RT pin. The charge pump has a lower $R_{OL}$ at higher frequencies. For Burst Mode operation it is recommended that the RT pin be tied to GND. This minimizes the charge pump $R_{OL}$, quickly charges the output up to the burst threshold and optimizes the duration of the low current sleep state.

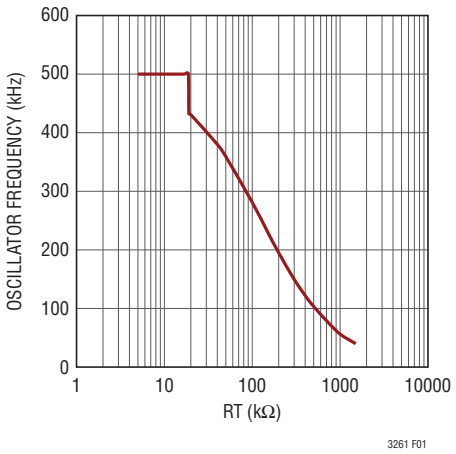



**Figure 1. Oscillator Frequency vs RT**

### Soft-Start

The LTC3261 has built in soft-start circuitry to prevent excessive current flow during start-up. The soft-start is achieved by internal circuitry that slowly ramps the amount of current available at the output storage capacitor. The soft-start circuitry is reset in the event of a commanded shutdown or thermal shutdown.

### Short-Circuit/Thermal Protection

The LTC3261 has built-in short-circuit current limit as well as overtemperature protection. During a short-circuit condition, the part automatically limits its output current to approximately 160mA. If the junction temperature exceeds approximately 175°C the thermal shutdown circuitry disables current delivery to the output. Once the junction temperature drops back to approximately 165°C current delivery to the output is resumed. When thermal protection is active the junction temperature is beyond the specified operating range. Thermal protection is intended for momentary overload conditions outside normal operation. Continuous operation above the specified maximum operating junction temperature may impair device reliability.

## APPLICATIONS INFORMATION

### Effective Open-Loop Output Resistance

The effective open-loop output resistance ($R_{OL}$) of a charge pump is a very important parameter which determines the strength of the charge pump. The value of this parameter depends on many factors such as the oscillator frequency ($f_{OSC}$), value of the flying capacitor ($C_{FLY}$), the nonoverlap time, the internal switch resistances ($R_S$) and the ESR of the external capacitors.

Typical $R_{OL}$ values as a function of temperature are shown in Figure 2

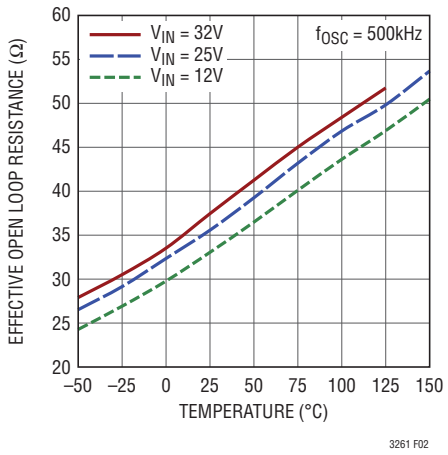



**Figure 2. Typical $R_{OL}$ vs Temperature**

### Input/Output Capacitor Selection

The style and value of capacitors used with the LTC3261 determine several important parameters such as regulator control loop stability, output ripple, charge pump strength and minimum turn-on time. To reduce noise and ripple, it is recommended that low ESR ceramic capacitors be used for the charge pump output. The charge pump output capacitor should retain at least 2µF of capacitance over operating temperature and bias voltage. Tantalum and aluminum capacitors can be used in parallel with a ceramic capacitor to increase the total capacitance but should not be used alone because of their high ESR. In constant frequency mode, the value of $C_{OUT}$ directly controls the amount of output ripple for a given load current. Increasing the size of $C_{OUT}$ will reduce the output ripple at the expense of higher minimum turn-on time. The peak-to-peak output ripple at the $V_{OUT}$ pin is approximately given by the expression:

$$V_{RIPPLE(P-P)} \approx \frac{I_{OUT}}{C_{OUT}} \bullet \left( \frac{1}{f_{OSC}} - t_{ON} \right)$$

where $f_{OSC}$ is the oscillator frequency $t_{ON}$ is the on-time of the oscillator (1µs) typical and $C_{OUT}$ is the value of the output capacitor.

