MAX860/MAX861

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

General Description

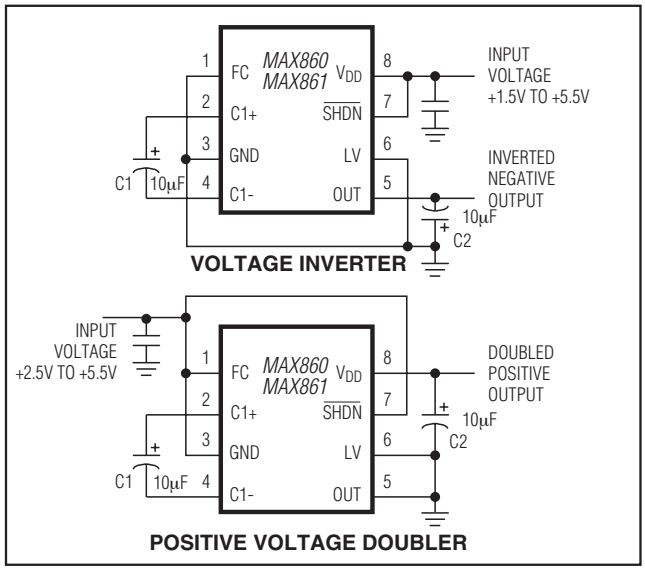
The MAX860/MAX861 charge-pump voltage converters invert input voltages ranging from +1.5V to +5.5V, or double input voltages ranging from +2.5V to +5.5V. Because of their high switching frequencies, these devices use only two small, low-cost capacitors. Their 50mA output makes switching regulators unnecessary, 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 200µA (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 ($\overline{SHDN}$) pin reduces current consumption to less than 1µA. 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 µMAX® and SO packages.

Applications

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

Typical Operating Circuit



µMAX is a registered trademark of Maxim Integrated Products, Inc.

Features

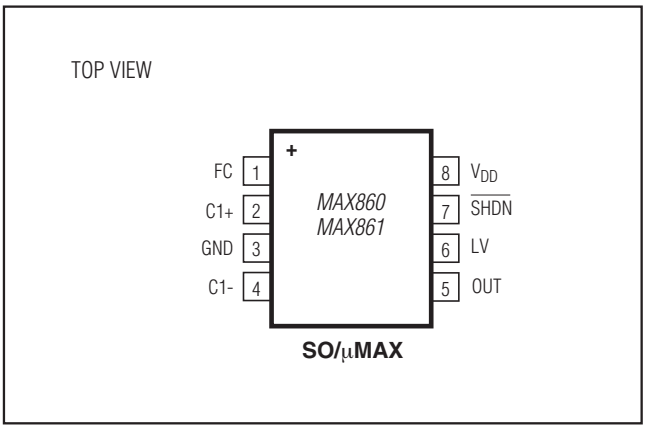
- **8-Pin, 1.11mm High µMAX Package**
- **Invert or Double the Input Supply Voltage**
- **Three Selectable Switching Frequencies**
- **High Frequency Reduces Capacitor Size**
- **87% Efficiency at 50mA**
- **200µA Quiescent Current (MAX860)**
- **1µA Shutdown Supply Current**
- **600mV Voltage Drop at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

Ordering Information

PART	TEMP RANGE	PIN-PACKAGE
MAX860ISA	-25°C to +85°C	8 SO
MAX860IUA	-25°C to +85°C	8 µMAX
MAX860C/D	0°C to +70°C	Dice*
MAX860ESA	-40°C to +85°C	8 SO
MAX860MJA	-55°C to +125°C	8 CERDIP†
MAX860MSA/PR3	-55°C to +125°C	8 SO
MAX861ISA	-25°C to +85°C	8 SO
MAX861IUA	-25°C to +85°C	8 µMAX
MAX861C/D	0°C to +70°C	Dice*
MAX861ESA	-40°C to +85°C	8 SO
MAX861MJA	-55°C to +125°C	8 CERDIP†

**Dice are tested at T_A = +25°C, DC parameters only.*
†Contact factory for availability.

Pin Configuration



For pricing, delivery, and ordering information, please contact Maxim Direct at 1-888-629-4642, or visit Maxim's website at www.maximintegrated.com.

