CHARGE PUMP DC-TO-DC VOLTAGE CONVERTER

FEATURES
- Wide Operating Voltage Range: 1.5V to 15V
- Boost Pin (Pin 1) for Higher Switching Frequency
- High Power Efficiency is 96%
- Easy to Use – Requires Only 2 External Non-Critical Passive Components
- Improved Direct Replacement for Industry Standard ICL7660 and Other Second Source Devices

APPLICATIONS
- Simple Conversion of +5V to ±5V Supplies
- Voltage Multiplication $V_{OUT} = \pm nV_{IN}$
- Negative Supplies for Data Acquisition Systems and Instrumentation
- RS232 Power Supplies
- Supply Splitter, $V_{OUT} = \pm V_S/2$

GENERAL DESCRIPTION
The TC7662B is a pin-compatible upgrade to the Industry standard TC7660 charge pump voltage converter. It converts a +1.5V to +15V input to a corresponding – 1.5 to – 15V output using only two low-cost capacitors, eliminating inductors and their associated cost, size and EMI.

The on-board oscillator operates at a nominal frequency of 10kHz. Frequency is increased to 35kHz when pin 1 is connected to $V^+$, allowing the use of smaller external capacitors. Operation below 10kHz (for lower supply current applications) is also possible by connecting an external capacitor from OSC to ground (with pin 1 open).

The TC7662B is available in both 8-pin DIP and 8-pin small outline (SO) packages in commercial and extended temperature ranges.

ORDERING INFORMATION

<table>
<thead>
<tr>
<th>Part No.</th>
<th>Package</th>
<th>Temperature Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>TC7662BCOA</td>
<td>8-Pin SOIC</td>
<td>0°C to +70°C</td>
</tr>
<tr>
<td>TC7662BCPA</td>
<td>8-Pin Plastic DIP</td>
<td>0°C to +70°C</td>
</tr>
<tr>
<td>TC7662BEOA</td>
<td>8-Pin SOIC</td>
<td>-40°C to +85°C</td>
</tr>
<tr>
<td>TC7662BEPA</td>
<td>8-Pin Plastic DIP</td>
<td>-40°C to +85°C</td>
</tr>
<tr>
<td>TC7660EV</td>
<td>Evaluation Kit for Charge Pump Family</td>
<td></td>
</tr>
</tbody>
</table>

FUNCTIONAL BLOCK DIAGRAM

[Diagram of the TC7662B charge pump circuit]

TC7662BCOA 8-Pin SOIC 0°C to +70°C
TC7662BCPA 8-Pin Plastic DIP 0°C to +70°C
TC7662BEOA 8-Pin SOIC -40°C to +85°C
TC7662BEPA 8-Pin Plastic DIP -40°C to +85°C
TC7660EV Evaluation Kit for Charge Pump Family
### TC7662B

**ABSOLUTE MAXIMUM RATINGS***

Supply Voltage ...................................................... +16.5V  
LV, Boost and OSC Inputs Voltage (Note 1)  
\( V^+ < 5.5V \) ........................................... \( -0.3V \) to \( (V^+ + 0.3V) \)  
\( > 5.5V \) ........................................... \((V^+ - 5.5V)\) to \( (V^+ + 0.3V) \)  
Current Into LV (Note 1)  
\( V^+ > 3.5V \) ........................................... 20\( \mu A \)  
Output Short Duration  
\( (V_{SUPPLY} \leq 5.5V) \) ......................................... Continuous  
Power Dissipation (TA \( \leq 70°C \)) (Note 2)  
Plastic DIP ...................................................... 730mW  
SO ............................................................ 470mW  

