

# "Get Pumped" with TelCom's DC-DC Charge Pump Converters

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## INTRODUCTION

Today's electronic equipment must be smaller and less expensive than ever before. The analog portions of many systems mandate special power supply requirements (such as negative or higher power supply voltages), resulting in added bulk and cost. The typical characteristics of these additional supplies are low cost, high efficiency, small size, and relatively low output current (usually less than 100mA).

Combinations of dedicated voltage sources (i.e. negative rectification of the AC input, additional batteries, special transformer windings, etc.) and linear regulators not only add cost and size, but cut system efficiency. Switch mode power supplies offer higher efficiency operation compared to linear regulators. Switched mode power supply schemes store energy in an LC circuit. The average voltage delivered to the load is regulated by pulse width or frequency modulating this stored energy. However, such topologies complicate matters by introducing radiated electromagnetic interference (EMI) as well as added cost and size.

TelCom's DC-to-DC charge pump voltage converters are the single, best answer to low output current, dedicated analog supplies. These charge pumps provide efficiency up to 99%. Instead of using an inductor, two external capacitors store energy, drastically reducing any radiated EMI. Offered in 8-pin surface mount ICs, TelCom's converters, coupled with two capacitors (see Figure 1), provide a low cost, small outline solution. When light-load, voltage inversion or doubling is needed, TelCom's charge pump DC-to-DC converters are the solution of choice.

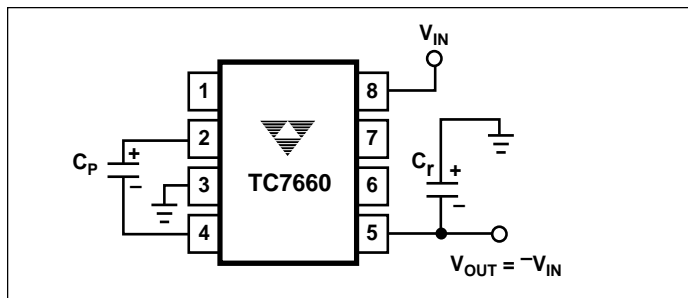


Figure 1. Voltage Inverter

## PRINCIPLES OF OPERATION

The charge pump DC-to-DC converter works on the principle of charge transfer. By storing charge in a "flying capacitor" and transferring this charge to a reservoir capacitor, the DC-to-DC converter can perform such common applications as voltage inversion and voltage doubling.

Look at the example of the voltage inverter in Figure 2. An internal oscillator and logic circuit controls a switch matrix consisting of  $S_1$  and  $S_2$ .

During the first half cycle both switches are in the left most position.  $C_P$  charges to the input voltage,  $V_{IN}$ . During the second half cycle, the switches move to the right. This ties the positive side of  $C_P$  to ground, and negative side of  $C_P$  to  $V_{OUT}$ , offsetting  $C_P$  by negative  $V_{IN}$  volts.  $C_P$  and  $C_R$  are now tied together in parallel, and charge is transferred from the flying capacitor,  $C_P$ , to the reservoir capacitor,  $C_R$ .

For now, assume that the switch losses are negligible, and the oscillator cycle time is at least 10 times the RC time constant of the external capacitors. Under these conditions, the DC-to-DC converter operates at close to 99% efficiency, with the only losses due to the supply current needed to run the oscillator and logic circuitry. With these assumptions made, the converter can be modeled as an ideal voltage source. To generate a more realistic model other things must be considered.

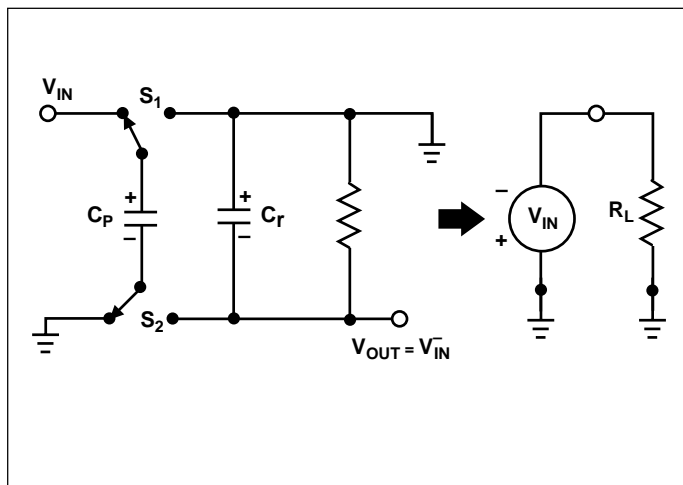


Figure 2. Charge Transfer

## REAL WORLD ANALYSIS

There is one P-channel (SW1) and three N-channel (SW2, SW3, and SW4) MOS power switches that allow charge to be transferred from the flying capacitor to the reservoir capacitor (see Figure 3). These switches are driven by the outputs of the logic circuitry which are synchronized to the internal oscillator frequency, divided by two.