19-0239; Rev 3; 8/13

ABSOLUTE MAXIMUM RATINGS

Supply Voltage (V_{DD} to GND or GND to OUT) ..... +6.0V
Input Voltage Range (LV, FC, $\overline{SHDN}$) ..... (OUT - 0.3V) to (V_{DD} + 0.3V)
Continuous Output Current (OUT, V_{DD}) 60mA
Output Short-Circuit to GND (Note 1) 1s
Continuous Power Dissipation (T_A = +70°C)
SO (derate 5.88mW/°C above +70°C) 471mW
µMAX (derate 4.2mW/°C above +70°C) 362mW
CERDIP (derate 8.00mW/°C above +70°C) 640mW
Operating Temperature Ranges
MAX86_I_A ..... -25°C to +85°C
MAX86_ESA ..... -40°C to +85°C
MAX86_M_A ..... -55°C to +125°C
Storage Temperature Range ..... -65°C to +160°C
Lead Temperature (soldering, 10s) ..... +300°C
Soldering Temperature (reflow) ..... +240°C

Note 1: OUT may be shorted to GND for 1sec without damage, but shorting OUT to V_{DD} may damage the device and should be avoided. Also, for temperatures above +85°C, OUT must not be shorted to GND or V_{DD}, even instantaneously, or device damage may result.

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

ELECTRICAL CHARACTERISTICS

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

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Supply Voltage	V_{DD}	R_L = 1kΩ	Inverter, LV = GND	1.5		5.5	V
			Doubler, LV = OUT	2.5		5.5	
No-Load Supply Current (Note 3)	I_{DD}	MAX860I/E	FC = V_{DD} = 5V		0.2	0.3	mA
			FC = V_{DD} = 3V		0.07		
			FC = GND		0.6	1.0	
			FC = OUT		1.4	2.5	
		MAX860M	FC = V_{DD}			0.4	
			FC = GND			1.3	
			FC = OUT			3.3	
		MAX861I/E	FC = V_{DD}		0.3	0.4	
			FC = GND		1.1	2.0	
			FC = OUT		2.5	5.0	
		MAX861M	FC = V_{DD}			0.5	
			FC = GND			2.6	
			FC = OUT			6.5	
Output Current	I_{OUT}	V_{DD} = 5V, V_{OUT} more negative than -3.75V		50	100		mA
		V_{DD} = 3V, V_{OUT} more negative than -2.5V		10	30		
Output Resistance (Note 4)	R_{OUT}	I_L = 50mA			12	25	Ω
		I_L = 10mA, V_{DD} = 2V			20	35	

ELECTRICAL CHARACTERISTICS (continued)

(Typical Operating Circuit (Inverter), V_{DD} = +5V, $\overline{SHDN}$ = V_{DD}, FC = LV = GND, C1 = C2 = 10µF (Note 2), T_A = T_{MIN} to T_{MAX}, unless otherwise noted. Typical values are at T_A = +25°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	µA
Power Efficiency (Note 6)		MAX860, FC = V_{DD}	R_L = 2kΩ from V_{DD} to OUT	93	96		%
			R_L = 1kΩ from OUT to GND	90	93		
		MAX861, FC = V_{DD}	R_L = 2kΩ from V_{DD} to OUT	93	96		
			R_L = 1kΩ from OUT to GND	88	92		
		MAX860/MAX861, FC = V_{DD}, I_L = 50mA to GND, C1 = C2 = 68µF			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	µA
			MAX86_M			10	
Time to Exit Shutdown		No load, V_{OUT} = -4V			500		µs

Note 2: C1 and C2 are low-ESR (<0.2Ω) 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 0.2Ω ESR of the test circuit's capacitors.

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

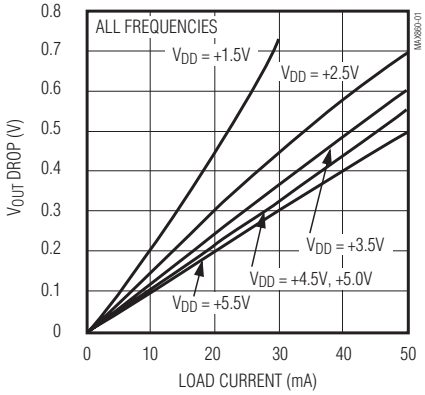
Note 6: At lowest frequencies, using 10µF capacitors gives worse efficiency figures than using the recommended capacitor values in Table 3, due to larger $1/(f_S \times C1)$ term in R_{OUT}.

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

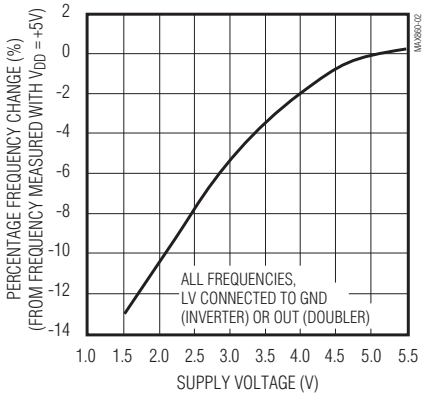
Typical Operating Characteristics

(All curves generated using the inverter circuit shown in the *Typical Operating Circuits* with LV = GND and T_A = +25°C, unless otherwise noted. Test results also valid for doubler mode with LV = OUT and T_A = +25°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.)