**ELECTRICAL CHARACTERISTICS:** \( V^+ = 5V, T_A = +25°C, OSC = \) Free running, Test Circuit Figure 2, Unless Otherwise Specified.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Test Conditions</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>( I^+ )</td>
<td>Supply Current (Note 3)</td>
<td>( R_L = \infty, +25°C )</td>
<td>—</td>
<td>80</td>
<td>160</td>
<td>( \mu A )</td>
</tr>
<tr>
<td></td>
<td>(Boost pin OPEN OR GND)</td>
<td>( 0°C \leq T_A \leq +70°C )</td>
<td>—</td>
<td>—</td>
<td>180</td>
<td>( \mu A )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( -40°C \leq T_A \leq +85°C )</td>
<td>—</td>
<td>—</td>
<td>180</td>
<td>( \mu A )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( -55°C \leq T_A \leq +125°C )</td>
<td>—</td>
<td>—</td>
<td>200</td>
<td>( \mu A )</td>
</tr>
<tr>
<td>( I^+ )</td>
<td>Supply Current</td>
<td>( (Boost pin = V^+) )</td>
<td>( 0°C \leq T_A \leq +70°C )</td>
<td>—</td>
<td>—</td>
<td>300</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( -40°C \leq T_A \leq +85°C )</td>
<td>—</td>
<td>—</td>
<td>350</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( -55°C \leq T_A \leq +125°C )</td>
<td>—</td>
<td>—</td>
<td>400</td>
<td>—</td>
</tr>
<tr>
<td>( V^+ )</td>
<td>Supply Voltage Range, High</td>
<td>( R_L = 10kΩ, LV ) Open, ( T_{MIN} \leq T_A \leq T_{MAX} )</td>
<td>3.0</td>
<td>—</td>
<td>15</td>
<td>V</td>
</tr>
<tr>
<td>( V_L )</td>
<td>Supply Voltage Range, Low</td>
<td>( R_L = 10kΩ, LV ) to GND, ( T_{MIN} \leq T_A \leq T_{MAX} )</td>
<td>1.5</td>
<td>—</td>
<td>3.5</td>
<td>V</td>
</tr>
<tr>
<td>( R_{OUT} )</td>
<td>Output Source Resistance</td>
<td>( I_{OUT} = 20mA, 0°C \leq T_A \leq +70°C )</td>
<td>—</td>
<td>65</td>
<td>100</td>
<td>( \Omega )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( I_{OUT} = 20mA, -40°C \leq T_A \leq +85°C )</td>
<td>—</td>
<td>120</td>
<td>—</td>
<td>( \Omega )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( I_{OUT} = 20mA, -55°C \leq T_A \leq +125°C )</td>
<td>—</td>
<td>150</td>
<td>—</td>
<td>( \Omega )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( I_{OUT} = 3mA, V^+ = 2V, LV ) to GND, ( 0°C \leq T_A \leq +70°C )</td>
<td>—</td>
<td>250</td>
<td>—</td>
<td>( \Omega )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( I_{OUT} = 3mA, V^+ = 2V, LV ) to GND, ( -40°C \leq T_A \leq +85°C )</td>
<td>—</td>
<td>300</td>
<td>—</td>
<td>( \Omega )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( I_{OUT} = 3mA, V^+ = 2V, LV ) to GND, ( -55°C \leq T_A \leq +125°C )</td>
<td>—</td>
<td>400</td>
<td>—</td>
<td>( \Omega )</td>
</tr>
<tr>
<td>( f_{OSC} )</td>
<td>Oscillator Frequency</td>
<td>( C_{OSC} = 0, ) Pin 1 Open or GND ( ) Pin 1 = ( V^+ )</td>
<td>5</td>
<td>10</td>
<td>—</td>
<td>kHz</td>
</tr>
<tr>
<td>( P_{Eff} )</td>
<td>Power Efficiency</td>
<td>( R_L = 5kΩ )</td>
<td>96</td>
<td>96</td>
<td>—</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( T_{MIN} \leq T_A \leq T_{MAX} )</td>
<td>95</td>
<td>97</td>
<td>—</td>
<td>%</td>
</tr>
<tr>
<td>( V_{OUT, Eff} )</td>
<td>Voltage Conversion Efficiency</td>
<td>( R_L = \infty )</td>
<td>99</td>
<td>99.9</td>
<td>—</td>
<td>%</td>
</tr>
<tr>
<td>( Z_{OSC} )</td>
<td>Oscillator Impedance</td>
<td>( V^+ = 2V )</td>
<td>—</td>
<td>1</td>
<td>—</td>
<td>kΩ</td>
</tr>
</tbody>
</table>