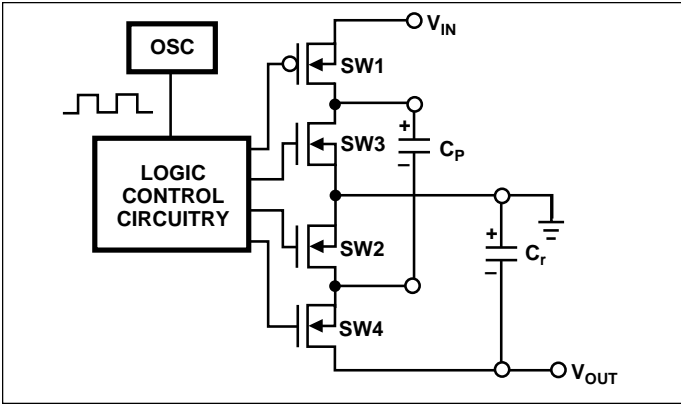


Figure 3. Switch Matrix

**CHARGING THE FLYING CAP**

During the first half cycle, SW1 and SW2 are ON, and SW3 and SW4 are OFF. The circuit can be simplified to that shown in Figure 4. The flying capacitor, Cp, is charged to a voltage, V<sub>Cp</sub>, based upon Equation 1. The total charge on the flying cap, q<sub>p</sub>, is equal to CpV<sub>Cp</sub>.

$$V_{Cp} = V_{IN} - V_{IN} e^{-(t/RCp)} + V_{Cp0} e^{-(t/RCp)}$$

where: V<sub>Cp0</sub> = V<sub>Cp</sub> at the beginning of the cycle  
 f<sub>CHARGE</sub> = 0.5 x f<sub>OSC</sub>  
 ∴ t = 50% x (1/ f<sub>CHARGE</sub>) = 1/f<sub>OSC</sub>  
 R = R<sub>SW1</sub> + R<sub>SW2</sub> + ESRC<sub>p</sub>  
 V<sub>IN</sub> = Supply Voltage

Equation 1.

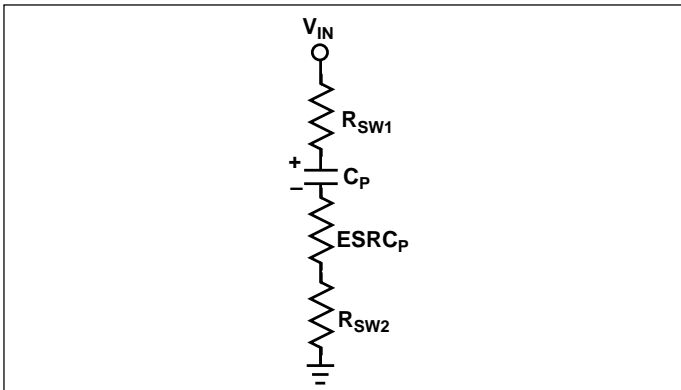


Figure 4. Charging Flying Capacitor

When operating a 100kHz, dt = 10 μsec. Consequently, if 10μF capacitors are being used, R will have to be <0.2Ω (RC is less than 5.5 time constants) to insure that V<sub>Cp</sub> charges to the full value of V<sub>IN</sub> within one half cycle. Consequently, smaller capacitors should be used when operating at higher frequencies.

**SUPPLYING ENERGY TO THE LOAD**

In addition to Cp being charged during this half cycle, the reservoir capacitor Cr, is supplying current to the load, as shown in Figure 5. At the beginning of this half cycle, Cr is switched from being charged, to supplying current to the load. This represents a

change in current equal in magnitude to 2xI<sub>L</sub>. The voltage on the output of the converter (pin 5) will drop instantaneously at the beginning of this half cycle due to the IR drop across Cr, and is reflected by 2xI<sub>L</sub>ESRC<sub>r</sub> in Equation 2. Assuming a constant current load condition, the discharge of Cr can be represented by the Equation 2. This equation can be used to approximate the devices output ripple voltage.

$$V_{Cr} = V_{Cr0} - 2xI_L ESRC_r - (I_L/C_r)dt$$

where: V<sub>Cr0</sub> = Voltage on Cr at time 0  
 I<sub>L</sub> = Load current  
 dt = 1/f<sub>OSC</sub>

Equation 2.