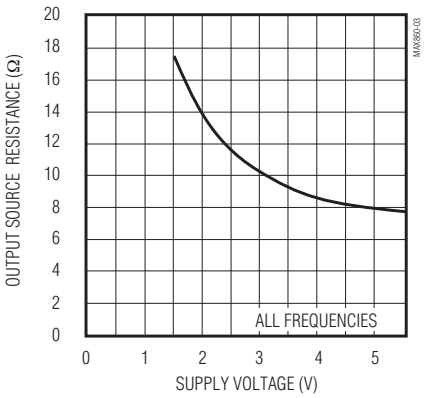
OUTPUT VOLTAGE DROP FROM SUPPLY VOLTAGE vs. LOAD CURRENT



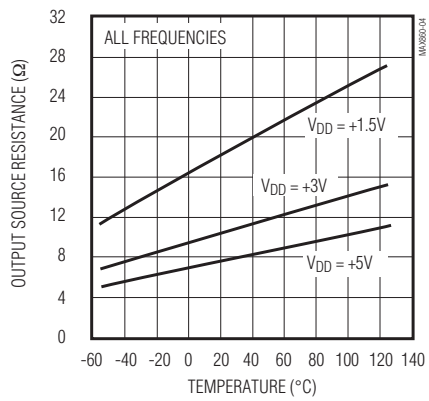
OSCILLATOR FREQUENCY vs. SUPPLY VOLTAGE



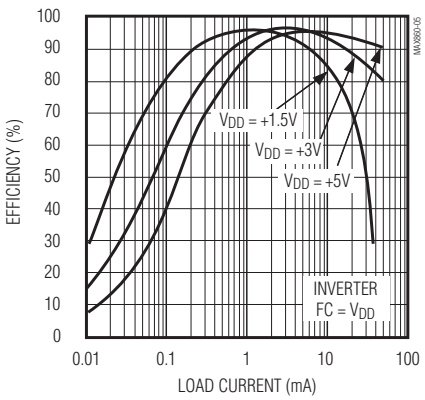
OUTPUT SOURCE RESISTANCE (R_O) vs. SUPPLY VOLTAGE



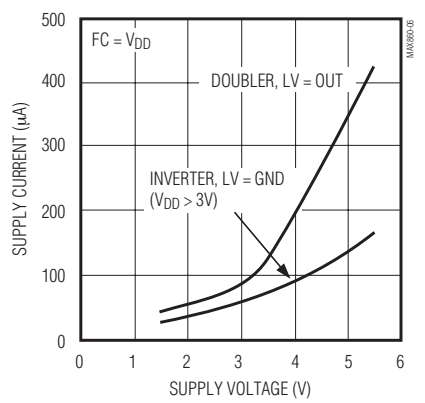
OUTPUT SOURCE RESISTANCE (R_O) vs. TEMPERATURE



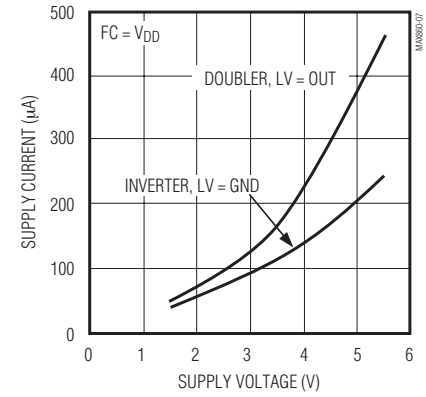
MAX860 EFFICIENCY vs. LOAD CURRENT



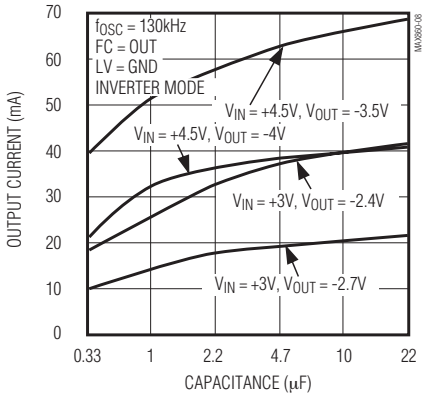
MAX860 SUPPLY CURRENT vs. SUPPLY VOLTAGE