**NOTES:**
1. Connecting any terminal to voltages greater than \( V^+ \) or less than GND may cause destructive latch-up. It is recommended that no inputs from sources operating from external supplies be applied prior to “power up” of the TC7662B.
2. Derate linearly above \( 50°C \) by \( 5.5 \) \( \text{mW/°C} \).
3. In the test circuit, there is no external capacitor applied to pin 7. However, when the device is plugged into a test socket, there is usually a very small but finite stray capacitance present, of the order of \( 5pF \).
4. The TC7662B can operate without an external diode over the full temperature and voltage range. This device will function in existing designs which incorporate an external diode with no degradation in overall circuit performance.
THEORETICAL POWER EFFICIENCY CONSIDERATIONS

In theory, a voltage converter can approach 100% efficiency if certain conditions are met:

A. The drive circuitry consumes minimal power.
B. The output switches have extremely low ON resistance and virtually no offset.
C. The impedances of the pump and reservoir capacitors are negligible at the pump frequency.

The TC7662B approaches these conditions for negative voltage conversion if large values of \( C_1 \) and \( C_2 \) are used. Energy is lost only in the transfer of charge between capacitors if a change in voltage occurs. The energy lost is defined by:

\[
E = \frac{1}{2} C_1 (V_1^2 - V_2^2)
\]

where \( V_1 \) and \( V_2 \) are the voltages on \( C_1 \) during the pump and transfer cycles. If the impedances of \( C_1 \) and \( C_2 \) are relatively high at the pump frequency (refer to Figure 2) compared to the value of \( R_L \), there will be a substantial difference in voltages \( V_1 \) and \( V_2 \). Therefore, it is desirable not only to make \( C_2 \) as large as possible to eliminate output voltage ripple, but also to employ a correspondingly large value for \( C_1 \) in order to achieve maximum efficiency of operation.

Dos and Don'ts

1. Do not exceed maximum supply voltages.
2. Do not connect the LV terminal to GND for supply voltages greater than 3.5 volts.
3. Do not short circuit the output to \( V^+ \) supply for voltages above 5.5 volts for extended periods; however, transient conditions including start-up are okay.
4. When using polarized capacitors in the inverting mode, the + terminal of C1 must be connected to pin 2 of the TC7662B and the – terminal of C2 must be connected to GND.

5. If the voltage supply driving the TC7662B has a large source impedance (25-30 ohms), then a 2.2µF capacitor from pin 8 to ground may be required to limit the rate of rise of the input voltage to less than 2V/μsec.

**TYPICAL APPLICATIONS**

**Simple Negative Voltage Converter**

The majority of applications will undoubtedly utilize the TC7662B for generation of negative supply voltages. Figure 3 shows typical connections to provide a negative supply where a positive supply of +1.5V to +15V is available. Keep in mind that pin 6 (LV) is tied to the supply negative (GND) for supply voltages below 3.5 volts.

The output characteristics of the circuit in Figure 3 can be approximated by an ideal voltage source in series with a resistance as shown in Figure 3b. The voltage source has a value of (V+). The output impedance (RO) is a function of the ON resistance of the internal MOS switches (shown in Figure 2), the switching frequency, the value of C1 and C2, and the ESR (equivalent series resistance) of C1 and C2. A good first order approximation for RO is:

\[
RO \equiv 2 \times 23 + \frac{1}{(5 \times 10^3 \times 10 \times 10^{-6})} + 4 \times ESR_{C1} + ESR_{C2}
\]

\[
RO \equiv (46 + 20 + 5 \times ESR_C) \Omega
\]

Since the ESRs of the capacitors are reflected in the output impedance multiplied by a factor of 5, a high value could potentially swamp out a low 1/(fPUMP x C1) term, rendering an increase in switching frequency or filter capacitor ineffective. Typical electrolytic capacitors may have ESRs as high as 10Ω.