ESRC<sub>r</sub> plays a direct part in contributing to the device's output ripple voltage. If the device is supplying a load of 20mA, and the capacitor has an ESR of 10Ω, a minimum output ripple of 200mV should be expected. Alternately, increasing f<sub>OSC</sub> will decrease the output ripple voltage. However, increasing f<sub>OSC</sub> results in increased switching loss (increased I<sub>SUPPLY</sub>). At some point, the switching losses will become significant enough that the dropoff in efficiency will negate the benefits of increasing the operating frequency.

Increasing f<sub>OSC</sub> also allows smaller capacitors to be used. Keep in mind that reduction in capacitor size typically results in increased ESR which will have a detrimental effect on output ripple at higher currents.

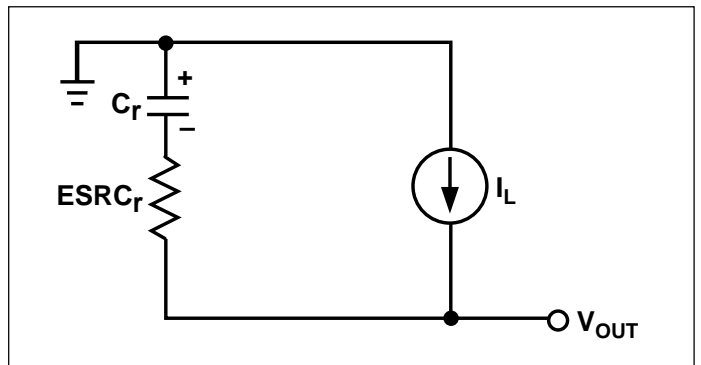


Figure 5. Supplying Current to Load

**TRANSFERRING CHARGE**

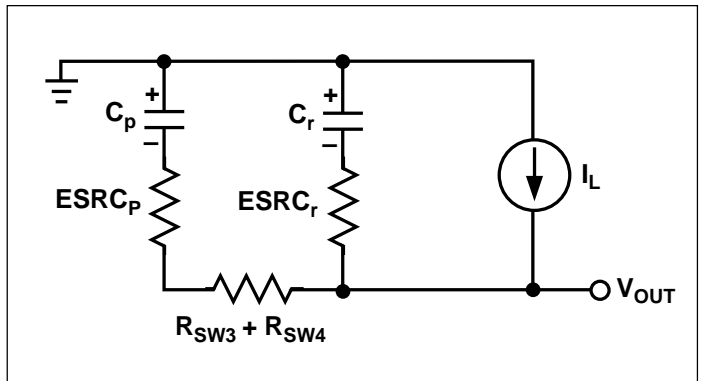


Figure 6. Charge Transfer Simplified Circuit

During the second phase of the cycle, SW1 and SW3 are turned OFF, and SW2 and SW4 are turned ON. The simplified circuit is shown in Figure 6. The logic timing is such that there is finite delay to insure that there will never be a continuous path from  $V_{IN}$  to ground.

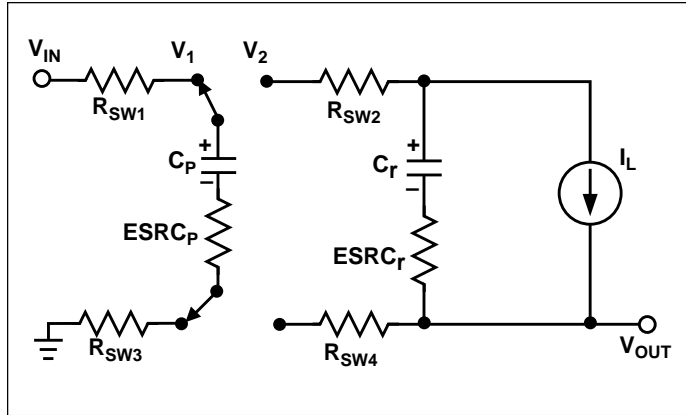


Figure 7. Charge Transfer

The flying capacitor now is tied in parallel with  $C_r$  and transfers a portion of its charge into  $C_r$ , as well as supplying current to the load. The voltage on  $C_p$  changes from  $V_1$ , prior to the switch, to  $V_2$ , at the end of the cycle (see Figure 7). This voltage  $V_2$  depends upon the energy dissipated through circuit switch resistance and capacitor ESR, as well as the energy delivered to the load. The energy lost is defined in Equation 3 below.

$$E = 1/2 C_r (V_1^2 - V_2^2)$$

Equation 3.

The amount of charge that has been transferred,  $q_{TRANSFER}$ , from the flying capacitor to the output is shown in Equation 4.

$$q_{TRANSFER} = C_p V_1 - C_p V_2 = C_p \Delta V_{C_p}$$

Equation 4.

