



## Compact, Dual-Output Charge Pump

MAX865

### General Description

The MAX865 is a CMOS charge-pump DC-DC converter in an ultra-small  $\mu$ MAX package. It produces positive and negative outputs from a single positive input, and requires only four capacitors. The charge pump first doubles the input voltage, then inverts the doubled voltage. The input voltage ranges from +1.5V to +6.0V.

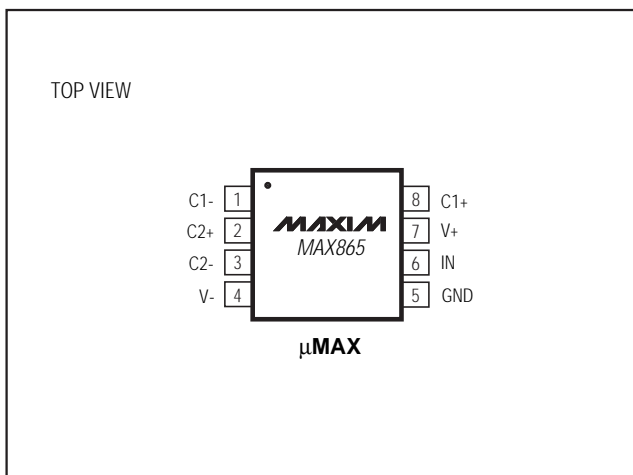
The internal oscillator is guaranteed to be between 20kHz and 38kHz, keeping noise above the audio range while consuming minimal supply current. A 75 $\Omega$  output impedance permits useful output currents up to 20mA.

The MAX865 comes in a 1.11mm-high, 8-pin  $\mu$ MAX package that occupies half the board area of a standard 8-pin SOIC. For a device with selectable frequencies and logic-controlled shutdown, refer to the MAX864 data sheet.

### Applications

- Low-Voltage GaAsFET Bias in Wireless Handsets
- VCO and GaAsFET Supplies
- Split Supply from 3 Ni Cells or 1 Li+ Cell
- Low-Cost Split Supply for Low-Voltage Data-Acquisition Systems
- Split Supply for Analog Circuitry
- LCD Panels

### Pin Configuration



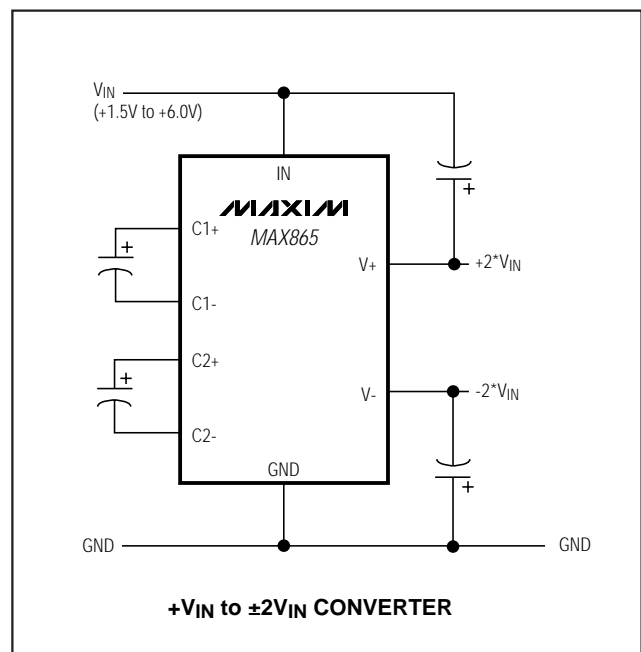
### Features

- ◆ 1.11mm-High  $\mu$ MAX Package
- ◆ Compact: Circuit Fits in 0.08in<sup>2</sup>
- ◆ Requires Only Four Capacitors
- ◆ Dual Outputs (positive and negative)
- ◆ +1.5V to +6.0V Input Voltage
- ◆ 20kHz (min) Frequency (above the audio range)