**Output Ripple**

ESR also affects the ripple voltage seen at the output. The total ripple is determined by 2 voltages, A and B, as shown in Figure 4. Segment A is the voltage drop across the ESR of C2 at the instant it goes from being charged by C1 (current flowing into C2) to being discharged through the load (current flowing out of C2). The magnitude of this current change is 2 x IOUT, hence the total drop is 2 x IOUT x ESR_{C2} volts. Segment B is the voltage change across C2 during time t2, the half of the cycle when C2 supplies current to the load. The drop at B is IOUT x t2/C2 volts. The peak-to-peak ripple voltage is the sum of these voltage drops:

\[
V_{RIPPLE} \equiv \left( \frac{1}{2 \times f_{PUMP} \times C_2} + ESR_{C2} \times I_{OUT} \right)
\]

Figure 3. Simple Negative Converter and its Output Equivalent

Figure 4. Output Ripple
Paralleling Devices

Any number of TC7662B voltage converters may be paralleled to reduce output resistance (Figure 5). The reservoir capacitor, \( C_2 \), serves all devices, while each device requires its own pump capacitor, \( C_1 \). The resultant output resistance would be approximately:

\[
R_{OUT} = \frac{R_{OUT \ (of \ TC7662B)}}{n \ (number \ of \ devices)}
\]

![Figure 5. Paralleling Devices](image)

Cascading Devices

The TC7662B may be cascaded as shown to produce larger negative multiplication of the initial supply voltage. However, due to the finite efficiency of each device, the practical limit is 10 devices for light loads. The output voltage is defined by:

\[
V_{OUT} = -n(V_{IN})
\]

where \( n \) is an integer representing the number of devices cascaded. The resulting output resistance would be approximately the weighted sum of the individual TC7662B \( R_{OUT} \) values.

![Figure 6. Cascading Devices for Increased Output Voltage](image)

Changing the TC7662B Oscillator Frequency

It may be desirable in some applications (due to noise or other considerations) to increase the oscillator frequency. This is achieved by one of several methods described below:

By connecting the BOOSTPin (Pin 1) to \( V^+ \), the oscillator charge and discharge current is increased and, hence the oscillator frequency is increased by approximately 3-1/2 times. The result is a decrease in the output impedance and ripple. This is of major importance for surface mount applications where capacitor size and cost are critical. Smaller capacitors, e.g., 0.1\( \mu \)F, can be used in conjunction with the Boost Pin in order to achieve similar output currents compared to the device free running with \( C_1 = C_2 = 1\mu \)F or 10\( \mu \)F. (Refer to graph of Output Source Resistance as a Function of Oscillator Frequency).

Increasing the oscillator frequency can also be achieved by overdriving the oscillator from an external clock as shown in Figure 7. In order to prevent device latchup, a 1k\( \Omega \) resistor must be used in series with the clock output. In a situation where the designer has generated the external clock frequency using TTL logic, the addition of a 10k\( \Omega \) pullup resistor to \( V^+ \) supply is required. Note that the pump frequency with external clocking, as with internal clocking, will be 1/2 of the clock frequency. Output transitions occur on the positive-going edge of the clock.

