19-1240; Rev 1; 2/04

Switched-Capacitor Voltage Inverters

General Description

The ultra-small MAX870/MAX871 monolithic, CMOS charge-pump inverters accept input voltages ranging from +1.4V to +5.5V. The MAX870 operates at 125kHz, and the MAX871 operates at 500kHz. Their high efficiency (90%) and low operating current (0.7mA for the MAX870) make these devices ideal for both battery-powered and board-level voltage-conversion applications.

Oscillator control circuitry and four power MOSFET switches are included on-chip. A typical MAX870/MAX871 application is generating a -5V supply from a +5V logic supply to power analog circuitry. Both parts come in a 5-pin SOT23-5 package and can deliver 25mA with a voltage drop of 500mV.

For a similar device with logic-controlled shutdown, refer to the MAX1720/MAX1721. For applications requiring more power, the MAX860 delivers up to 50mA with a voltage drop of 600mV, in a space-saving µMAX package.

Applications

Local -5V Supply from 5V Logic Supply

Small LCD Panels

Cell Phones

Medical Instruments

Handy-Terminals, PDAs

Battery-Operated Equipment

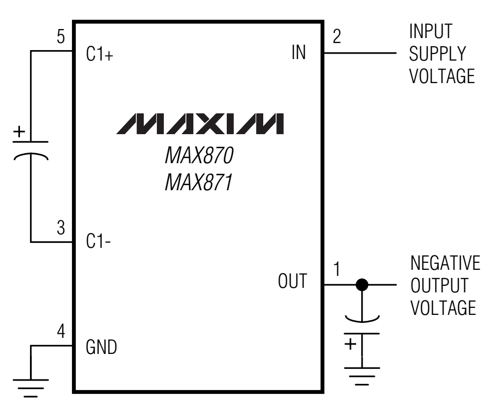
Features

- ♦ **5-Pin SOT23-5 Package**
- ♦ **99% Voltage Conversion Efficiency**
- ♦ **Invert Input Supply Voltage**
- ♦ **0.7mA Quiescent Current (MAX870)**
- ♦ **+1.4V to +5.5V Input Voltage Range**
- ♦ **Require Only Two Capacitors**
- ♦ **25mA Output Current**
- ♦ **Shutdown Control**

Ordering Information

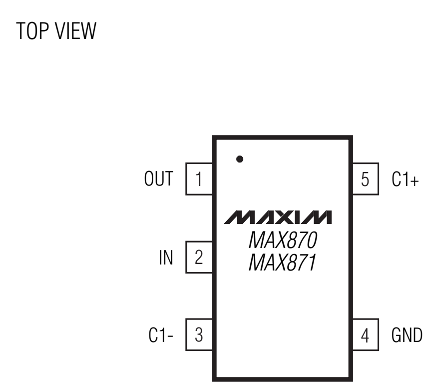
PART	TEMP RANGE	PIN-PACKAGE	SOT TOP MARK
MAX870EUK	-40°C to +85°C	5 SOT23-5	ABZN
MAX871EUK	-40°C to +85°C	5 SOT23-5	ABZO

Typical Operating Circuit



NEGATIVE VOLTAGE CONVERTER

Pin Configuration



SOT23-5

Switched-Capacitor Voltage Inverters

ABSOLUTE MAXIMUM RATINGS

IN to GND ....+6.0V to -0.3V
OUT to GND ....-6.0V to +0.3V
C1+ ....(V_{IN} + 0.3V) to -0.3V
C1- ....(V_{OUT} - 0.3V) to +0.3V
OUT Output Current 50mA
OUT Short Circuit to GND ....Indefinite
Continuous Power Dissipation (T_A = +70°C)
  SOT23-5 (derate 7.1mW/°C above +70°C)..................571mW
Operating Temperature Range
  MAX870EUK/MAX871EUK ....-40°C to +85°C
Storage Temperature Range ....-65°C to +160°C
Lead Temperature (soldering, 10s) ....+300°C