### Ordering Information

PART	TEMP. RANGE	PIN-PACKAGE
MAX865C/D	0°C to +70°C	Dice
MAX865EUA	-40°C to +85°C	8 $\mu$ MAX

### Typical Operating Circuit



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## ABSOLUTE MAXIMUM RATINGS

V+ to GND .....	+12V, -0.3V
IN to GND .....	+6.2V, -0.3V
V- to GND .....	-12V, +0.3V
V- Output Current .....	100mA
V- Short-Circuit to GND .....	Indefinite
Continuous Power Dissipation (T <sub>A</sub> = +70°C)	
μMAX (derate 4.1mW/°C above +70°C) .....	330mW

Operating Temperature Range	
MAX865EUA .....	-40°C to +85°C
Storage Temperature Range .....	-65°C to +160°C
Lead Temperature (soldering, 10sec) .....	+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

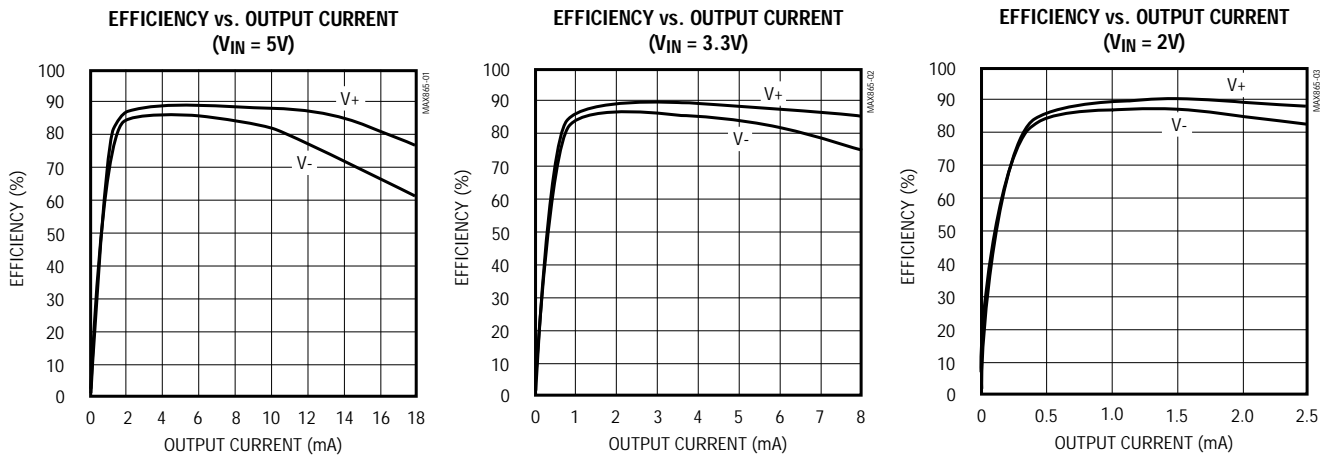
(V<sub>IN</sub> = 5V, C1 = C2 = C3 = C4 = 3.3μF, T<sub>A</sub> = T<sub>MIN</sub> to T<sub>MAX</sub>, unless otherwise noted. Typical values are at T<sub>A</sub> = +25°C.)

PARAMETER	CONDITIONS	MIN	TYP	MAX	UNITS
Minimum Supply Voltage	R <sub>LOAD</sub> = 10kΩ	2.0	1.5		V
Maximum Supply Voltage	R <sub>LOAD</sub> = 10kΩ			6.0	V
Supply Current	T <sub>A</sub> = +25°C		0.6	1.05	mA
	T <sub>A</sub> = -40°C to +85°C (Note 1)			1.15	
Oscillator Frequency	T <sub>A</sub> = +25°C	19.5	24	32.5	kHz
	T <sub>A</sub> = -40°C to +85°C (Note 1)	18		34	
Output Resistance	I <sub>V+</sub> = 1mA, I <sub>V-</sub> = 0mA	T <sub>A</sub> = +25°C	150	200	Ω
		T <sub>A</sub> = T <sub>MIN</sub> to T <sub>MAX</sub>		280	
	V <sub>+</sub> = 10V (forced), I <sub>V-</sub> = 1mA	T <sub>A</sub> = +25°C	75	100	
		T <sub>A</sub> = T <sub>MIN</sub> to T <sub>MAX</sub>		140	
Power Efficiency	I <sub>L</sub> = 5mA		85		%
Voltage Conversion Efficiency	V <sub>+</sub> , R <sub>L</sub> = ∞	95	99		%
	V <sub>-</sub> , R <sub>L</sub> = ∞	90	98		

**Note 1:** These specifications are guaranteed by design and are not production tested.

## Typical Operating Characteristics

(Circuit of Figure 1, V<sub>IN</sub> = 5V, T<sub>A</sub> = +25°C, unless otherwise noted.)