Just as the value of $C_{OUT}$ controls the amount of output ripple, the value of $C_{IN}$ controls the amount of ripple present at the input ($V_{IN}$) pin. The amount of bypass capacitance required at the input depends on the source impedance driving $V_{IN}$. For best results it is recommended that $V_{IN}$ be bypassed with at least 2µF of low ESR capacitance. A high ESR capacitor such as tantalum or aluminum will have higher input noise than a low ESR ceramic capacitor. Therefore, a ceramic capacitor is recommended as the main bypass capacitance with a tantalum or aluminum capacitor used in parallel if desired.

### Flying Capacitor Selection

The flying capacitor controls the strength of the charge pump. A 1µF or greater ceramic capacitor is suggested for the flying capacitor for applications requiring the full rated output current of the charge pump.

For very light load applications, the flying capacitor may be reduced to save space or cost. For example, a 0.2µF capacitor might be sufficient for load currents up to 20mA. A smaller flying capacitor leads to a larger effective open-loop resistance ($R_{OL}$) and thus limits the maximum load current that can be delivered by the charge pump.

### Ceramic Capacitors

Ceramic capacitors of different materials lose their capacitance with higher temperature and voltage at different rates. For example, a capacitor made of X5R or X7R material will retain most of its capacitance from –40°C to 85°C whereas a Z5U or Y5V style capacitor will lose considerable capacitance over that range. Z5U and Y5V capacitors may also have a poor voltage coefficient causing them to lose 60% or more of their capacitance when the rated voltage is applied. Therefore when comparing different capacitors, it is often more appropriate to compare the amount of achievable capacitance for a given case size rather than discussing the specified capacitance value. The capacitor manufacture's data sheet

## APPLICATIONS INFORMATION

should be consulted to ensure the desired capacitance at all temperatures and voltages. Table 1 is a list of ceramic capacitor manufacturers and their websites.

**Table 1**

| | |
|---|---|
| AVX | www.avxcorp.com |
| Kemet | www.kemet.com |
| Murata | www.murata.com |
| Taiyo Yuden | www.t-yuden.com |
| Vishay | www.vishay.com |
| TDK | www.component.tdk.com |

### Layout Considerations

Due to high switching frequency and high transient currents produced by LTC3261, careful board layout is necessary for optimum performance. A true ground plane and short connections to all the external capacitors will improve performance and ensure proper regulation under all conditions. Figure 3 shows an example layout for the LTC3261.

The flying capacitor nodes $C^+$ and $C^-$ switch large currents at a high frequency. These nodes should not be routed close to sensitive pins such as the RT pin .

### Thermal Management

At high input voltages and maximum output current, there can be substantial power dissipation in the LTC3261. If the junction temperature increases above approximately 175°C, the thermal shutdown circuitry will automatically deactivate the output. To reduce the maximum junction temperature, a good thermal connection to the PC board ground plane is recommended. Connecting the exposed pad of the package to a ground plane under the device on two layers of the PC board can reduce the thermal resistance of the package and PC board considerably.

### Derating Power at High Temperatures

To prevent an overtemperature condition in high power applications, Figure 4 should be used to determine the maximum combination of ambient temperature and power dissipation.

The power dissipated in the LTC3261 should always fall under the line shown for a given ambient temperature.

The power dissipated in the LTC3261 is:

$$P_D = (V_{IN} - |V_{OUT}|) \bullet (I_{OUT})$$

where $I_{OUT}$ denotes output current at the $V_{OUT}$ pin.

The derating curve in Figure 4 assumes a maximum thermal resistance, $\theta_{JA}$, of 40°C/W for the package. This can be achieved from a printed circuit board layout with a solid ground plane and a good connection to the exposed pad of the LTC3261 package.

It is recommended that the LTC3261 be operated in the region corresponding to $T_J \leq 150°C$ for continuous operation as shown in Figure 4. Short-term operation may be acceptable for $150°C < T_J < 175°C$ but long-term operation in this region should be avoided as it may reduce the life of the part or cause degraded performance. For $T_J > 175°C$ the part will be in thermal shutdown.