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

(V_{IN} = +5V, C1 = C2 = 1µF (MAX870), C1 = C2 = 0.33µF (MAX871), **T_A = 0°C to +85°C**, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Supply Current	T_A = +25°C (Note 3)	MAX870		0.7	1.0	mA
		MAX871		2.7	3.8	
Minimum Supply Voltage	R_{LOAD} = 10kΩ	T_A = +25°C	1.4	1.0		V
		T_A = 0°C to + 85°C	1.5			
Maximum Supply Voltage	R_{LOAD} = 10kΩ				5.5	V
Oscillator Frequency	T_A = +25°C	MAX870	81	125	169	kHz
		MAX871	325	500	675	
Power Efficiency	R_{LOAD} = 500kΩ, T_A =+25°C	MAX870		90		%
		MAX871		75		
Voltage Conversion Efficiency	R_{LOAD} = ∞, T_A =+25°C	MAX870	98	99.3		%
		MAX871	96	99		
Output Resistance (Note 1)	I_{OUT} = 5mA, T_A = +25°C, MAX870	C1 = C2 = 1µF		20	50	Ω
	I_{OUT} = 5mA, T_A = +25°C, MAX870	C1 = C2 = 0.47µF		25		
	I_{OUT} = 5mA, T_A = +25°C, MAX871	C1 = C2 = 0.33µF		20	50	
	I_{OUT} = 5mA, T_A = +25°C, MAX871	C1 = C2 = 0.22µF		25		
	I_{OUT} = 5mA, T_A = +25°C, MAX871	C1 = C2 = 0.1µF		35		
	I_{OUT} = 5mA, T_A = 0°C to + 85°C				65	

Note 1: Capacitor contribution is approximately 20% of the output impedance [ESR + 1 / (pump frequency x capacitance)].

ELECTRICAL CHARACTERISTICS

(V_{IN} = +5V, C1 = C2 = 1µF (MAX870), C1 = C2 = 0.33µF (MAX871), **T_A = -40°C to +85°C**, unless otherwise noted.) (Note 2)

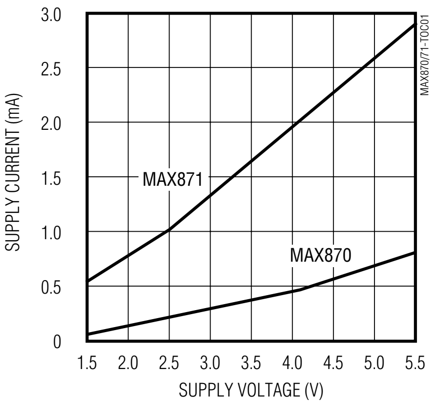
PARAMETER	CONDITIONS		MIN	TYP	MAX	UNITS
Supply Current (Note 3)	MAX870				1.3	mA
	MAX871				4.4	
Minimum Supply-Voltage Range	R_{LOAD} = 10kΩ		1.6			V
Maximum Supply-Voltage Range	R_{LOAD} = 10kΩ				5.5	V
Oscillator Frequency	MAX870		56		194	kHz
	MAX871		225		775	
Output Resistance	I_{OUT} = 5mA				65	Ω
Voltage Conversion Efficiency	R_{LOAD} = ∞	MAX870	97			%
		MAX871	95			

Note 2: All -40°C to +85°C specifications are guaranteed by design.
Note 3: The MAX870/MAX871 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.

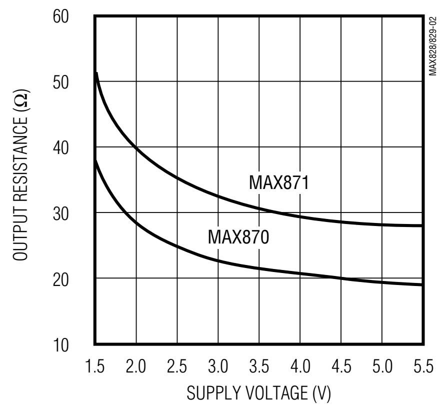
Typical Operating Characteristics

(Circuit of Figure 1, V_{IN} = +5V, C1 = C2 = C3, T_A = +25°C, unless otherwise noted.)