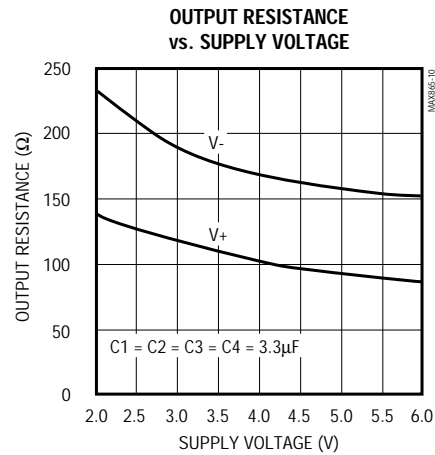
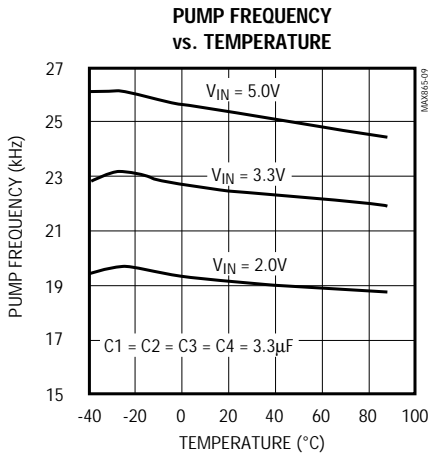
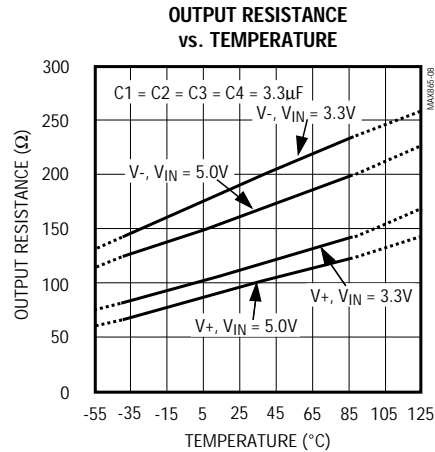
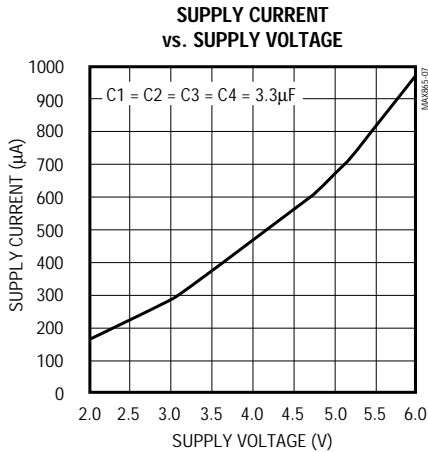
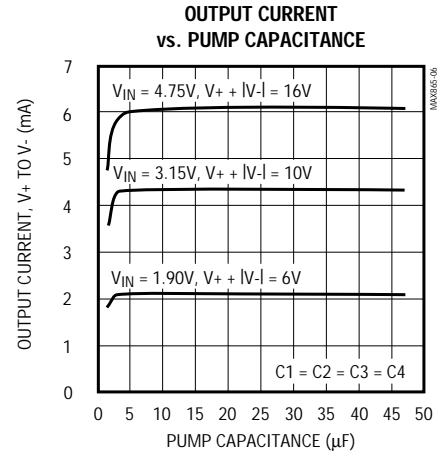
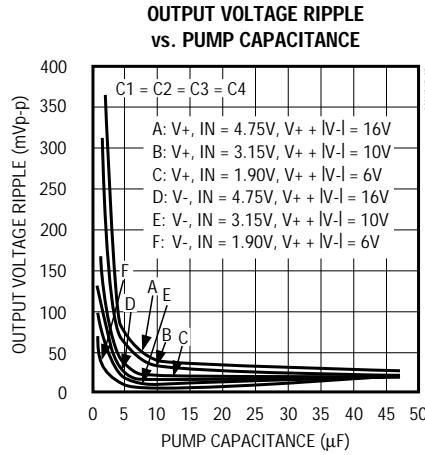
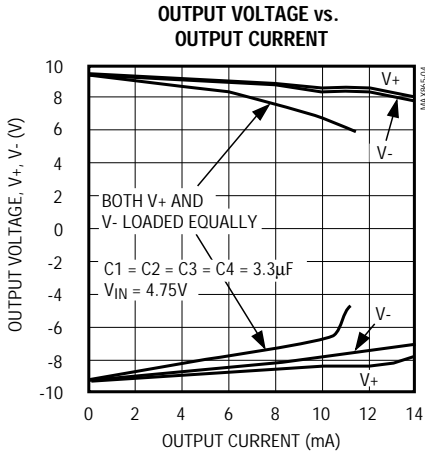


