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# 50mA, Frequency-Selectable, Switched-Capacitor Voltage Converters

## General Description

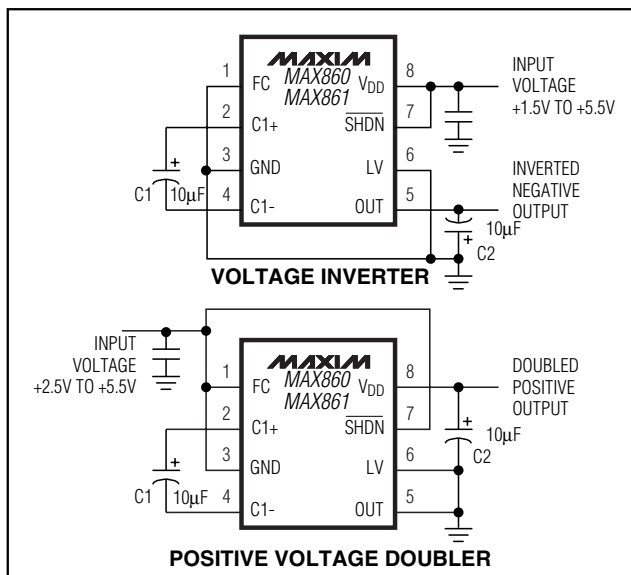
The MAX860/MAX861 charge-pump voltage converters invert input voltages ranging from +1.5V to +5.5V, or double input voltages ranging from +2.5V to +5.5V. Because of their high switching frequencies, these devices use only two small, low-cost capacitors. Their 50mA output makes switching regulators unnecessary, eliminating inductors and their associated cost, size, and EMI. Greater than 90% efficiency over most of the load-current range, combined with a typical operating current of only 200 $\mu$ A (MAX860), provides ideal performance for both battery-powered and board-level voltage-conversion applications.

A frequency-control (FC) pin provides three switching-frequencies to optimize capacitor size and quiescent current and to prevent interference with sensitive circuitry. Each device has a unique set of three available frequencies. A shutdown (SHDN) pin reduces current consumption to less than 1 $\mu$ A. The MAX860/MAX861 are suitable for use in applications where the ICL7660 and MAX660's switching frequencies are too low. The MAX860/MAX861 are available in 8-pin  $\mu$ MAX and SO packages.

## Applications

Portable Computers  
 Medical Instruments  
 Interface Power Supplies  
 Hand-Held Instruments  
 Operational-Amplifier Power Supplies

## Typical Operating Circuit



## Features

- ◆ 8-Pin, 1.11mm High  $\mu$ MAX Package
- ◆ Invert or Double the Input Supply Voltage
- ◆ Three Selectable Switching Frequencies
- ◆ High Frequency Reduces Capacitor Size
- ◆ 87% Efficiency at 50mA
- ◆ 200 $\mu$ A Quiescent Current (MAX860)
- ◆ 1 $\mu$ A Shutdown Supply Current
- ◆ 600mV Voltage Drop at 50mA Load
- ◆ 12 $\Omega$  Output Resistance

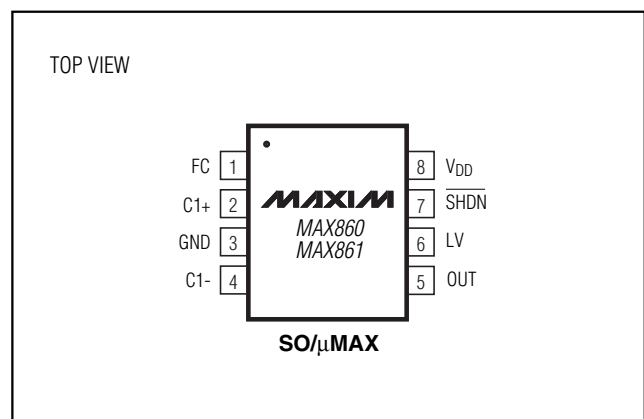
## Ordering Information

| PART      | TEMP RANGE      | PIN-PACKAGE           |
|-----------|-----------------|-----------------------|
| MAX860ISA | -25°C to +85°C  | 8 SO                  |
| MAX860IUA | -25°C to +85°C  | 8 $\mu$ MAX           |
| MAX860C/D | 0°C to +70°C    | Dice*                 |
| MAX860ESA | -40°C to +85°C  | 8 SO                  |
| MAX860MJA | -55°C to +125°C | 8 CERDIP <sup>†</sup> |
| MAX861ISA | -25°C to +85°C  | 8 SO                  |
| MAX861IUA | -25°C to +85°C  | 8 $\mu$ MAX           |
| MAX861C/D | 0°C to +70°C    | Dice*                 |
| MAX861ESA | -40°C to +85°C  | 8 SO                  |
| MAX861MJA | -55°C to +125°C | 8 CERDIP <sup>†</sup> |

\*Dice are tested at  $T_A = +25^\circ\text{C}$ , DC parameters only.

<sup>†</sup>Contact factory for availability.