Knowing that the switch is operating at  $f_{OSC}$ , an expression for current can be written as:

$$\begin{aligned} I &= C \, dV/dt = C_p (V_1 - V_2) / dt \\ dt &= 1/f_{OSC} \\ I &= C_p (V_1 - V_2) / (1/f_{OSC}) \\ \text{or } I &= (V_1 - V_2) / (1/f_{OSC} C_p) \end{aligned}$$

Equation 5.

An expression for the equivalent impedance during the transfer cycle can thus be written as:

$$R_{TRANSFER} = (1/f_{OSC} C_p)$$

## OUTPUT OF IMPEDANCE

If we take into account what we now know about the switch resistance and capacitor ESR, we can generate a more accurate model for the charge pump, as an ideal voltage source in series with a resistor (see Figure 8). This resistor,  $R_O$ , represents the device's output resistance and is comprised of the following:

- (1) Series resistance of  $R_{SW1}$ ,  $R_{SW2}$  and  $ESRC_1$  when  $C_p$  is charging.
- (2) Series resistance of  $R_{SW3}$ ,  $R_{SW4}$ , and  $ESRC_1$  when  $C_p$  is transferring charge to  $C_r$ .
- (3) The equivalent resistance during the charge transfer cycle.
- (4) The equivalent series resistance of the reservoir capacitor,  $ESRC_r$ . This expression is summarized in Equation 6 below.

$$\begin{aligned} R_O &= 2(ESRC_p + R_{SW1} + R_{SW2}) + \\ &2(ESRC_p + R_{SW3} + R_{SW4}) + \\ &R_{TRANSFER} + ESRC_r \end{aligned}$$

where:  $R_{TRANSFER} = (1/f_{OSC} C_p)$

Equation 6.

Note that because the switches are only ON for half a cycle, the average resistance is multiplied by a factor of two.

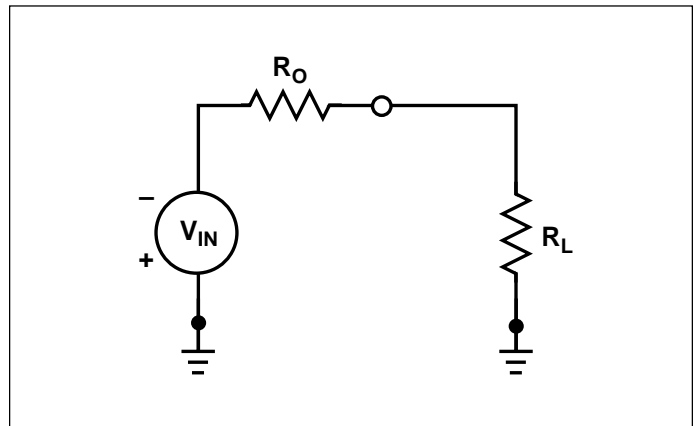


Figure 8. Charge Pump Model

If we assume that the switch resistances are equal,  $R_O$  simplifies to:

$$R_O = 4R_{SW} + 4ESRC_p + R_{TRANSFER} + ESRC_r$$

where:  $R_{TRANSFER} = (1/f_{OSC} C_p)$

The switch resistance is a function of the transistor geometries and process technology. The user has little control over its value, but should be aware that  $R_{SW}$  is sensitive to temperature and supply voltage.  $R_{SW}$  will decrease with increasing supply voltage or decreasing temperature. Because  $R_{SW}$  is multiplied by a factor of four, increasing  $R_{SW}$  can have a significant effect on overall output resistance.

Looking at the remaining expressions that make up  $R_O$ , the following can be stated:

- (1)  $ESR_{C_p}$  has a four times larger effect on  $R_O$  than  $ESR_{C_p}$ .
- (2) Lowering  $f_{OSC}$  will increase  $R_O$ .
- (3) Increasing  $f_{OSC}$  will decrease  $R_O$  to a point. Eventually ESR will dominate, nullifying further increases in  $f_{OSC}$ .

## CAPACITOR SELECTION

The two major factors that contribute to the charge pumps output resistance are the IC's internal switch resistance, and the ESR of capacitors  $C_1$  and  $C_2$ . The internal switch resistance must be accepted as is. However, it is critical that the ESR of  $C_1$  and  $C_2$  be minimized to insure optimal device operation. The external capacitor value and type that best suits the designer's size and cost requirements should be selected.

Ceramic capacitors offer the lowest ESR, followed by, in order of increasing ESR, OS-CON, Film, Aluminum Electrolytics and Tantalum capacitors. Within one technology, ESR tends to closely track physical capacitor volume, given capacitance value and voltage rating are constant. Consequently, lower ESR is usually obtained at the cost of increased capacitor size.

Film capacitors are quickly negated as a viable solution based upon their excessive cost and size.