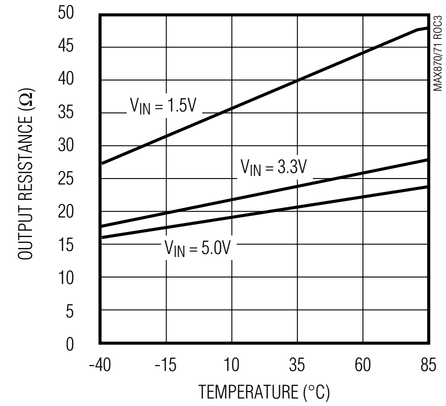
SUPPLY CURRENT vs. SUPPLY VOLTAGE



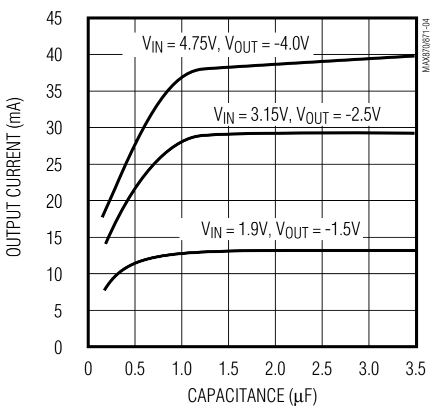
OUTPUT RESISTANCE vs. SUPPLY VOLTAGE



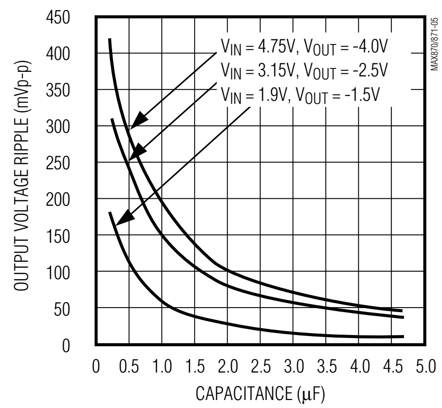
MAX870 OUTPUT RESISTANCE vs. TEMPERATURE



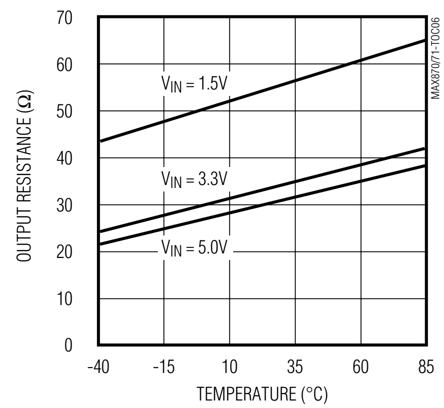
MAX870 OUTPUT CURRENT vs. CAPACITANCE



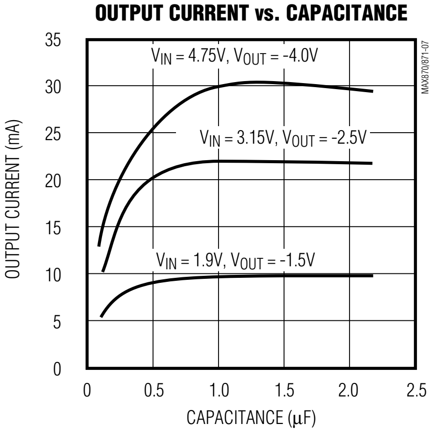
MAX870 OUTPUT VOLTAGE RIPPLE vs. CAPACITANCE



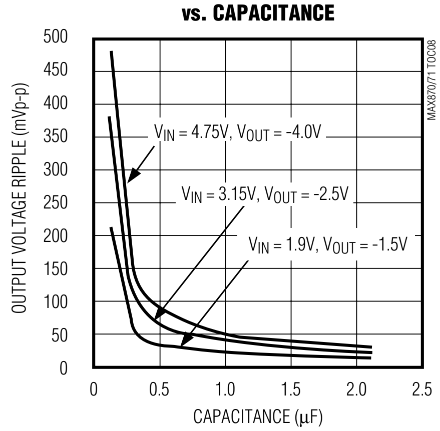
MAX871 OUTPUT RESISTANCE vs. TEMPERATURE



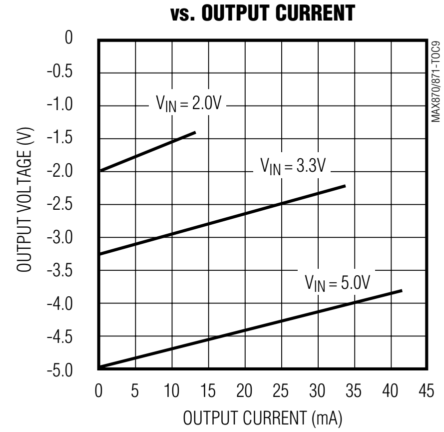
MAX871 OUTPUT CURRENT vs. CAPACITANCE



MAX871 OUTPUT VOLTAGE RIPPLE vs. CAPACITANCE



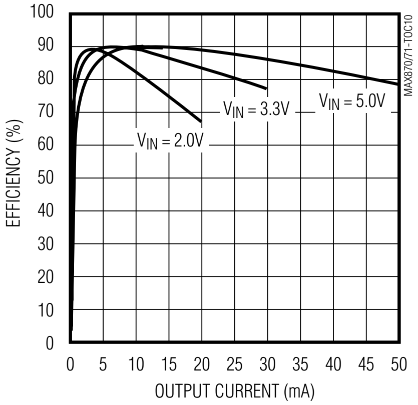
MAX870 OUTPUT VOLTAGE vs. OUTPUT CURRENT