## Pin Configuration





# 50mA, Frequency-Selectable, Switched-Capacitor Voltage Converters

MAX860/MAX861

## ELECTRICAL CHARACTERISTICS (continued)

(Typical Operating Circuit (Inverter),  $V_{DD} = +5V$ ,  $\overline{SHDN} = V_{DD}$ ,  $FC = LV = GND$ ,  $C1 = C2 = 10\mu F$  (Note 2),  $T_A = T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted. Typical values are at  $T_A = +25^\circ C$ .)

| PARAMETER                     | SYMBOL   | CONDITIONS   |                                       | MIN | TYP  | MAX | UNITS   |
|-------------------------------|----------|--|---------------------------------------|-----|------|-----|---------|
| Switching Frequency (Note 5)  | $f_s$    | MAX860   | $FC = V_{DD}$                         | 3   | 6    |     | kHz     |
|                               |          |  | $FC = GND$                            | 30  | 50   |     |         |
|                               |          |  | $FC = OUT$                            | 80  | 130  |     |         |
|                               |          | MAX861   | $FC = V_{DD}$                         | 8   | 13   |     |         |
|                               |          |  | $FC = GND$                            | 60  | 100  |     |         |
|                               |          |  | $FC = OUT$                            | 160 | 250  |     |         |
| FC Current (from $V_{DD}$ )   | $I_{FC}$ | $FC < 4V$  |                                       |     | -2   | -4  | $\mu A$ |
| Power Efficiency (Note 6)     |          | MAX860,<br>$FC = V_{DD}$   | $R_L = 2k\Omega$ from $V_{DD}$ to OUT | 93  | 96   |     | %       |
|                               |          |  | $R_L = 1k\Omega$ from OUT to GND      | 90  | 93   |     |         |
|                               |          | MAX861,<br>$FC = V_{DD}$   | $R_L = 2k\Omega$ from $V_{DD}$ to OUT | 93  | 96   |     |         |
|                               |          |  | $R_L = 1k\Omega$ from OUT to GND      | 88  | 92   |     |         |
|                               |          | MAX860/MAX861, $FC = V_{DD}$ ,<br>$I_L = 50mA$ to GND, $C1 = C2 = 68\mu F$ |                                       |     | 87   |     |         |
| Voltage-Conversion Efficiency |          | No load  |                                       | 99  | 99.9 |     | %       |
| $\overline{SHDN}$ Threshold   | $V_{IH}$ | $LV = GND$   |                                       | 1.2 |      |     | V       |
|                               | $V_{IL}$ |  |                                       |     |      | 0.3 |         |
| Shutdown Supply Current       |          | $\overline{SHDN} < 0.3V$   | MAX86_I/E                             |     |      | 1   | $\mu A$ |
|                               |          |  | MAX86_M                               |     |      | 10  |         |
| Time to Exit Shutdown         |          | No load, $V_{OUT} = -4V$   |                                       | 500 |      |     | $\mu s$ |

**Note 2:** C1 and C2 are low-ESR ( $<0.2\Omega$ ) aluminum electrolytics. Capacitor ESR adds to the circuit's output resistance. Using capacitors with higher ESR may reduce output voltage and efficiency.

**Note 3:** MAX860/MAX861 may draw high supply current during startup, up to the minimum operating supply voltage. To guarantee proper startup, the input supply must be capable of delivering 90mA more than the maximum load current.