Ceramic capacitors offer the lowest ESR, but can be cost prohibitive. Their relatively low volumetric efficiency can result in size restrictions. Also, they exhibit an order of magnitude increase in ESR as operating temperature drops from  $+25^{\circ}\text{C}$  to  $-55^{\circ}\text{C}$ .

OS-CON capacitors offer an ESR only slightly higher than ceramics but consume more volume. The OS-CON capacitor exhibits excellent linearity from  $-55^{\circ}\text{C}$  to  $+125^{\circ}\text{C}$ .

Aluminum Electrolytics are ideal for low cost applications where board space is not of concern. Electrolytics, like OS-CON capacitors are typically offered in a radial lead package, but are available in surface mount styles.

Tantalum capacitors offer an ESR similar to the Aluminum Electrolytic, but their excellent volumetric efficiency provides the smallest profile solution at a reasonable cost.

Table 1 identifies suppliers of low ESR capacitors. Most manufacturers do not identify ESR but rather provide DF, (dissipation factor) specifications at 120Hz. The lower the DF the lower the ESR, as ESR is derived from the following equation:

$$ESR = DF / (2\pi fC)$$

The table identifies ESR values where they have been provided by the manufacturer.

## LAYOUT

To insure good noise performance, use the following basic layout practices:

- Minimize stray inductance by keeping board trace lengths to a minimum.
- Minimize ground impedance by employing a ground plane.
- Mount the charge pump IC as close to the load as possible to minimize output impedance.
- Mount the supply decoupling and pump capacitors as close as possible to the charge pump IC.

**Table 1. ESR for various Manufacturers and Capacitor Types**

| Manufacturer | Series | DF @ 120Hz | ESR @ 100kHz | Cap (μF) | Working Voltage | Size            | Capacitor Type       |
|--------------|--------|------------|--------------|----------|-----------------|-----------------|----------------------|
| Chemi-Con    | MV     | 0.12       | —            | 4.7      | 50              | 3.0 x 5.2       | Surf Mt Alum Elec    |
| Sanyo        | CV-GS  | 0.14       | —            | 4.7      | 25              | 4.3 x 4.3 x 5.4 | Surf Mt Alum Elec    |
| Panasonic    | VS     | 0.14       | —            | 4.7      | 25              | 3.0 x 5.4       | Surf Mt Alum Elec    |
| Panasonic    | CB     | 0.06       | —            | 4.7      | 16              | 7.9 x 5.3 x 3.3 | Surf Mt Spec Polymer |
| Sanyo        | SM     | 0.07       | 0.150Ω       | 4.7      | 20              | 7.0 x 7.0 x 9.0 | Surf Mt OS-CON       |
| Marcon       | THC    | <.05       | ≈ 0.05Ω      | 4.7      | 25              | 3.2 x 2.5 x 2.0 | Ceramic Chip         |
| Marcon       | TCC    | <.05       | —            | 4.7      | 25              | 5.6 x 5.0 x 2.5 | Ceramic Chip         |
| Mallory      | T491/5 | .06        | —            | 4.7      | 25              | 6.0 x 3.2 x 4.5 | Tantalum Chip        |
| Marcon       | MCS    | —          | —            | 4.7      | 20              | 3.5 x 2.8 x 1.9 | Tantalum Chip        |
| Matsuo       | 267E   | .06        | 0.8Ω         | 4.7      | 20              | 3.5 x 2.8 x 1.9 | Tantalum Chip        |
| AVX          | TAJ    | .06        | <3Ω          | 4.7      | 20              | 3.5 x 2.8 x 1.9 | Tantalum Chip        |
| AVX          | TAJ    | .06        | 5Ω           | 3.3      | 16              | 3.5 x 2.8 x 1.2 | Tantalum Chip        |
| Panasonic    | TE     | .06        | —            | 4.7      | 25              | 3.5 x 2.8 x 2.2 | Tantalum Chip        |