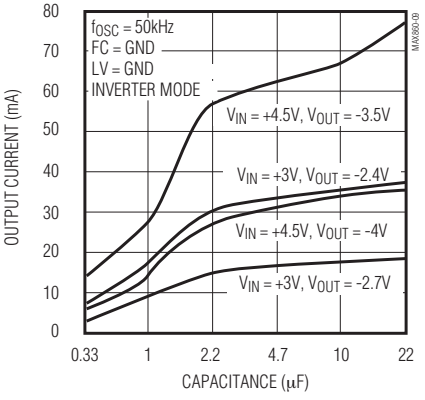
MAX861 SUPPLY CURRENT vs. SUPPLY VOLTAGE



MAX860 OUTPUT CURRENT vs. CAPACITANCE HIGH-FREQUENCY MODE



MAX860 OUTPUT CURRENT vs. CAPACITANC MEDIUM-FREQUENCY MODE

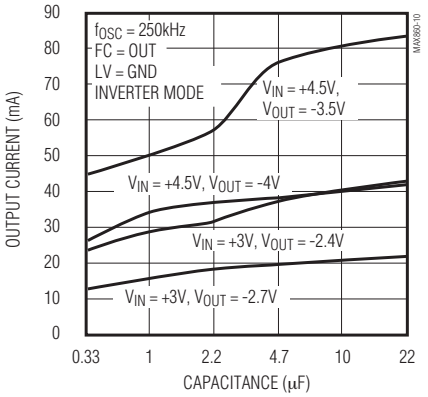


50mA, Frequency-Selectable, Switched-Capacitor Voltage Converters

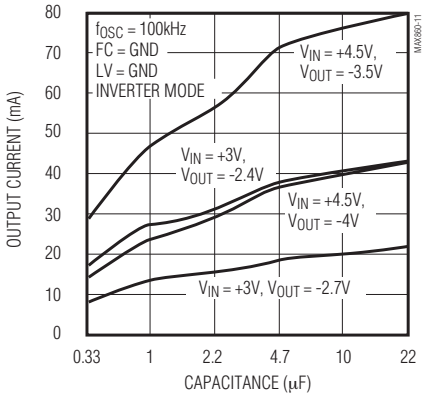
Typical Operating Characteristics (continued)

(All curves generated using the inverter circuit shown in the *Typical Operating Circuits* with LV = GND and T_A = +25°C, unless otherwise noted. Test results also valid for doubler mode with LV = OUT and T_A = +25°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.)

MAX861
OUTPUT CURRENT vs. CAPACITANCE
HIGH-FREQUENCY MODE



MAX861
OUTPUT CURRENT vs. CAPACITANCE
MEDIUM-FREQUENCY MODE



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	$\overline{SHDN}$	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

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 1µA.

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 12Ω (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 $\overline{SHDN}$ input shuts down the device. In inverter mode, connect $\overline{SHDN}$ to V_{DD} if it is not used. In doubler mode, connect $\overline{SHDN}$ 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_{DD} to OUT draw current from the input supply.

In the doubling configuration, loads connected from the V_{DD} pin to the GND pin are not powered in shutdown mode. Loads connected from the V_{DD} 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_{DD} 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.

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 10µF 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 8Ω and f_S is the switching frequency. R_{OUT} is typically 12Ω when using capacitors with 0.2Ω 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 (µF)
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 0.33µF to 22µF. 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

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.

$$V_{RIPPLE} = \frac{I_{OUT}}{2 \times f_S \times C2} + 2 \times I_{OUT} \times ESR_{C2}$$

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_{DD} to GND, current from the supply switches between 2 x I_{OUT} 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_{DD} to OUT, the circuit draws 2 x I_{OUT} 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 unloaded output voltage is nominally -2 x V_{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