**Note 4:** Specified output resistance includes the effect of the  $0.2\Omega$  ESR of the test circuit's capacitors.

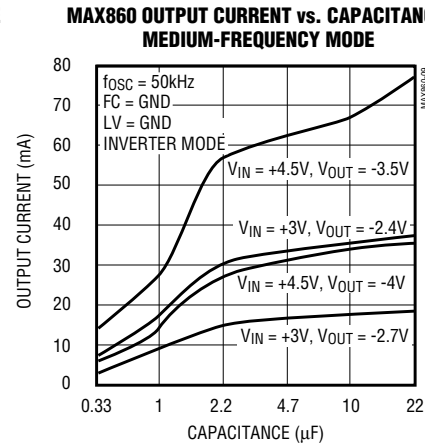
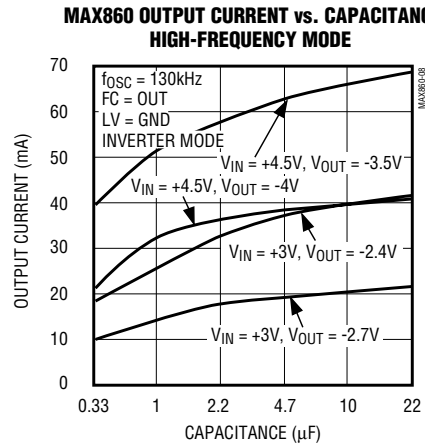
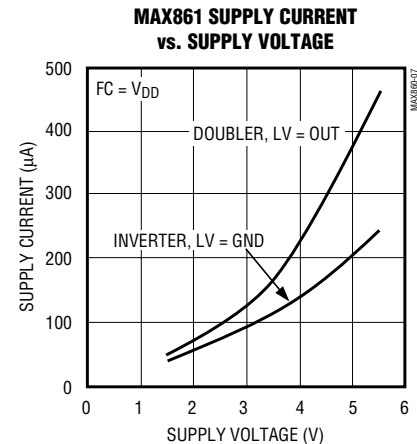
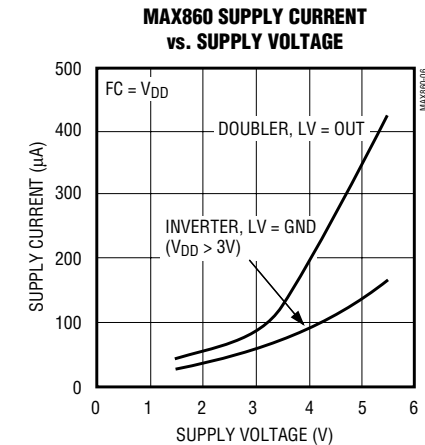
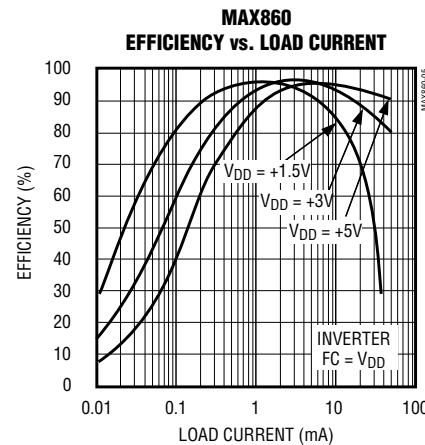
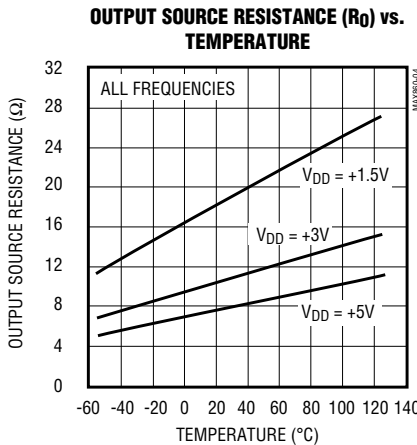
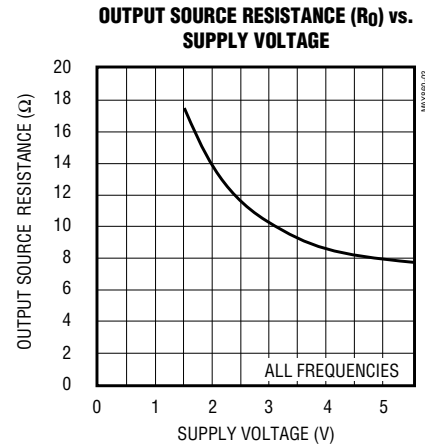
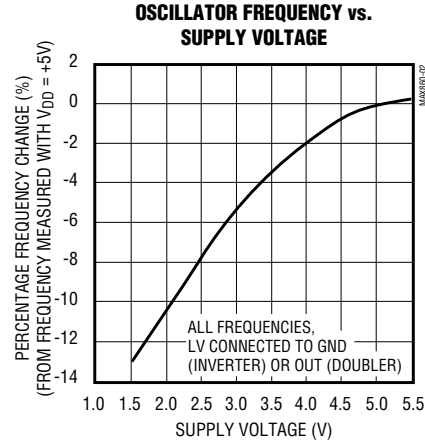
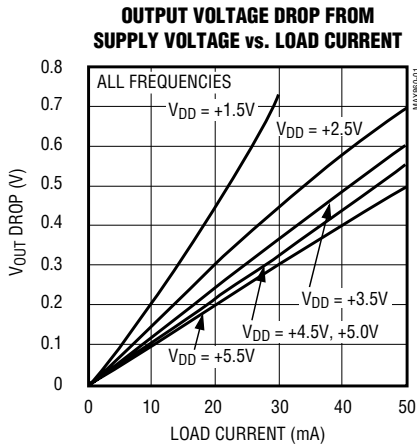
**Note 5:** The switches are driven directly at the oscillator frequency, without any division.

**Note 6:** At lowest frequencies, using  $10\mu F$  capacitors gives worse efficiency figures than using the recommended capacitor values in Table 3, due to larger  $1/(f_s \times C1)$  term in  $R_{OUT}$ .

# 50mA, Frequency-Selectable, Switched-Capacitor Voltage Converters

## Typical Operating Characteristics

(All curves generated using the inverter circuit shown in the *Typical Operating Circuits* with LV = GND and  $T_A = +25^\circ\text{C}$ , unless otherwise noted. Test results also valid for doubler mode with LV = OUT and  $T_A = +25^\circ\text{C}$ . All capacitor values used are those recommended in Table 3, unless otherwise noted. The output resistance curves represent the resistance of the device itself, which is  $R_{OUT}$  in the equation for  $R_{OUT}$  shown in the *Capacitor Selection* section.)