# Compact, Dual-Output Charge Pump

MAX865

## Typical Operating Characteristics (continued)

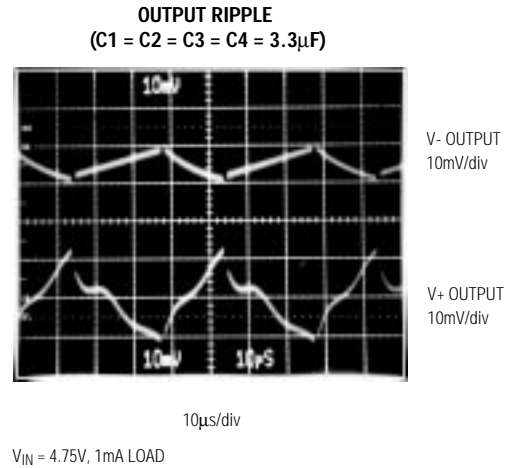
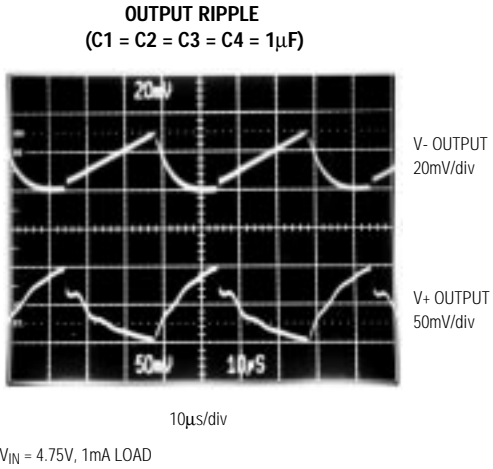
(Circuit of Figure 1,  $V_{IN} = 5V$ ,  $T_A = +25^\circ C$ , unless otherwise noted.)



# Compact, Dual-Output Charge Pump

## Typical Operating Characteristics (continued)

(Circuit of Figure 1,  $V_{IN} = 5V$ ,  $T_A = +25^\circ C$ , unless otherwise noted.)



## Pin Description

PIN	NAME	FUNCTION
1	C1-	Negative Terminal of the Flying Boost Capacitor
2	C2+	Positive Terminal of the Flying Inverting Capacitor
3	C2-	Negative Terminal of the Flying Inverting Capacitor
4	V-	Output of the Inverting Charge Pump
5	GND	Ground
6	IN	Positive Power-Supply Input
7	V+	Output of the Boost Charge Pump
8	C1+	Positive Terminal of the Flying Boost Capacitor