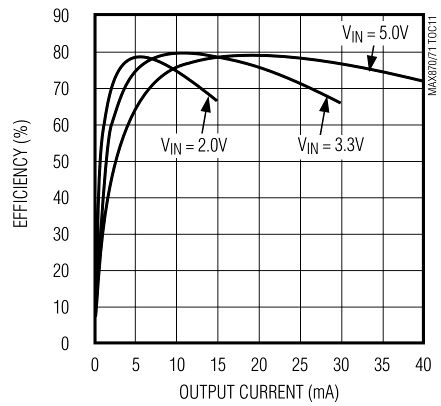
Typical Operating Characteristics (continued)

(Circuit of Figure 1, V_{IN} = +5V, C1 = C2 = C3, T_A = +25°C, unless otherwise noted.)

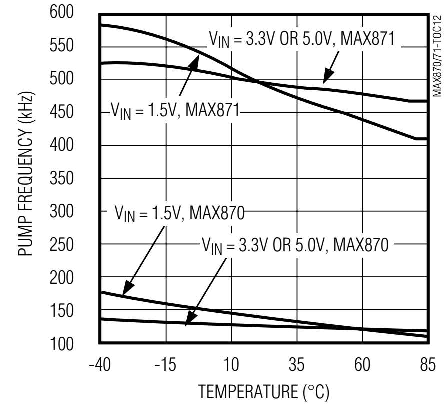
MAX870
EFFICIENCY vs. OUTPUT CURRENT



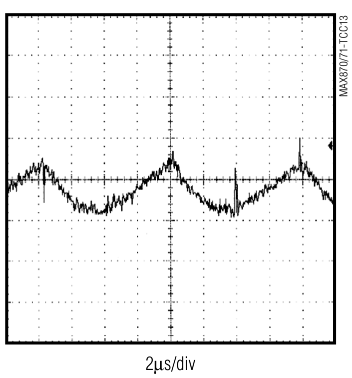
MAX871
EFFICIENCY vs. OUTPUT CURRENT



PUMP FREQUENCY vs. TEMPERATURE

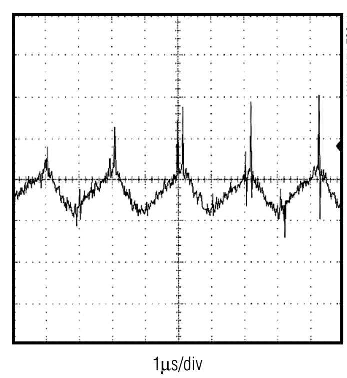


MAX870
OUTPUT NOISE AND RIPPLE



V_{IN} = 3.3V, V_{OUT} = -3.18V, I_{OUT} = 5mA, 20mV/div, AC COUPLED

MAX871
OUTPUT NOISE AND RIPPLE



V_{IN} = 3.3V, V_{OUT} = -3.14V, I_{OUT} = 5mA, 20mV/div, AC COUPLED

Pin Description

PIN	NAME	FUNCTION
1	OUT	Inverting Charge-Pump Output
2	IN	Positive Power-Supply Input
3	C1-	Flying Capacitor's Negative Terminal
4	GND	Ground
5	C1+	Flying Capacitor's Positive Terminal

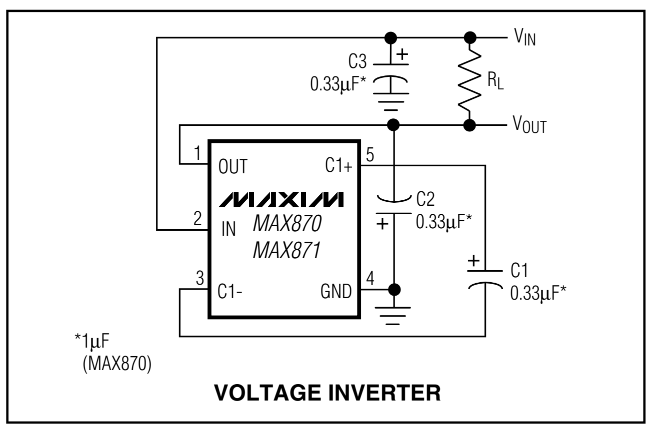


Figure 1. Test Circuit

Detailed Description

The MAX870/MAX871 capacitive charge pumps invert the voltage applied to their input. For highest performance, use low equivalent series resistance (ESR) capacitors (e.g., ceramic).