**Table 1. ESR for various Manufacturers and Capacitor Types (Cont.)**

| Manufacturer | Series  | DF @ 120Hz | ESR @ 100kHz | Cap (μF) | Working Voltage | Size            | Capacitor Type    |
|--------------|---------|------------|--------------|----------|-----------------|-----------------|-------------------|
| Illinois Cap | RZM     | .12        | ≈ 4Ω         | 4.7      | 50              | 5.0 x 11.0      | Radial Ld Al Elec |
| Panasonic    | HF      | .08        | —            | 4.7      | 25              | 6.3 x 11.2      | Radial Ld Al Elec |
| Panasonic    | KF      | .10        | —            | 4.7      | 25              | 4.0 x 7.0       | Radial Ld Al Elec |
| Mallory      | SSR     | .10        | —            | 4.7      | 50              | 4.0 x 7.0       | Radial Ld Al Elec |
| United Chemi | SXE     | .10        | —            | 4.7      | 50              | 4.0 x 7.0       | Radial Ld Al Elec |
| Marcon       | LSM     | —          | —            | 4.7      | 25              | 4.0 x 5.0       | Radial Ld Al Elec |
| Sanyo        | UGX     | .12        | —            | 4.7      | 35              | 4.0 x 5.0       | Radial Ld Al Elec |
| RGA          | LESR    | .06        | —            | 4.7      | 50              | 8.0 x 11.5      | Radial Ld Al Elec |
| Sanyo        | SG      | .05        | 0.125Ω       | 4.7      | 25              | 6.3 x 6.8       | Rad Ld OS-CON     |
| Sanyo        | SL      | .06        | 0.150Ω       | 4.7      | 25              | 6.3 x 5.0       | Rad Ld OS-CON     |
| Panasonic    | MF      | .06        | —            | 4.7      | 25              | 3.7 x 4.1 x 5.6 | Radial Ld Tant    |
| Mallory      | TDL/TDC | .05        | —            | 4.7      | 25              | 8.6 x 10.16     | Radial Ld Tant    |
| Matsuo       | 202     | .06        | —            | 4.7      | 25              | 4.8 x 7.5       | Radial Ld Tant    |
| AVX          | TAP     | .06        | —            | 4.7      | 25              | 8.5 x 10.0      | Radial Ld Tant    |
| AVX          | TMH     | .06        | —            | 4.7      | 20              | 3.8 x 6.3       | Radial Ld Tant    |

## PRODUCT OVERVIEW

TelCom offers fourteen products in the charge pump DC-DC converter family (see Table 2). All fourteen products are offered in 8-Pin DIP and SOIC packages. These products are ideal for use in any low current, voltage inversion or doubling applications.

The TC7660 is a stripped down converter that is ideal for low current (<20mA) applications with  $V_{IN}$  ranges of 1.5V – 10V.

The TC7660H is an upgrade of the TC7660. Its oscillator runs at a higher frequency (120kHz), which facilitates the use of smaller external capacitors. Using the same size capacitors will result in a reduced output ripple voltage.

The TC1044S and TC7660S offer increased operating voltages up to 12V, as well as a BOOST pin that allows the oscillator to run at 45kHz. In addition, these devices have a slightly lower output impedance which supports slightly higher load currents than the TC7660 and TC7660H.

The TC7662B offers an even higher operating voltage of 15V. The TC7662B has comparable output impedance to the TC1044S and TC7660S.

The TC7662A has a significant reduction in its output impedance over the aforementioned devices. This enables the TC7662A to be used in applications where load currents up to 60mA exist. The TC7662A operates with input voltages up to 18V.

The TC962 is a sister part to the TC7662A, with slightly lower output impedance. The TC962 can supply up to 80mA of load current. In addition, the TC962 has an on board 6.4V zener reference, as well as FREQx2 pin, for doubling the oscillator frequency.

The most robust charge pump is the TC660 which was designed to handle heavier loads. It can support load currents up to 100mA.

The TCM680 is slightly different than the aforementioned devices in that it provides both positive and inverting voltage

doubling functions at the same time. This is ideal for use in portable systems where a ±5V bias needs to be generated from two 1.5V cells.

The TC682 is a subset of the TCM680. It generates an output voltage equal to  $-2xV_{IN}$ . The TC682 is the only device of its kind available, and uses a proprietary technique to generate a  $-2xV_{IN}$  output, without generating  $+2xV_{IN}$ . This results in a 50% reduction in supply current as compared to the TCM680.

The TCM850 differs from the other charge pumps as the output voltage is regulated. The TCM850 is designed for applications where a regulated negative output is required. It is ideal for generating the negative voltage bias for GaAs transistors in cellular phones and liquid crystal displays. A shutdown feature allows the TCM850 to draw as little as 1μA in a standby mode.

A more detailed summary of these products can be found in Table 2.

## CHARGE PUMP EVALUATION KIT

The TC7660EV can be used to evaluate 11 products in TelCom's family of charge-pump based DC-DC converters, excluding the TCM851/2/3. The TCM850/1/2/3 are supported by a dedicated evaluation kit, the TCM850EV. These kits allow evaluation of all charge pump devices on a 4-inch by 6-inch card. Contact TelCom Semiconductor for details about the TC7660EV, the TCM850EV and the entire line of DC-to-DC charge pump converters.