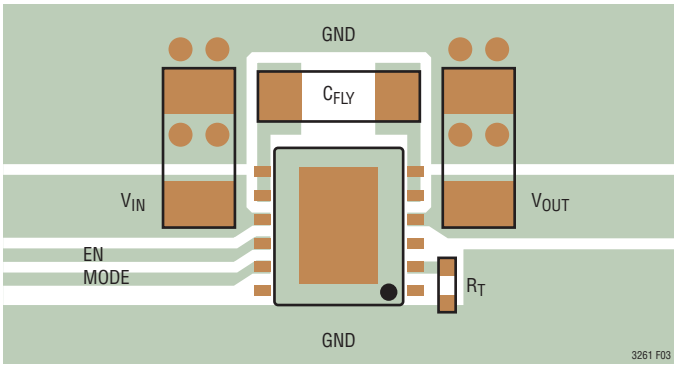



**Figure 3. Recommended Layout**

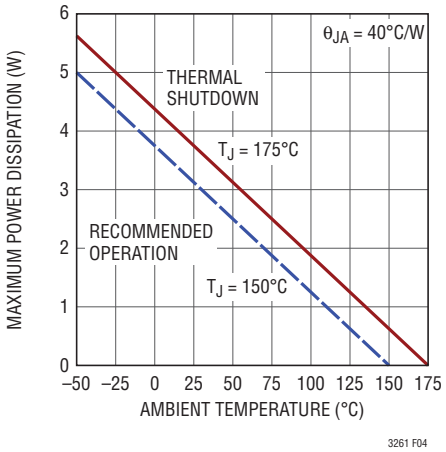
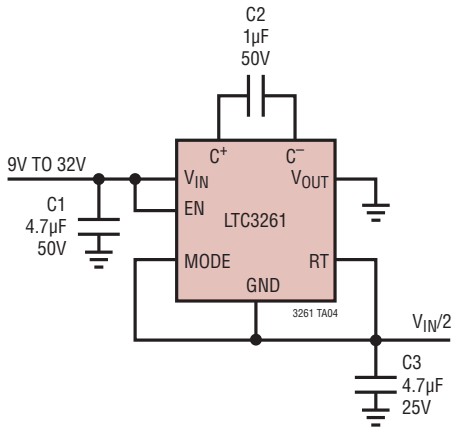