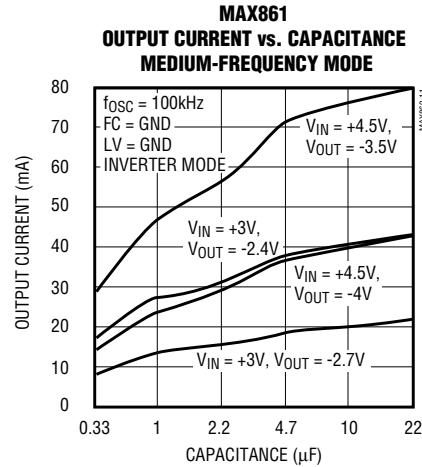
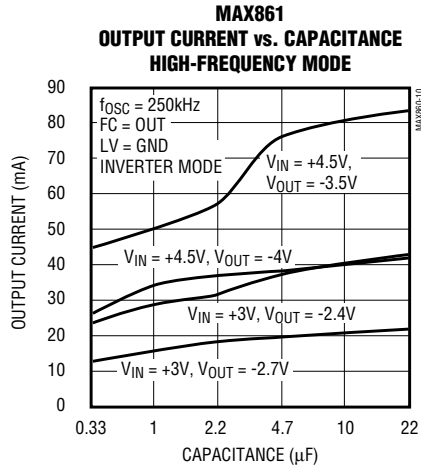


# 50mA, Frequency-Selectable, Switched-Capacitor Voltage Converters

MAX860/MAX861

## Typical Operating Characteristics (continued)

(All curves generated using the inverter circuit shown in the *Typical Operating Circuits* with LV = GND and  $T_A = +25^\circ\text{C}$ , unless otherwise noted. Test results also valid for doubler mode with LV = OUT and  $T_A = +25^\circ\text{C}$ . All capacitor values used are those recommended in Table 3, unless otherwise noted. The output resistance curves represent the resistance of the device itself, which is  $R_{O}$  in the equation for  $R_{OUT}$  shown in the *Capacitor Selection* section.)



## Pin Description

| PIN | NAME                     | FUNCTION   |   |
|-----|--------------------------|--|---|
|     |                          | INVERTER   | DOUBLER   |
| 1   | FC                       | Frequency Control, see Table 1   | Frequency Control, see Table 1  |
| 2   | C1+                      | Flying-Capacitor Positive Terminal   | Flying-Capacitor Positive Terminal  |
| 3   | GND                      | Ground   | Positive Input Supply   |
| 4   | C1-                      | Flying-Capacitor Negative Terminal   | Flying-Capacitor Negative Terminal  |
| 5   | OUT                      | Negative Output  | Ground  |
| 6   | LV                       | Low-Voltage-Operation Input. Connect to GND.   | Low-Voltage-Operation Input. Connect to OUT.  |
| 7   | $\overline{\text{SHDN}}$ | Active-Low Shutdown Input. Connect to $V_{DD}$ if not used. Connect to GND to disable the charge pump. | Active-Low Shutdown Input. Connect to GND pin if not used. Connect to OUT to disable the charge pump. |
| 8   | $V_{DD}$                 | Positive Input Supply  | Doubled Positive Output   |

# 50mA, Frequency-Selectable, Switched-Capacitor Voltage Converters

## Detailed Description

The MAX860/MAX861 capacitive charge pumps either invert or double the voltage applied to their inputs. For highest performance, use low equivalent series resistance (ESR) capacitors. See the *Capacitor Selection* section for more details. The frequency-control (FC) pin allows you to choose one of three switching frequencies; these three selectable frequencies are different for each device. When shut down, MAX860/MAX861 current consumption reduces to less than 1 $\mu$ A.

## Common Applications

### Voltage Inverter

The most common application for these devices is a charge-pump voltage inverter (see *Typical Operating Circuits*). This application requires only two external components—capacitors C1 and C2—plus a bypass capacitor if necessary (see *Bypass Capacitor* section). Refer to the *Capacitor Selection* section for suggested capacitor types and values.

Even though the MAX860/MAX861's output is not actively regulated, it is fairly insensitive to load-current changes. A circuit output source resistance of 12 $\Omega$  (calculated using the formula given in the *Capacitor Selection* section) means that, with a +5V input, the output voltage is -5V under no load and decreases to -4.4V with a 50mA load. The MAX860/MAX861 output source resistance (used to calculate the circuit output source resistance) vs. temperature and supply voltage are shown in the *Typical Operating Characteristics* graphs.

Calculate the output ripple voltage using the formula given in the *Capacitor Selection* section.

### Positive Voltage Doubler

The MAX860/MAX861 can also operate as positive voltage doublers (see *Typical Operating Circuits*). This application requires only two external components, capacitors C1 and C2. The no-load output is twice the input voltage. The electrical specifications in the doubler mode are very similar to those of the inverter mode except for the Supply Voltage Range (see *Electrical Characteristics* table) and No-Load Supply Current (see graph in *Typical Operating Characteristics*). The circuit output source resistance and output ripple voltage are calculated using the formulas in the *Capacitor Selection* section.