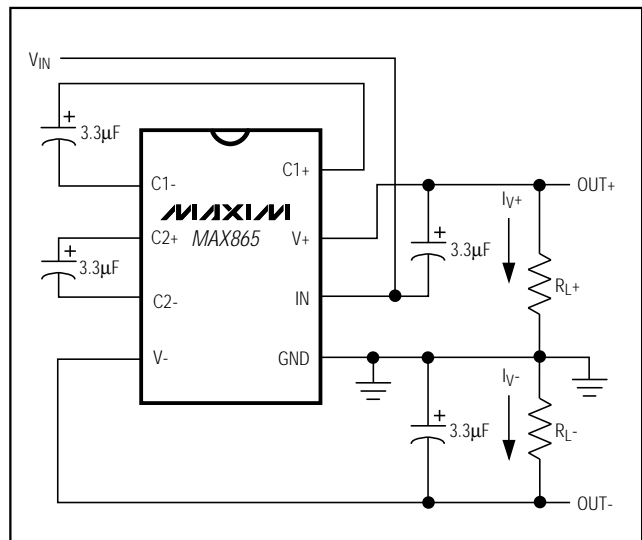


Figure 1. Test Circuit

# Compact, Dual-Output Charge Pump

## Detailed Description

The MAX865 contains all the circuitry needed to implement a voltage doubler/inverter. Only four external capacitors are needed. These may be polarized electrolytic or ceramic capacitors with values ranging from 1 $\mu$ F to 100 $\mu$ F.

Figure 2a shows the ideal operation of the positive voltage doubler. The on-chip oscillator generates a 50% duty-cycle clock signal. During the first half cycle, switches S2 and S4 open, switches S1 and S3 close, and capacitor C1 charges to the input voltage ( $V_{IN}$ ). During the second half cycle, switches S1 and S3 open, switches S2 and S4 close, and capacitor C1 is level shifted upward by  $V_{IN}$ . Assuming ideal switches and no load on C3, charge transfers into C3 from C1 such that the voltage on C3 will be  $2V_{IN}$ , generating the positive supply output ( $V_+$ ).

Figure 2b illustrates the ideal operation of the negative converter. The switches of the negative converter are out of phase with the positive converter. During the second half cycle, switches S6 and S8 open and switches S5 and S7 close, charging C2 from  $V_+$  (pumped up to  $2V_{IN}$  by the positive charge pump) to GND. In the first half of the clock cycle, switches S5

and S7 open, switches S6 and S8 close, and the charge on capacitor C2 transfers to C4, generating the negative supply. The eight switches are CMOS power MOSFETs. Switches S1, S2, S4, and S5 are P-channel devices, while switches S3, S6, S7, and S8 are N-channel devices.

## Charge-Pump Output

The MAX865 is not a voltage regulator: the output source resistance of either charge pump is approximately 150 $\Omega$  at room temperature with  $V_{IN} = +5V$ , and  $V_+$  and  $V_-$  will approach +10V and -10V, respectively, when lightly loaded. Both  $V_+$  and  $V_-$  will droop toward GND as the current draw from either  $V_+$  or  $V_-$  increases, since  $V_-$  is derived from  $V_+$ . Treating each converter separately, the droop of the negative supply ( $V_{DROOP-}$ ) is the product of the current draw from  $V_-$  ( $I_{V-}$ ) and the source resistance of the negative converter ( $R_{S-}$ ):

$$V_{DROOP-} = I_{V-} \times R_{S-}$$

The droop of the positive supply ( $V_{DROOP+}$ ) is the product of the current draw from the positive supply ( $I_{LOAD+}$ ) and the source resistance of the positive