**Figure 4. Maximum Power Dissipation vs Ambient Temperature**

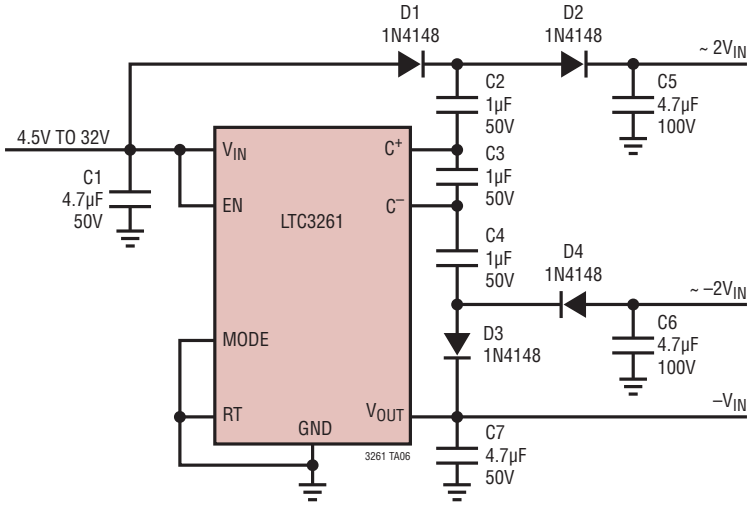
## TYPICAL APPLICATIONS

### High Input Divide by 2 Voltage Divider



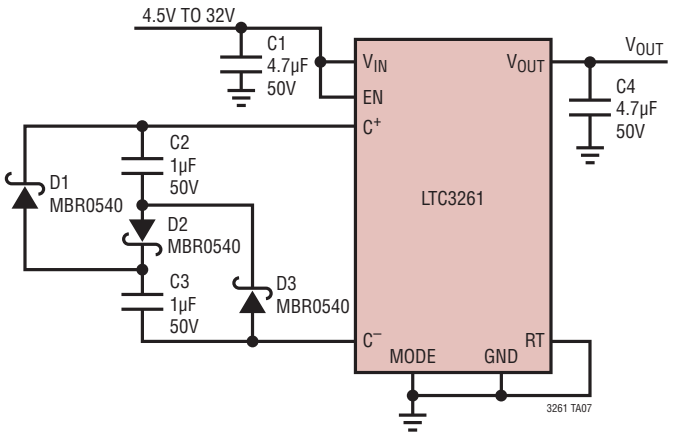

NOTE: MINIMUM LOAD OF 120µA IS REQUIRED TO ASSURE START-UP

### Inverting Charge Pump with Bipolar Doubler




NOTE: $I_{2VIN} \bullet 2 + I_{-2VIN} \bullet 2 + I_{OUT} < = 100mA$

### High Voltage to Inverted Low Voltage Charge Pump

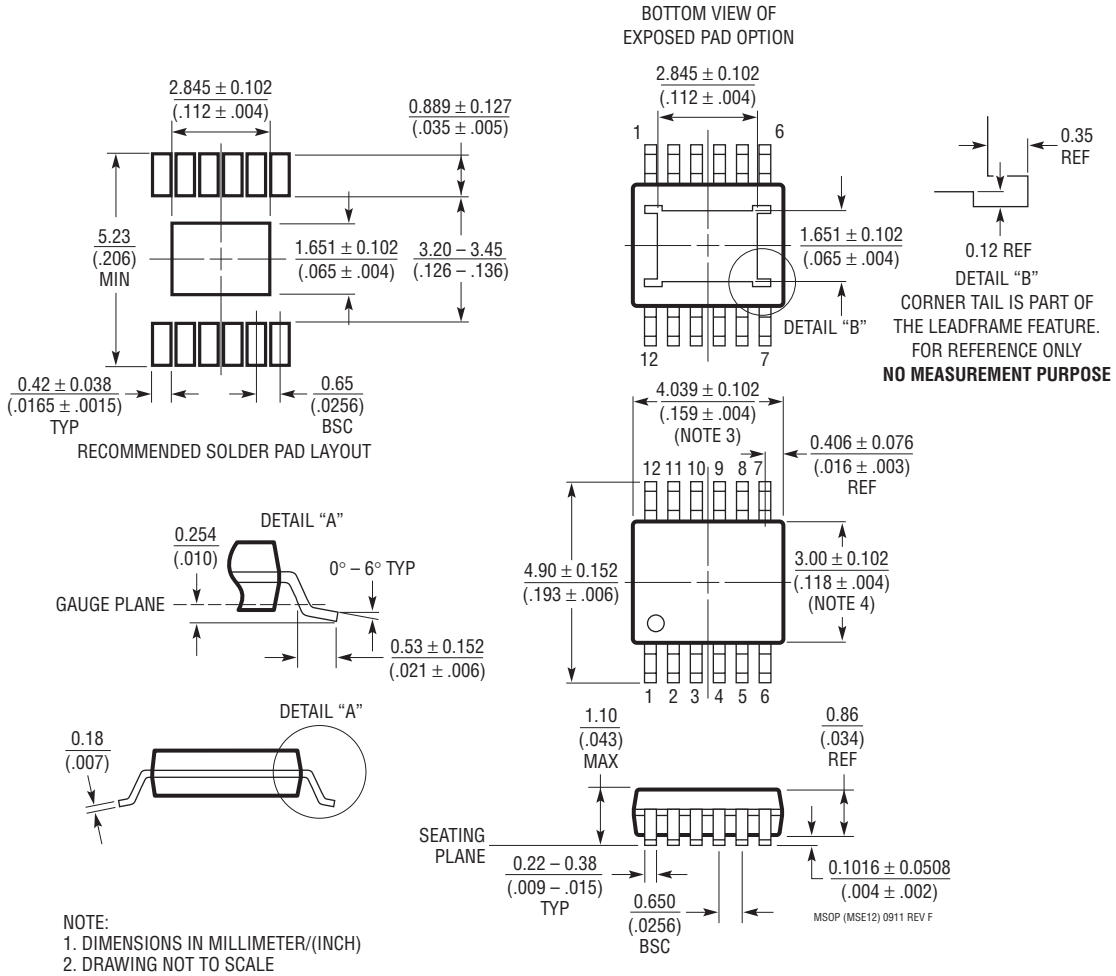



$$V_{OUT} \sim -\left(\frac{V_{IN} - V_f - |I_{OUT}| \bullet R_{OL}}{2} - V_f\right)$$