### Active-Low Shutdown Input

When driven low, the SHDN input shuts down the device. In inverter mode, connect SHDN to V<sub>DD</sub> if it is not used. In doubler mode, connect SHDN to GND if it

is not used. When the device is shut down, all active circuitry is turned off.

In the inverting configuration, loads connected from OUT to GND are not powered in shutdown mode. However, a reverse-current path exists through two diodes between OUT and GND; therefore, loads connected from V<sub>DD</sub> to OUT draw current from the input supply.

In the doubling configuration, loads connected from the V<sub>DD</sub> pin to the GND pin are not powered in shutdown mode. Loads connected from the V<sub>DD</sub> pin to the OUT pin draw current from the input supply through a path similar to that of the inverting configuration (described above).

## Frequency Control

Charge-pump frequency for both devices can be set to one of three values. Each device has a unique set of three available frequencies, as indicated in Table 1. The oscillator and charge-pump frequencies are the same (i.e., the charge-pump frequency is not half the oscillator frequency, as it is on the MAX660, MAX665, and ICL7660).

**Table 1. Nominal Switching Frequencies\***

| FC CONNECTION                | FREQUENCY (kHz) |        |
|------------------------------|-----------------|--------|
|                              | MAX860          | MAX861 |
| FC = V <sub>DD</sub> or open | 6               | 13     |
| FC = GND                     | 50              | 100    |
| FC = OUT                     | 130             | 250    |

\*See the *Electrical Characteristics* for detailed switching-frequency specifications.

A higher switching frequency minimizes capacitor size for the same performance and increases the supply current (Table 2). The lowest fundamental frequency of the switching noise is equal to the minimum specified switching frequency (e.g., 3kHz for the MAX860 with FC open). The spectrum of noise frequencies extends above this value because of harmonics in the switching waveform. To get best noise performance, choose the device and FC connection to select a minimum switching frequency that lies above your sensitive bandwidth.

## Low-Voltage-Operation Input

LV should be connected to GND for inverting operation. To enhance compatibility with the MAX660, MAX665, and ICL7660, you may float LV if the input voltage exceeds 3V. In doubling mode, LV must be connected to OUT for all input voltages.

# 50mA, Frequency-Selectable, Switched-Capacitor Voltage Converters

**Table 2. Switching-Frequency Trade-Offs**

| ATTRIBUTE      | LOWER FREQUENCY | HIGHER FREQUENCY |
|----------------|-----------------|------------------|
| Output Ripple  | Larger          | Smaller          |
| C1, C2 Values  | Larger          | Smaller          |
| Supply Current | Smaller         | Larger           |

## Applications Information

### Capacitor Selection

The MAX860/MAX861 are tested using 10 $\mu$ F capacitors for both C1 and C2, although smaller or larger values can be used (Table 3). Smaller C1 values increase the output resistance; larger values reduce the output resistance. Above a certain point, increasing the capacitance of C1 has a negligible effect (because the output resistance becomes dominated by the internal switch resistance and the capacitor ESR). Low-ESR capacitors provide the lowest output resistance and ripple voltage. The output resistance of the entire circuit (inverter or doubler) is approximately:

$$R_{OUT} = R_O + 4 \times ESR_{C1} + ESR_{C2} + 1 / (f_S \times C1)$$

where  $R_O$  (the effective resistance of the MAX860/MAX861's internal switches) is approximately 8 $\Omega$  and  $f_S$  is the switching frequency.  $R_{OUT}$  is typically 12 $\Omega$  when using capacitors with 0.2 $\Omega$  ESR and  $f_S$ , C1, and C2 values suggested in Table 3. When C1 and C2 are so large (or the switching frequency is so high) that the internal switch resistance dominates the output resistance, estimate the output resistance as follows:

$$R_{OUT} = R_O + 4 \times ESR_{C1} + ESR_{C2}$$

A typical design procedure is as follows:

- 1) Choose C1 and C2 to be the same, for convenience.
- 2) Select  $f_S$ :
  - a) If you want to avoid a specific noise frequency, choose  $f_S$  appropriately.
  - b) If you want to minimize capacitor cost and size, choose a high  $f_S$ .
  - c) If you want to minimize current consumption, choose a low  $f_S$ .
- 3) Choose a capacitor based on Table 3, although higher or lower values can be used to optimize performance. Table 4 lists manufacturers who provide low-ESR capacitors.

**Table 3. Suggested Capacitor Values\***

| NOMINAL FREQUENCY (kHz) | C1, C2 ( $\mu$ F) |
|-------------------------|-------------------|
| 6                       | 68                |
| 13                      | 47                |
| 50                      | 10                |
| 100                     | 4.7               |
| 130                     | 4.7               |
| 250                     | 2.2               |

\*In addition to Table 3, four graphs in the *Typical Operating Characteristics* section show typical output current for C1 and C2 capacitances ranging from 0.33 $\mu$ F to 22 $\mu$ F. Output current is plotted for inputs of 4.5V (5V - 10%) and 3.0V (3.3V - 10%), and also for 10% and 20% output droop from the ideal  $-V_{IN}$  value.