**Table 2. Charge Pump Product Summary**

| Pin #                             | Part Number                          |   |   |   |  |   |  |  |   |   |  |  |   |   |  |
|-----------------------------------|--------------------------------------|---|---|---|--|---|--|--|---|---|--|--|---|---|--|
|                                   | TC660                                | TC682   | TC962   | TC1044S   | TC1121   | TC1142  | TC7660   | TC7660H                                | TC7660S   | TC7662A   | TC7662B  | TCM680   | TCM828                                  | TCM829                                  | TCM850-3   |
| 1                                 | FC                                   | C <sub>1</sub> <sup>-</sup>                                     | Zener   | Boost   | FC   | C <sub>1</sub> <sup>+</sup>   | N/C  | N/C                                    | Boost   | N/C   | Boost  | 0  | OUT                                     | OUT                                     | C <sup>+</sup>   |
| 2                                 | C <sup>+</sup>                       | C <sub>2</sub> <sup>+</sup>                                     | C <sup>+</sup>  | C <sup>+</sup>  | C <sup>+</sup>   | C <sub>2</sub> <sup>+</sup>   | C <sup>+</sup>                                   | C <sup>+</sup>                         | C <sup>+</sup>  | C <sup>+</sup>  | C <sup>+</sup>   | C <sub>2</sub> <sup>+</sup>                              | V <sub>IN</sub>                         | V <sub>IN</sub>                         | C <sup>-</sup>   |
| 3                                 | GND                                  | C <sub>2</sub> <sup>-</sup>                                     | GND   | GND   | GND  | C <sub>2</sub> <sup>-</sup>   | GND  | GND                                    | GND   | GND   | GND  | V <sub>OUT</sub>   | C <sup>-</sup>                          | C <sup>-</sup>                          | NEG/OUT  |
| 4                                 | C <sup>-</sup>                       | NC  | C <sup>-</sup>  | C <sup>-</sup>  | C <sup>-</sup>   | V <sub>OUT</sub>  | C <sup>-</sup>                                   | C <sup>-</sup>                         | C <sup>-</sup>  | C <sup>-</sup>  | C <sup>-</sup>   | V <sub>OUT</sub>   | GND                                     | GND                                     | SHDN/OSC   |
| 5                                 | V <sub>OUT</sub>                     | GND   | V <sub>OUT</sub>  | V <sub>OUT</sub>  | V <sub>OUT</sub>   | GND   | V <sub>OUT</sub>                                 | V <sub>OUT</sub>                       | V <sub>OUT</sub>  | V <sub>OUT</sub>  | V <sub>OUT</sub>   | GND  | C <sup>+</sup>                          | C <sup>+</sup>                          | FB/CONT  |
| 6                                 | LV                                   | V <sub>IN</sub>   | Freq x 2  | LV  | SHDN   | V <sub>IN</sub>   | LV   | LV                                     | LV  | N/C   | LV   | V <sub>IN</sub>  | V <sub>IN</sub>                         | V <sub>IN</sub>                         | OUT  |
| 7                                 | OSC                                  | C <sub>1</sub> <sup>+</sup>                                     | OSC   | OSC   | OSC  | C <sub>1</sub> <sup>+</sup>   | OSC  | OSC                                    | OSC   | OSC   | OSC  | C <sub>1</sub> <sup>+</sup>                              | C <sub>1</sub> <sup>+</sup>             | C <sub>1</sub> <sup>+</sup>             | GND  |
| 8                                 | V <sup>+</sup>                       | V <sub>OUT</sub>  | V <sup>+</sup>  | V <sup>+</sup>  | V <sub>IN</sub>  | OSC/SHDN  | V <sup>+</sup>                                   | V <sup>+</sup>                         | V <sup>+</sup>  | V <sup>+</sup>  | V <sup>+</sup>   | V <sub>OUT</sub>   | V <sub>OUT</sub>                        | V <sub>OUT</sub>                        | IN   |
| <b>Primary Applications</b>       | V <sub>IN</sub> or 2 V <sub>IN</sub> | -2V <sub>IN</sub>   | V <sub>IN</sub> or 2 V <sub>IN</sub>                                  | V <sub>IN</sub> or 2 V <sub>IN</sub>  | V <sub>IN</sub> or 2 V <sub>IN</sub>   | -2V <sub>IN</sub>   | V <sub>IN</sub> or 2 V <sub>IN</sub>             | V <sub>IN</sub> or 2 V <sub>IN</sub>   | V <sub>IN</sub> or 2 V <sub>IN</sub>  | V <sub>IN</sub> or 2 V <sub>IN</sub>  | V <sub>IN</sub> or 2 V <sub>IN</sub>   | ± 2V <sub>IN</sub>                                       |   |   | REG-V <sub>IN</sub>  |
| <b>Packages</b>                   |                                      |   |   |   |  |   |  |  |   |   |  |  |   |   |  |
| SOT-23A-5                         |                                      |   |   |   |  |   |  |  |   |   |  |  | X                                       | X                                       |  |