During the first half-cycle, switches S2 and S4 open, switches S1 and S3 close, and capacitor C1 charges to the voltage at IN (Figure 2). During the second half-cycle, S1 and S3 open, S2 and S4 close, and C1 is level shifted downward by V_{IN} volts. This connects C1 in parallel with the reservoir capacitor C2. If the voltage across C2 is smaller than the voltage across C1, then charge flows from C1 to C2 until the voltage across C2 reaches $-V_{IN}$. The actual voltage at the output is more positive than $-V_{IN}$, since switches S1–S4 have resistance and the load drains charge from C2.

Charge-Pump Output

The MAX870/MAX871 are not voltage regulators: the charge pump's output source resistance is approximately 20Ω at room temperature (with V_{IN} = +5V), and V_{OUT} approaches -5V when lightly loaded. V_{OUT} will droop toward GND as load current increases. The droop of the negative supply (V_{DROOP-}) equals the current draw from OUT (I_{OUT}) times the negative converter's source resistance (RS-):

$$V_{DROOP-} = I_{OUT} \times RS-$$

The negative output voltage will be:

$$V_{OUT} = -(V_{IN} - V_{DROOP-})$$

Efficiency Considerations

The efficiency of the MAX870/MAX871 is dominated by its quiescent supply current (I_Q) at low output current and by its output impedance (R_{OUT}) at higher output current; it is given by:

$$\eta \cong \frac{I_{OUT}}{I_{OUT} + I_Q}\left(1 - \frac{I_{OUT} \times R_{OUT}}{V_{IN}}\right)$$

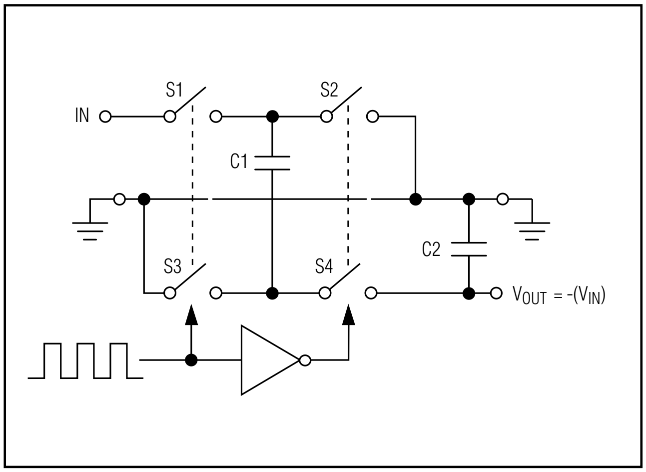


Figure 2. Ideal Voltage Inverter

where the output impedance is roughly approximated by:

$$R_{OUT} \cong \frac{1}{(f_{OSC}) \times C1} + 2R_{SW} + 4ESR_{C1} + ESR_{C2}$$

The first term is the effective resistance of an ideal switched-capacitor circuit (Figures 3a and 3b), and R_{SW} is the sum of the charge pump's internal switch resistances (typically 8Ω to 9Ω at V_{IN} = +5V). The typical output impedance is more accurately determined from the *Typical Operating Characteristics*.

Applications Information

Capacitor Selection

To maintain the lowest output resistance, use capacitors with low ESR (Table 1). The charge-pump output resistance is a function of C1's and C2's ESR. Therefore, minimizing the charge-pump capacitor's ESR minimizes the total output resistance.

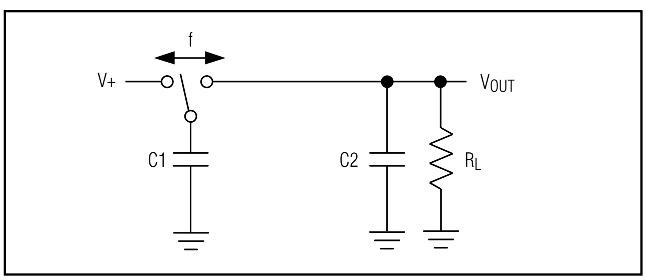


Figure 3a. Switched-Capacitor Model

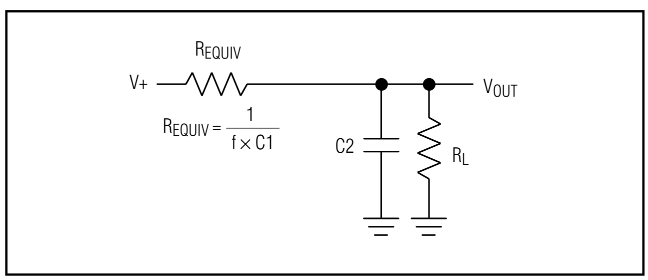


Figure 3b. Equivalent Circuit

Flying Capacitor (C1)

Increasing the flying capacitor's size reduces the output resistance. Small C1 values increase the output resistance. Above a certain point, increasing C1's capacitance has a negligible effect, because the output resistance becomes dominated by the internal switch resistance and capacitor ESR.