**Table 4. Low-ESR Capacitor Manufacturers**

| MANUFACTURER—Series      | PHONE          | FAX            | COMMENTS                            |
|--------------------------|----------------|----------------|-------------------------------------|
| AVX TPS Series           | (803) 946-0629 | (803) 626-3123 | Low-ESR tantalum, SMT               |
| AVX TAG Series           | (803) 946-0629 | (803) 626-3123 | Low-cost tantalum, SMT              |
| Matsuo 267 Series        | (714) 969-2491 | (714) 960-6492 | Low-cost tantalum, SMT              |
| Sprague 595 Series       | (603) 224-1961 | (613) 224-1430 | Low-ESR tantalum, SMT               |
| Sanyo MV-GX Series       | (619) 661-6835 | (619) 661-1055 | Aluminum electrolytic, through hole |
| Sanyo CV-GX Series       | (619) 661-6835 | (619) 661-1055 | Aluminum electrolytic, SMT          |
| Nichicon PL Series       | (847) 843-7500 | (847) 843-2798 | Aluminum electrolytic, through hole |
| United Chemicon (Marcon) | (847) 696-2000 | (847) 696-9278 | Ceramic SMT                         |
| TDK                      | (847) 390-4461 | (847) 390-4405 | Ceramic SMT                         |



# 50mA, Frequency-Selectable, Switched-Capacitor Voltage Converters

## Flying Capacitor, C1

Increasing the size of the flying capacitor reduces the output resistance.

## Output Capacitor, C2

Increasing the size of the output capacitor reduces the output ripple voltage. Decreasing its ESR reduces both output resistance and ripple. Smaller capacitance values can be used if one of the higher switching frequencies is selected, if less than the maximum rated output current (50mA) is required, or if higher ripple can be tolerated. The following equation for peak-to-peak ripple applies to both the inverter and doubler circuits.

$$V_{\text{RIPPLE}} = \frac{I_{\text{OUT}}}{2 \times f_s \times C_2} + 2 \times I_{\text{OUT}} \times \text{ESR}_{C_2}$$

## Bypass Capacitor

Bypass the incoming supply to reduce its AC impedance and the impact of the MAX860/MAX861's switching noise. The recommended bypassing depends on the circuit configuration and where the load is connected.

When the inverter is loaded from OUT to GND or the doubler is loaded from V<sub>DD</sub> to GND, current from the supply switches between 2 × I<sub>OUT</sub> and zero. Therefore, use a large bypass capacitor (e.g., equal to the value of C1) if the supply has a high AC impedance.

When the inverter and doubler are loaded from V<sub>DD</sub> to OUT, the circuit draws 2 × I<sub>OUT</sub> constantly, except for short switching spikes. A 0.1μF bypass capacitor is sufficient.

## Cascading Devices

Two devices can be cascaded to produce an even larger negative voltage, as shown in Figure 1. The

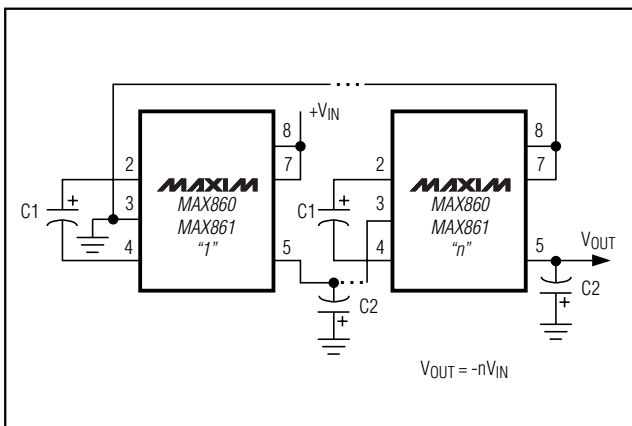


Figure 1. Cascading MAX860s or MAX861s to Increase Output Voltage

unloaded output voltage is nominally  $-2 \times V_{\text{IN}}$ , but this is reduced slightly by the output resistance of the first device multiplied by the quiescent current of the second. The output resistance of the complete circuit is approximately *five times* the output resistance of a single MAX860/MAX861.

Three or more devices can be cascaded in this way, but output resistance rises dramatically, and a better solution is offered by inductive switching regulators (such as the MAX755, MAX759, MAX764, or MAX774). Connect LV as with a standard inverter circuit (see *Pin Description*).

The maximum load current and startup current of nth cascaded circuit must not exceed the maximum output current capability of (n-1)th circuit to ensure proper startup.