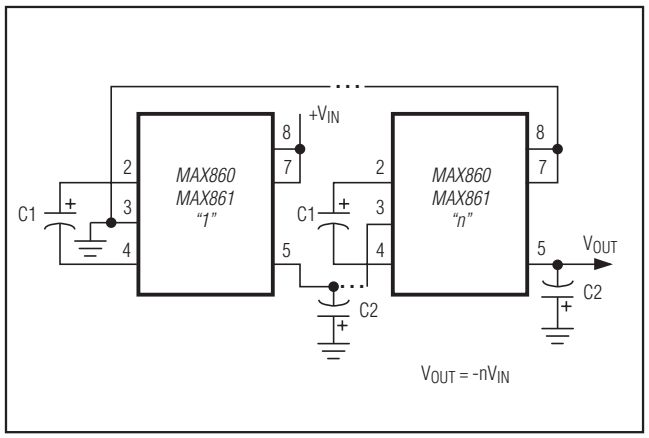


Figure 1. Cascading MAX860s or MAX861s to Increase Output Voltage

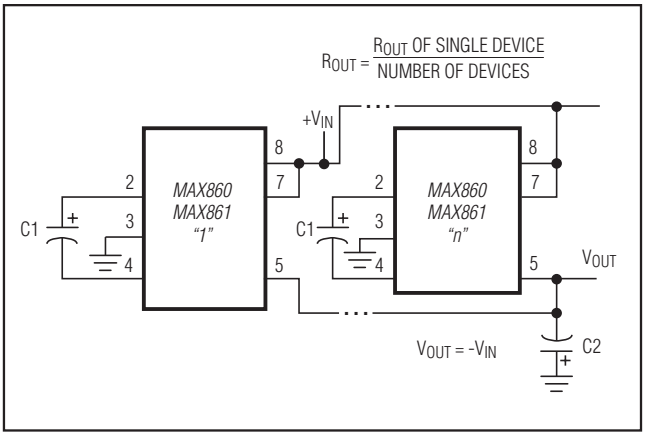


Figure 2. Paralleling MAX860s or MAX861s to Reduce Output Resistance

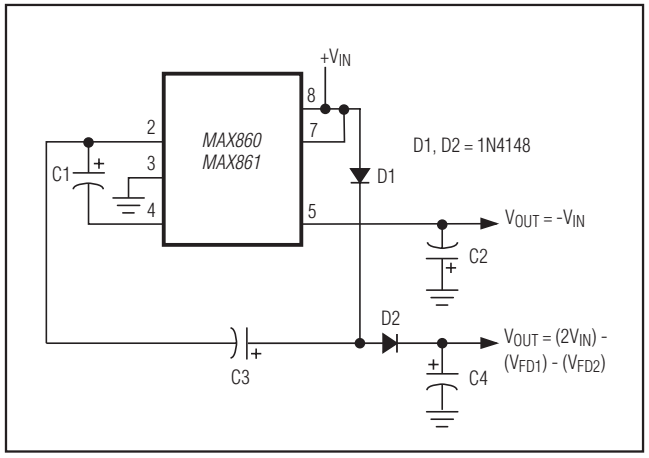


Figure 3. Combined Doubler and Inverter

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.

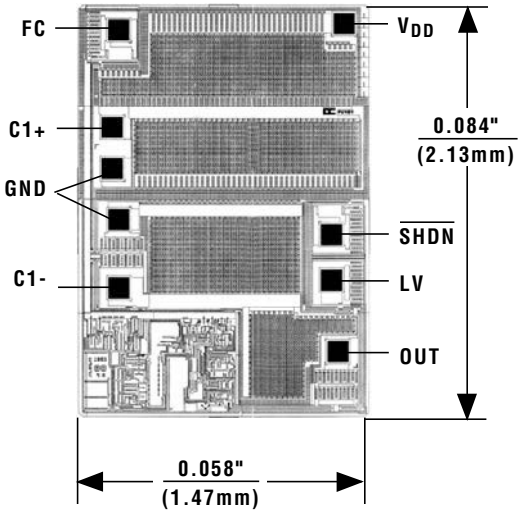
The MAX660, MAX665, and ICL7660 have an OSC pin instead of $\overline{SHDN}$. MAX660, MAX665, and ICL7660 normal operation is with OSC floating (although OSC can be overdriven). If OSC is floating, pin 7 ($\overline{SHDN}$) should be jumpered to V_{DD} to enable the MAX860/MAX861 permanently. Do not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

The MAX860/MAX861 operate with FC either floating or connected to V_{DD}, 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.

Table 5. Product Selection Guide

PART NUMBER	OUTPUT CURRENT (mA)	OUTPUT RESISTANCE (Ω)	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

Chip Topography



PROCESS: BiCMOS

SUBSTRATE CONNECTED TO V_{DD}

Package Information

For the latest package outline information and land patterns (footprints), go to **www.maximintegrated.com/packages**. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

PACKAGE TYPE	PACKAGE CODE	OUTLINE NO.	LAND PATTERN NO.
8 SO	S8-4	21-0041	90-0096
8 CDIP	J8-2	21-0045	—
8 µMAX	U8-1	21-0036	90-0092

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	7/94	Initial release	—
2	4/03	Updated *Electrical Characteristics* and *Cascading Devices* section.	3, 8
3	8/13	Added MAX860MSA/PR3 to data sheet and revised *Absolute Maximum Ratings*.	1, 2

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