Output Capacitor (C2)

Increasing the output capacitor's size reduces the output ripple voltage. Decreasing its ESR reduces both output resistance and ripple. Smaller capacitance values can be used with light loads if higher output ripple can be tolerated. Use the following equation to calculate the peak-to-peak ripple:

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

Input Bypass Capacitor

Bypass the incoming supply to reduce its AC impedance and the impact of the MAX870/MAX871's switching noise. The recommended bypassing depends on the circuit configuration and on where the load is connected.

When the inverter is loaded from OUT 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 is loaded from IN to OUT, the circuit draws 2 x I_{OUT} constantly, except for short switching spikes. A 0.1µF bypass capacitor is sufficient.

Voltage Inverter

The most common application for these devices is a charge-pump voltage inverter (Figure 1). This application requires only two external components—capacitors C1 and C2—plus a bypass capacitor, if necessary. Refer to the *Capacitor Selection* section for suggested capacitor types.

Cascading Devices

Two devices can be cascaded to produce an even larger negative voltage (Figure 4). The unloaded output voltage is normally -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. When cascading more than two devices, the output resistance rises dramatically. For applications requiring larger negative voltages, see the MAX864 and MAX865 data sheets. The maximum load current and startup current of the n^{th} cascaded circuit must not exceed the maximum output current capability of the $(n-1)^{th}$ circuit to ensure proper stability.

Table 1. Low-ESR Capacitor Manufacturers

PRODUCTION METHOD	MANUFACTURER	SERIES	PHONE	FAX
Surface-Mount Tantalum	AVX	TPS series	(803) 946-0690	(803) 626-3123
	Matsuo	267 series	(714) 969-2491	(714) 960-6492
	Sprague	593D, 595D series	(603) 224-1961	(603) 224-1430
Surface-Mount Ceramic	AVX	X7R	(803) 946-0690	(803) 626-3123
	Matsuo	X7R	(714) 969-2491	(714) 960-6492

Table 2. Capacitor Selection for Minimum Output Resistance or Capacitor Size

PART	f_{OSC}	CAPACITORS TO MINIMIZE OUTPUT RESISTANCE (R_O = 23Ω, TYP) C1 = C2	CAPACITORS TO MINIMIZE SIZE (R_O = 40Ω, TYP) C1 = C2
MAX870	125kHz	1µF	0.33µF
MAX871	500kHz	0.33µF	0.1µF