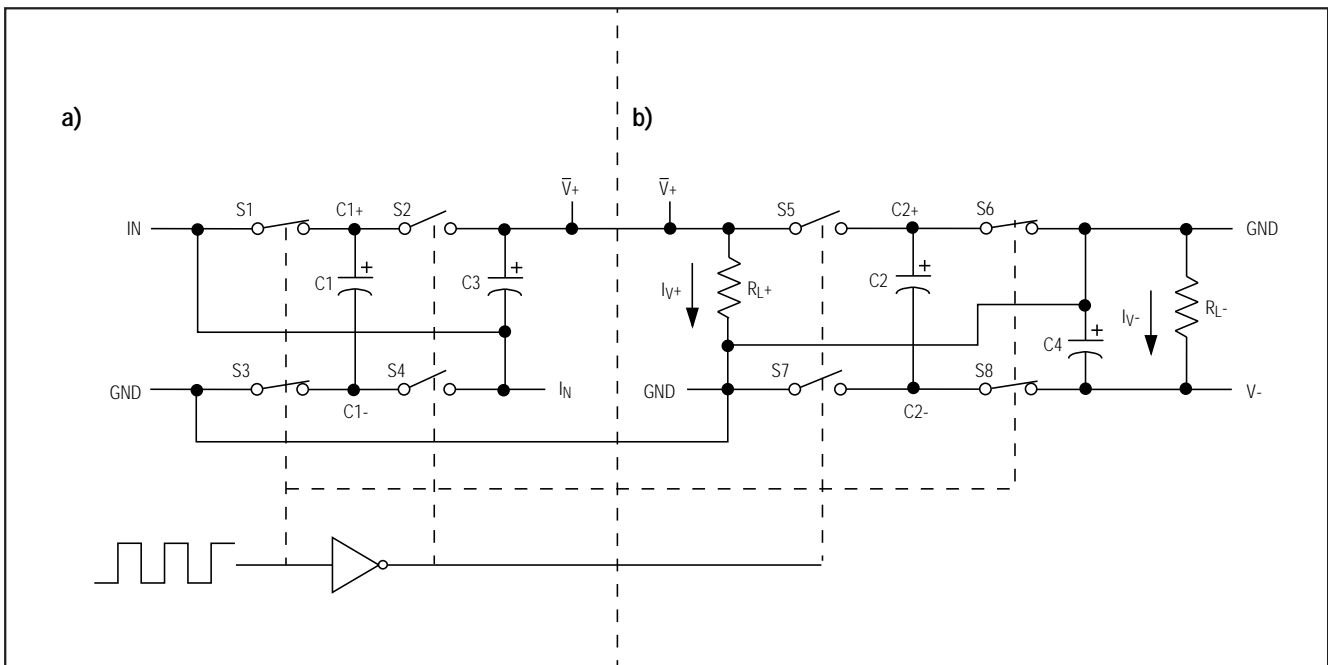


Figure 2. Idealized Voltage Quadrupler: a) Positive Charge Pump; b) Negative Charge Pump

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converter ( $RS_+$ ), where  $I_{LOAD+}$  is the combination of  $I_{V-}$  and the external load on  $V_+$  ( $I_{V+}$ ):

$$V_{DROOP+} = I_{LOAD+} \times RS_+ = (I_{V+} + I_{V-}) \times RS_+$$

Determine  $V_+$  and  $V_-$  as follows:

$$V_+ = 2V_{IN} - V_{DROOP+}$$

$$V_- = (V_+ - V_{DROOP-}) = (2V_{IN} - V_{DROOP+} - V_{DROOP-})$$

The output resistance for the positive and negative charge pumps are tested and specified separately. The positive charge pump is tested with  $V_-$  unloaded. The negative charge pump is tested with  $V_+$  supplied from an external source, isolating the negative charge pump.

Current draw from either  $V_+$  or  $V_-$  is supplied by the reservoir capacitor alone during one half cycle of the clock. Calculate the resulting ripple voltage on either output as follows:

$$V_{RIPPLE} = \frac{1}{2} I_{LOAD} (1 / f_{PUMP}) (1 / C_{RESERVOIR})$$

where  $I_{LOAD}$  is the load on either  $V_+$  or  $V_-$ . For the typical  $f_{PUMP}$  of 30kHz with 3.3µF reservoir capacitors, the ripple is 25mV when  $I_{LOAD}$  is 5mA. Remember that, in most applications, the total load on  $V_+$  is the  $V_+$  load current ( $I_{V+}$ ) and the current taken by the negative charge pump ( $I_{V-}$ ).

### Efficiency Considerations

Theoretically, a charge-pump voltage multiplier can approach 100% power efficiency under the following conditions:

- The charge-pump switches have virtually no offset and extremely low on-resistance.
- The drive circuitry consumes minimal power.
- The impedances of the reservoir and pump capacitors are negligible.