# PACKAGE DESCRIPTION

**Please refer to http://www.linear.com/designtools/packaging/ for the most recent package drawings.**

**MSE Package**
**12-Lead Plastic MSOP, Exposed Die Pad**
(Reference LTC DWG # 05-08-1666 Rev F)



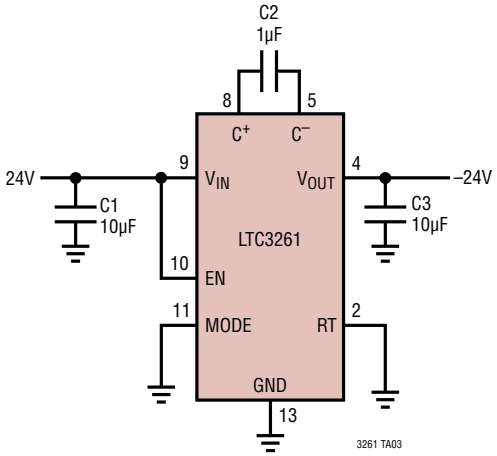

NOTE:
1. DIMENSIONS IN MILLIMETER/(INCH)
2. DRAWING NOT TO SCALE
3. DIMENSION DOES NOT INCLUDE MOLD FLASH, PROTRUSIONS OR GATE BURRS.
   MOLD FLASH, PROTRUSIONS OR GATE BURRS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
4. DIMENSION DOES NOT INCLUDE INTERLEAD FLASH OR PROTRUSIONS.
   INTERLEAD FLASH OR PROTRUSIONS SHALL NOT EXCEED 0.152mm (.006") PER SIDE
5. LEAD COPLANARITY (BOTTOM OF LEADS AFTER FORMING) SHALL BE 0.102mm (.004") MAX
6. EXPOSED PAD DIMENSION DOES INCLUDE MOLD FLASH. MOLD FLASH ON E-PAD SHALL
   NOT EXCEED 0.254mm (.010") PER SIDE.



Information furnished by Linear Technology Corporation is believed to be accurate and reliable. However, no responsibility is assumed for its use. Linear Technology Corporation makes no representation that the interconnection of its circuits as described herein will not infringe on existing patent rights.

## TYPICAL APPLICATION

**24V to –24V Inverter**




## RELATED PARTS

| PART NUMBER | DESCRIPTION | COMMENTS |
|---|---|---|
| LTC1144 | Switched-Capacitor Wide Input Range Voltage Converter with Shutdown | Wide Input Voltage Range: 2V to 18V, $I_{SD}$ < 8µA, SO8 Package |
| LTC1514/LTC1515 | Step-Up/Step-Down Switched-Capacitor DC/DC Converters | $V_{IN}$: 2V to 10V, $V_{OUT}$: 3.3V to 5V, $I_Q$ = 60µA, SO8 Package |
| LT®1611 | 150mA Output, 1.4MHz Micropower Inverting Switching Regulator | $V_{IN}$: 0.9V to 10V, $V_{OUT}$ = ±34V, ThinSOT™ Package |
| LT1614 | 250mA Output, 600kHz Micropower Inverting Switching Regulator | $V_{IN}$: 0.9V to 6V, $V_{OUT}$ = ±30V, $I_Q$ = 1mA, MS8, SO8 Packages |
| LTC1911 | 250mA, 1.5MHz Inductorless Step-Down DC/DC Converter | $V_{IN}$: 2.7V to 5.5V, $V_{OUT}$ = 1.5V/1.8V, $I_Q$ = 180µA, MS8 Package |
| LTC3250/LTC3250-1.2/ LTC3250-1.5 | Inductorless Step-Down DC/DC Converters | $V_{IN}$: 3.1V to 5.5V, $V_{OUT}$ = 1.2V, 1.5V, $I_Q$ = 35µA, ThinSOT Package |
| LTC3251 | 500mA Spread Spectrum Inductorless Step-Down DC/DC Converter | $V_{IN}$: 2.7V to 5.5V, $V_{OUT}$: 0.9V to 1.6V, 1.2V, 1.5V, $I_Q$ = 9µA, MS10E Package |
| LTC3252 | Dual 250mA, Spread Spectrum Inductorless Step-Down DC/DC Converter | $V_{IN}$: 2.7V to 5.5V, $V_{OUT}$: 0.9V to 1.6V, $I_Q$ = 50µA, DFN12 Package |
| LT1054/LT1054L | Switched-Capacitor Voltage Converters with Regulator | $V_{IN}$: 3.5V to 15V/7V, $I_{OUT}$ = 100mA/125mA, N8, S08, SO16 Packages |




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