## Paralleling Devices

Paralleling multiple MAX860s or MAX861s reduces the output resistance. As illustrated in Figure 2, each device requires its own pump capacitor (C1), but the reservoir capacitor (C2) serves all devices. C2's value should be increased by a factor of n, where n is the number of devices. Figure 2 shows the equation for calculating output resistance. An alternative solution is to use the MAX660 or MAX665, which are capable of supplying up to 100mA of load current. Connect LV as with a standard inverter circuit (see *Pin Description*).

## Combined Doubler/Inverter

In the circuit of Figure 3, capacitors C1 and C2 form the inverter, while C3 and C4 form the doubler. C1 and C3 are the pump capacitors; C2 and C4 are the reservoir capacitors. Because both the inverter and doubler use part of the charge-pump circuit, loading either output causes both outputs to decline towards GND. Make

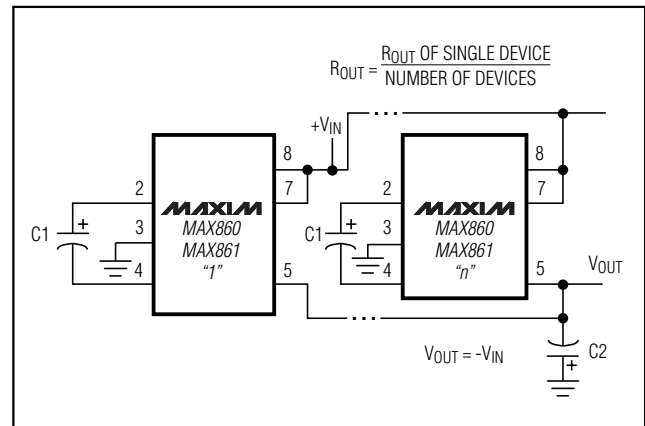


Figure 2. Paralleling MAX860s or MAX861s to Reduce Output Resistance

# 50mA, Frequency-Selectable, Switched-Capacitor Voltage Converters

**MAX860/MAX861**

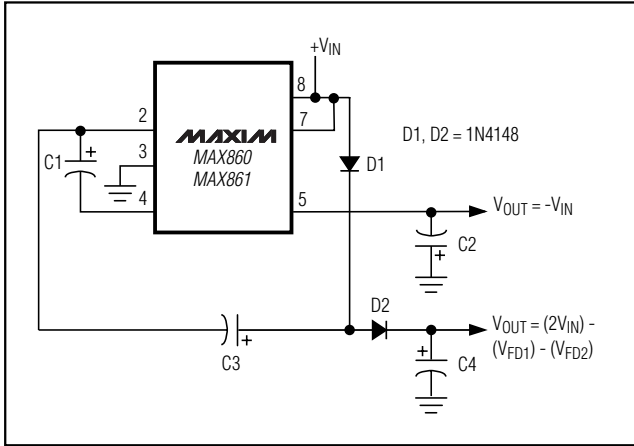


Figure 3. Combined Doubler and Inverter

Table 5. Product Selection Guide

| PART NUMBER | OUTPUT CURRENT (mA) | OUTPUT RESISTANCE ( $\Omega$ ) | SWITCHING FREQUENCY (kHz) |
|-------------|---------------------|--------------------------------|---------------------------|
| MAX660      | 100                 | 6.5                            | 5/40                      |
| MAX665      | 100                 | 6.5                            | 5/40                      |
| MAX860      | 50                  | 12                             | 6/50/130                  |
| MAX861      | 50                  | 12                             | 13/100/250                |
| ICL7660     | 10                  | 55                             | 5                         |

sure the sum of the currents drawn from the two outputs does not exceed 60mA. Connect LV as with a standard inverter circuit (see *Pin Description*).

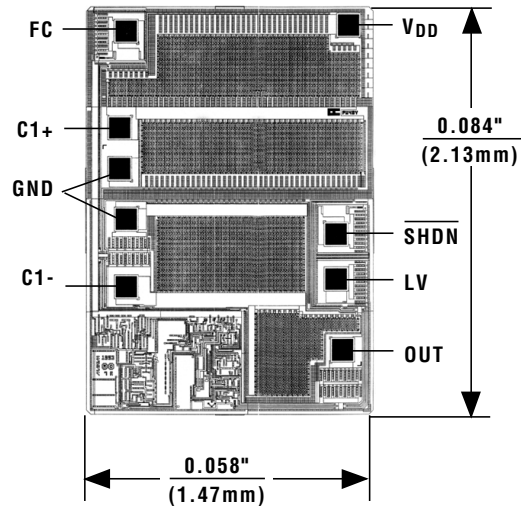
### Compatibility with MAX660/MAX665/ICL7660

The MAX860/MAX861 can be used in sockets designed for the MAX660, MAX665, and ICL7660 with a minimum of one wiring change. This section gives advice on installing a MAX860/MAX861 into a socket designed for one of the earlier devices.

The MAX660, MAX665, and ICL7660 have an OSC pin instead of SHDN. MAX660, MAX665, and ICL7660 normal operation is with OSC floating (although OSC can be overdriven). If OSC is floating, pin 7 (SHDN) should be jumpered to V<sub>DD</sub> to enable the MAX860/MAX861 permanently. Do not leave SHDN on the MAX860/MAX861 floating.