For the MAX865, the energy loss per clock cycle is the sum of the energy loss in the positive and negative converters, as follows:

$$\begin{aligned} LOSS_{CYCLE} &= LOSS_{POS} + LOSS_{NEG} \\ &= \frac{1}{2} C1 [(V_+)^2 - 2(V_+) (V_{IN})] \\ &\quad + \frac{1}{2} C2 [(V_+)^2 - (V_-)^2] \end{aligned}$$

The average power loss is simply:

$$P_{LOSS} = LOSS_{CYCLE} \times f_{PUMP}$$

Resulting in an efficiency of:

$$\eta = \text{Total Output Power} / (\text{Total Output Power} - P_{LOSS})$$

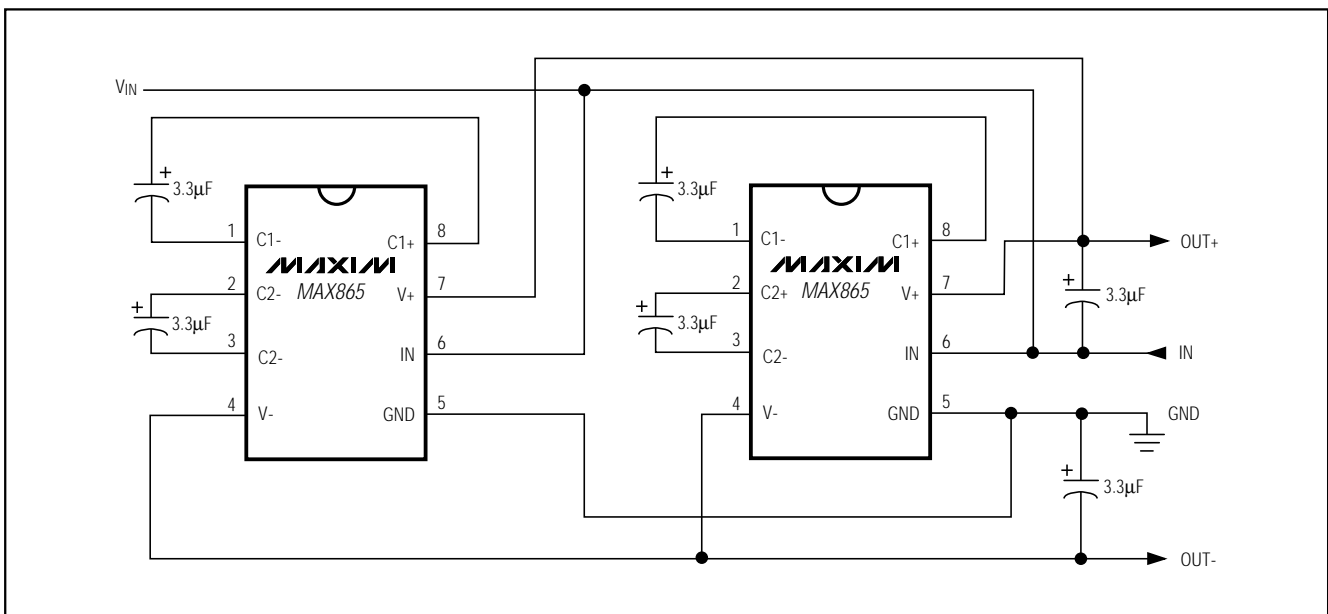


Figure 3. Paralleling MAX865s

# Compact, Dual-Output Charge Pump

A substantial voltage difference exists between  $(V_+ - V_{IN})$  and  $V_{IN}$  for the positive pump, and between  $|V_-|$  and  $|V_-|$  if the impedances of the pump capacitors (C1 and C2) are large with respect to their output loads.

Larger values of reservoir capacitors (C3 and C4) reduce output ripple. Larger values of both pump and reservoir capacitors improve power efficiency.

## Charge-Pump Capacitor Selection

To maintain the lowest output resistance, use capacitors with low effective series resistance (ESR). The charge-pump output resistance is a function of C1, C2, C3, and C4's ESR. Therefore, minimizing the charge-pump capacitors' ESR minimizes the total output resistance.