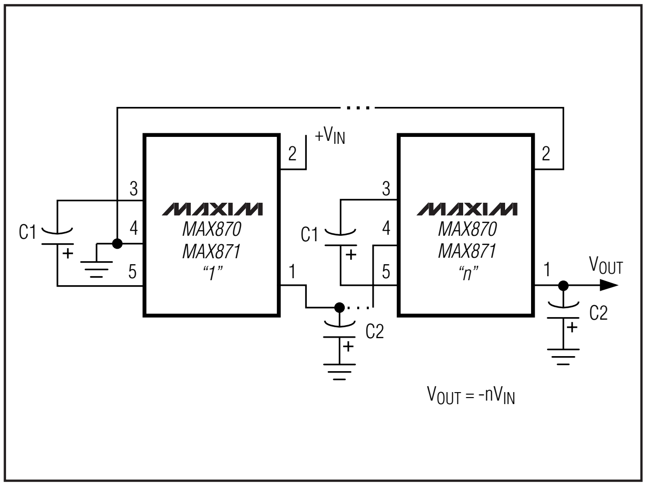


Figure 4. Cascading MAX870s or MAX871s to Increase Output Voltage

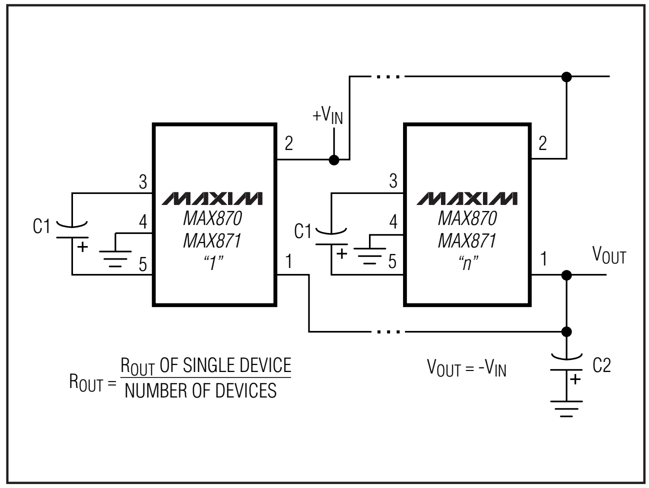


Figure 5. Paralleling MAX870s or MAX871s to Reduce Output Resistance

Paralleling Devices

Paralleling multiple MAX870s or MAX871s reduces the output resistance. Each device requires its own pump capacitor (C1), but the reservoir capacitor (C2) serves all devices (Figure 5). Increase C2's value by a factor of n, where n is the number of parallel devices. Figure 5 shows the equation for calculating output resistance.

Combined Doubler/Inverter

In the circuit of Figure 6, 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 toward GND. Make sure the sum of the currents drawn from the two outputs does not exceed 40mA.

Heavy Output Current Loads

Under heavy loads, where higher supply is sourcing current into OUT, the OUT supply must not be pulled above ground. Applications that sink heavy current into OUT require a Schottky diode (1N5817) between GND and OUT, with the anode connected to OUT (Figure 7).

Layout and Grounding

Good layout is important, primarily for good noise performance. To ensure good layout, mount all components as close together as possible, keep traces short to minimize parasitic inductance and capacitance, and use a ground plane.

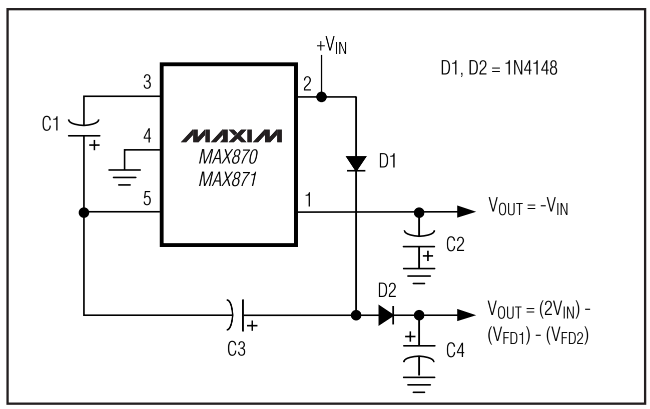


Figure 6. Combined Doubler and Inverter

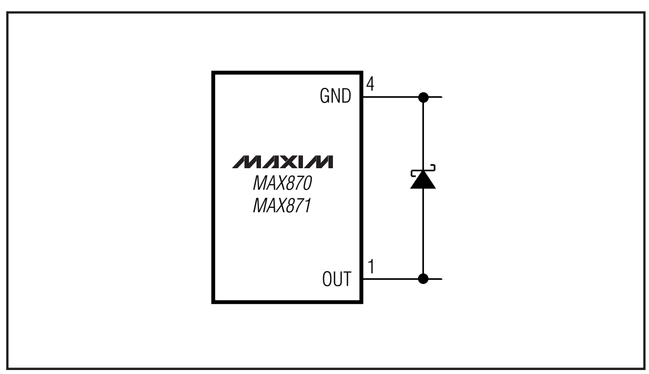


Figure 7. High V- Load Current

Shutdown Control

For a similar device with logic-controlled shutdown, please refer to the MAX1720/MAX1721. To add manual shutdown control to the MAX870/MAX871, use the circuit in Figure 8. The output resistance of the MAX870/MAX871 will typically be 20Ω plus two times the output resistance of the buffer driving IN. The 0.1µF capacitor at the IN pin absorbs the transient input currents of the MAX870/MAX871.

The output resistance of the buffer driving the IN pin can be reduced by connecting multiple buffers in parallel. The polarity of the shutdown signal can also be changed by using a noninverting buffer to drive IN.