| 8-PDIP C,E                        | X                                    | X   | X   | X   | X  |   | X  | X                                      | X   | X   | X  | X  |   |   |  |
| 8-Pin MSOP C, E                   |                                      |   |   | X   | X  |   |  |  |   |   |  |  |   |   |  |
| 8-Pin SOIC C, E                   | X                                    | X   | X   | X   | X  |   | X  | X                                      | X   | X   | X  | X  |   |   | X  |
| 8-Pin CDIP I, M                   | X                                    | X   | X   | X   | X  |   | X  | X                                      | X   | X   | X  | X  |   |   |  |
| 16-Pin SOIC C, E                  |                                      |   | X   |   |  |   |  |  |   |   |  |  |   |   |  |
| <b>Features</b>                   |                                      |   |   |   |  |   |  |  |   |   |  |  |   |   |  |
| V <sub>IN</sub>                   | 1.5V – 5V                            | 2.4V – 5.5V   | 3V – 18V  | 1.5V – 12V  | 1.5V – 5.5V  | 2.5V – 6.5V   | 1.5V – 10V                                       | 1.5V – 10V                             | 1.5V – 12V  | 3V – 18V  | 1.5V – 15V   | 2V – 5.5V  | 1.5V – 5.5V                             | 1.5V – 5.5V                             | 5-10V  |
| F <sub>OSC</sub>                  | 10kHz                                | 12kHz   | 12kHz   | 10kHz   | 10kHz  | 180kHz  | 120kHz   | 120kHz                                 | 10kHz   | 12kHz   | 10kHz  | 21kHz  | 12kHz                                   | 35kHz                                   | 100kHz   |
| f <sub>OSC</sub> Boost            | 90kHz                                | N/A   | 24kHz   | 45kHz   | 200kHz   | N/A   | N/A  | N/A                                    | 45kHz   | N/A   | N/A  | N/A  | N/A                                     | N/A                                     | N/A  |
| OSC Over Drive                    | X                                    |   | X   | X   | X  | X   | X  | X                                      | X   | X   | X  |  |   |   |  |
| Zener Ref.                        |                                      |   | X   |   |  |   |  |  |   |   |  |  |   |   |  |
| LV Pin                            | X                                    |   |   | X   |  |   | X  | X                                      | X   | X   |  |  |   |   |  |
| R <sub>O</sub> (Typ. ohms)        | 6.5Ω                                 | 140Ω  | 32Ω   | 60Ω   | 6.5Ω   | 40Ω   | 70Ω  | 55Ω                                    | 60Ω   | 40  | 65Ω  | 140Ω   | 20Ω                                     | 20Ω                                     | 70Ω  |
| I <sub>SUPPLY</sub> (Typ.)        | 200μA*                               | 185μA   | 190μA   | 80μA  | 200μA**  | 200μA   | 80μA   | 460μA                                  | 80μA  | 190μA   | 80μA   | 500μA  | 60μA                                    | 150μA                                   | 2mA  |
| I <sub>SHDN</sub> (Typ.)          | N/A**                                | N/A   | N/A**   | N/A**   | 2μA  | <1μA  | N/A**  | N/A                                    | N/A**   | N/A**   | N/A**  | N/A  | N/A                                     | N/A                                     | 0.5μA  |
| <b>Summary</b>                    |                                      |   |   |   |  |   |  |  |   |   |  |  |   |   |  |
| Highest Current (100mA) Boost Pin |                                      | Low Current (10mA), Inverting Voltage Doubler, Uses Only 3 Caps | High Current (80mA), 6.2V Zener Reference, Wide V <sub>IN</sub> Range | Medium Current (40mA), TC7660 w/Higher V <sub>IN</sub> & I <sub>OUT</sub> , Boost Pin | Highest Current (100mA), Small Package, High Frequency w/SHDN & Oscillator Boost Pin | Medium Current (<20mA), High Frequency Doubling Inverter w/SHDN & Oscillator Over Drive | Low Current (20mA), Low V <sub>IN</sub> No Boost | High Frequency, Small Value Capacitors | Medium Current (40mA), TC7660 w/Higher V <sub>IN</sub> & I <sub>OUT</sub> , Boost Pin | Medium Current (60mA), TC962 w/out Reference or Freq x 2 Wide V <sub>IN</sub> Range | Medium Current (40mA) TC1044S/TC7660S w/Higher V <sub>IN</sub> & Slightly Higher R <sub>ON</sub> | Low Current (10mA), Positive & Inverting Voltage Doubler | Medium Current (25mA), Smallest Package | Medium Current (25mA), Smallest Package | Low Current (<5mA), Low Ripple, Regulated Inverter w/ Shutdown |

\*FC = Opened or GND \*\* I<sub>SHDN</sub> is not specified. Device can be placed into sleep mode by tying OSC to GND.

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