![Figure 7. External Clocking](image)

It is also possible to increase the conversion efficiency of the TC7662B at low load levels by lowering the oscillator frequency. This reduces the switching losses, and is shown in Figure 8. However, lowering the oscillator frequency will cause an undesirable increase in the impedance of the pump (\( C_1 \)) and reservoir (\( C_2 \)) capacitors; this is overcome by increasing the values of \( C_1 \) and \( C_2 \) by the same factor that the frequency has been reduced. For example, the addition of a 100pF capacitor between pin 7 (Osc) and \( V^+ \) will lower the oscillator frequency to 1kHz from its nominal frequency of 10kHz (multiple of 10), and thereby necessitate a corresponding increase in the value of \( C_1 \) and \( C_2 \) (from 10\( \mu \)F to 100\( \mu \)F).
**Positive Voltage Doubling**

The TC7662B may be employed to achieve positive voltage doubling using the circuit shown in Figure 9. In this application, the pump inverter switches of the TC7662B are used to charge $C_1$ to a voltage level of $V^+ - V_F$ (where $V^+$ is the supply voltage and $V_F$ is the forward voltage on $C_1$ plus the supply voltage ($V^+$) applied through diode $D_2$ to capacitor $C_2$). The voltage thus created on $C_2$ becomes $(2V^+) - (2V_F)$, or twice the supply voltage minus the combined forward voltage drops of diodes $D_1$ and $D_2$.

The source impedance of the output ($V_{OUT}$) will depend on the output current, but for $V^+ = 5V$ and an output current of 10 mA, it will be approximately $60\Omega$.

**Combined Negative Voltage Conversion and Positive Supply Multiplication**

Figure 10 combines the functions shown in Figures 3 and 9 to provide negative voltage conversion and positive voltage doubling simultaneously. This approach would be, for example, suitable for generating $+9V$ and $-5V$ from an existing $+5V$ supply. In this instance, capacitors $C_1$ and $C_3$ perform the pump and reservoir functions, respectively, for the generation of the negative voltage, while capacitors $C_2$ and $C_4$ are pump and reservoir, respectively, for the doubled positive voltage. There is a penalty in this configuration which combines both functions, however, in that the source impedances of the generated supplies will be somewhat higher due to the finite impedance of the common charge pump driver at pin 2 of the device.

**Voltage Splitting**

The bidirectional characteristics can also be used to split a higher supply in half, as shown in Figure 11. The combined load will be evenly shared between the two sides and a high value resistor to the LV pin ensures start-up. Because the switches share the load in parallel, the output impedance is much lower than in the standard circuits, and higher currents can be drawn from the device. By using this circuit, and then the circuit of Figure 6, $+15V$ can be converted (via $+7.5V$ and $-7.5V$) to a nominal $-15V$, though with rather high series resistance ($\sim 250\Omega$).
Regulated Negative Voltage Supply

In some cases, the output impedance of the TC7662B can be a problem, particularly if the load current varies substantially. The circuit of Figure 12 can be used to overcome this by controlling the input voltage, via an ICL7611 low-power CMOS op amp, in such a way as to maintain a nearly constant output voltage. Direct feedback is advisable, since the TC7662B’s output does not respond instantaneously to change in input, but only after the switching delay. The circuit shown supplies enough delay to accommodate the TC7662B, while maintaining adequate feedback. An increase in pump and storage capacitors is desirable, and the values shown provide an output impedance of less than 5Ω to a load of 10mA.

**Figure 13. RS232 Levels from a Single 5V Supply**

**Figure 12. Regulating the Output Voltage**
TYPICAL CHARACTERISTICS

Supply Current vs. Temperature
(with Boost Pin = \( V_{\text{IN}} \))

Voltage Conversion

Output Source Resistance vs. Supply Voltage

Output Source Resistance vs. Temperature

Output Voltage vs. Output Current

Supply Current vs. Temperature
TYPICAL CHARACTERISTICS (cont.)

Unloaded Osc Freq vs. Temperature

Unloaded Osc Freq vs. Temperature with Boost Pin = V_IN

PACKAGE DIMENSIONS

8-Pin Plastic DIP

Dimensions: inches (mm)
PACKAGE DIMENSIONS (Cont.)

8-Pin SOIC

Dimensions: inches (mm)