The MAX860/MAX861 operate with FC either floating or connected to V<sub>DD</sub>, OUT, or GND; each connection defines the oscillator frequency. Thus, any of the normal MAX660, MAX665, or ICL7660 connections to pin 1 will work with the MAX860/MAX861, without modifications. Changes to the FC connection are only required if you want to adjust the operating frequency.

### Chip Topography

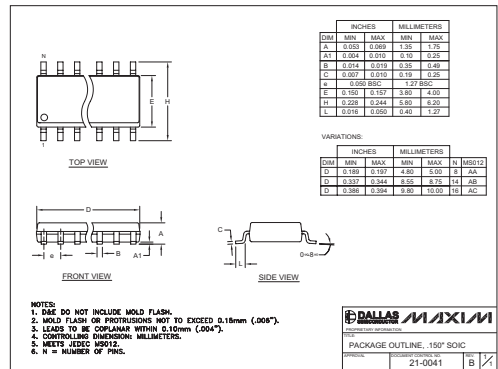
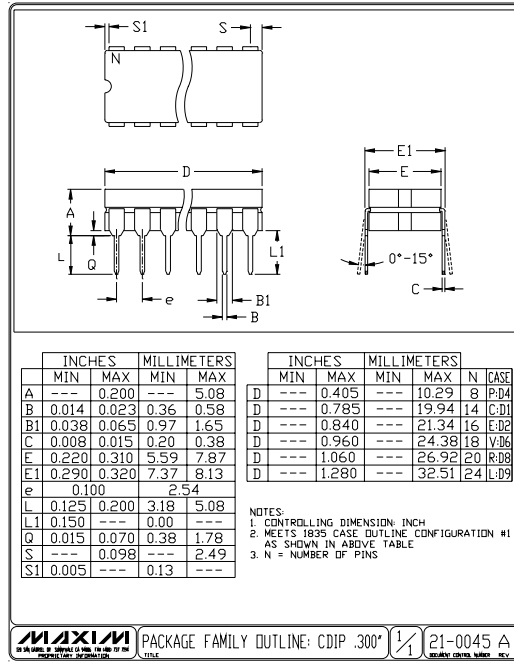


TRANSISTOR COUNT: 101  
SUBSTRATE CONNECTED TO V<sub>DD</sub>

# 50mA, Frequency-Selectable, Switched-Capacitor Voltage Converters

## Package Information

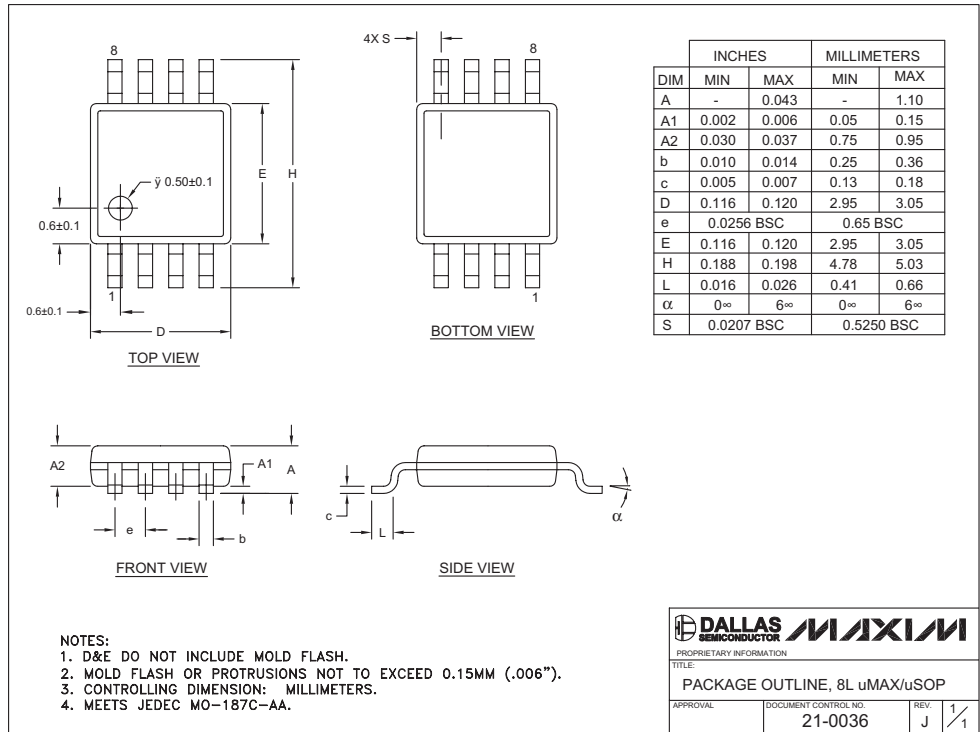
(The package drawing(s) in this data sheet may not reflect the most current specifications. For the latest package outline information go to [www.maxim-ic.com/packages](http://www.maxim-ic.com/packages).)



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