## Applications Information

### Positive and Negative Converter

The MAX865 is most commonly used as a dual charge-pump voltage converter that provides positive and negative outputs of two times a positive input voltage. The *Typical Operating Circuit* shows that only four external components are needed: capacitors C1 and C3 for the positive pump, C2 and C4 for the negative pump. In most applications, all four capacitors are low-cost, 3.3 $\mu$ F polarized electrolytics. For applications where PC board space is at a premium and very low currents are being drawn from the MAX865, 1 $\mu$ F capacitors may be used for the pump capacitors C1 and C2, with 1 $\mu$ F reservoir capacitors C3 and C4. Capacitors C2 and C4 must be rated at 12V or greater.

### Paralleling Devices

Paralleling multiple MAX865s (Figure 3) reduces the output resistance of both the positive and negative converters. The effective output resistance is the output resistance of one device divided by the number of devices. Separate C1 and C2 charge-pump capacitors are required for each MAX865, but the reservoir capacitors C3 and C4 can be shared.

### Heavy Output Current Loads

When under heavy loads, where  $V_+$  is sourcing current into  $V_-$  (i.e., load current flows from  $V_+$  to  $V_-$ , rather than from supply to ground), do not allow the  $V_-$  supply to pull above ground. In applications where large currents flow from  $V_+$  to  $V_-$ , use a Schottky diode (1N5817) between GND and  $V_-$ , with the anode connected to GND (Figure 4).

### 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
- Use a ground plane.

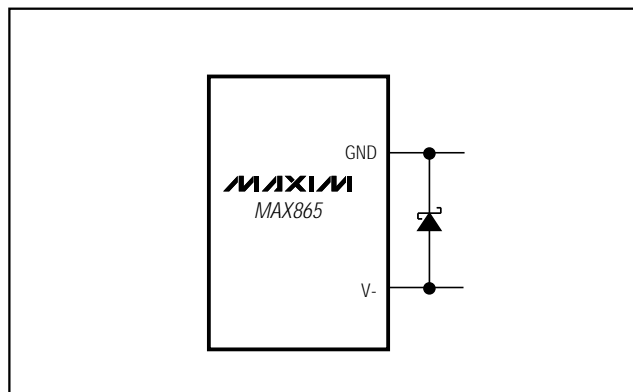
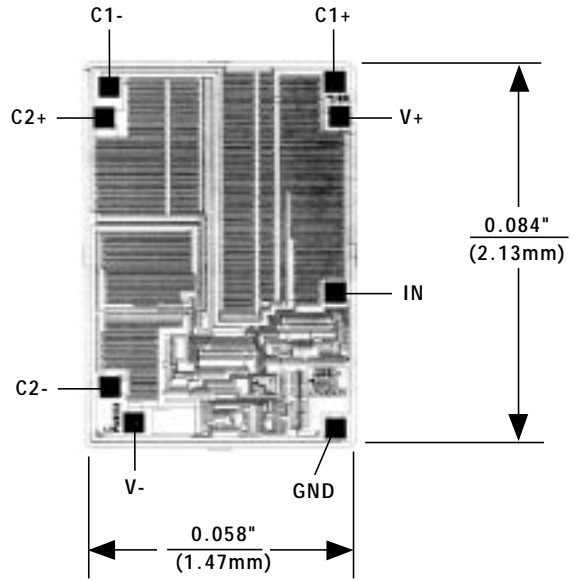


Figure 4. A Schottky diode protects the MAX865 when large currents flow from  $V_+$  to  $V_-$ .

# Compact, Dual-Output Charge Pump

## Chip Topography

TRANSISTOR COUNT: 80  
 SUBSTRATE CONNECTED TO V+



## Package Information

DIM	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.036	0.044	0.91	1.11
A1	0.004	0.008	0.10	0.20
B	0.010	0.014	0.25	0.36
C	0.005	0.007	0.13	0.18
D	0.116	0.120	2.95	3.05
E	0.116	0.120	2.95	3.05
e	0.0256		0.65	
H	0.188	0.198	4.78	5.03
L	0.016	0.026	0.41	0.66
α	0° to 6°		0° to 6°	

21-0036D

**8-PIN μMAX  
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