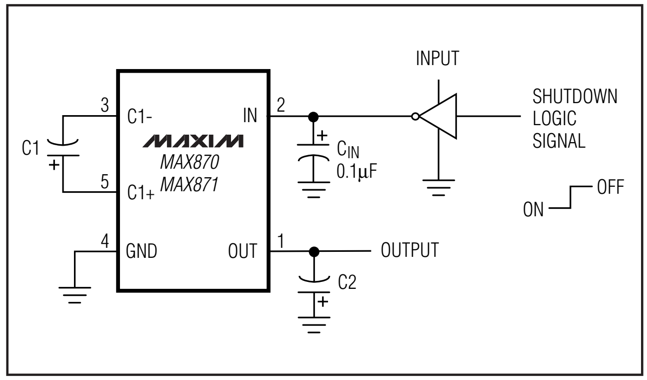


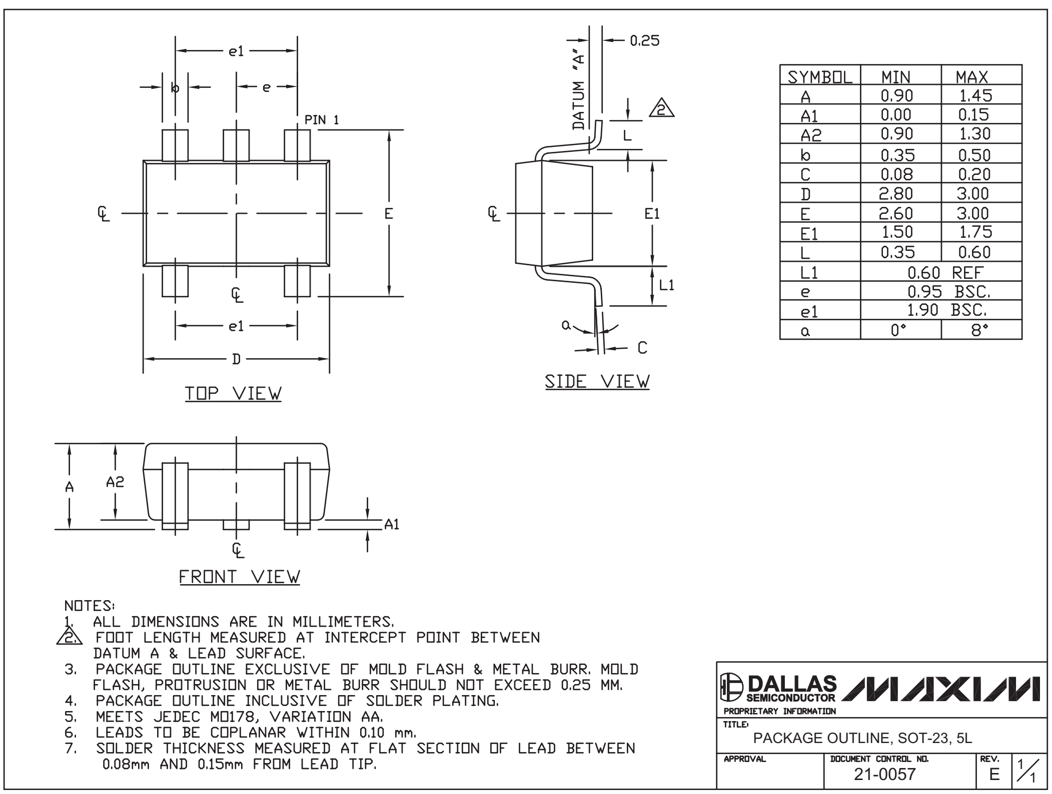
Figure 8. Shutdown Control

Chip Information

TRANSISTOR COUNT: 58

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**.)



SYMBOL	MIN	MAX
A	0.90	1.45
A1	0.00	0.15
A2	0.90	1.30
b	0.35	0.50
C	0.08	0.20
D	2.80	3.00
E	2.60	3.00
E1	1.50	1.75
L	0.35	0.60
L1	0.60 REF	
e	0.95 BSC.	
e1	1.90 BSC.	
a	0°	8°

NOTES:
1. ALL DIMENSIONS ARE IN MILLIMETERS.
2. FOOT LENGTH MEASURED AT INTERCEPT POINT BETWEEN DATUM A & LEAD SURFACE.
3. PACKAGE OUTLINE EXCLUSIVE OF MOLD FLASH & METAL BURR. MOLD FLASH, PROTRUSION OR METAL BURR SHOULD NOT EXCEED 0.25 MM.
4. PACKAGE OUTLINE INCLUSIVE OF SOLDER PLATING.
5. MEETS JEDEC MO178, VARIATION AA.
6. LEADS TO BE COPLANAR WITHIN 0.10 mm.
7. SOLDER THICKNESS MEASURED AT FLAT SECTION OF LEAD BETWEEN 0.08mm AND 0.15mm FROM LEAD TIP.