125mA, Frequency-Selectable, Switched-Capacitor Voltage Converters

ABSOLUTE MAXIMUM RATINGS

IN ....-0.3V to +6V
LV...(V_{OUT} - 0.3V) to (V_{IN} + 0.3V)
CAP+ ....-0.3V to (V_{IN} + 0.3V)
SHDN, FSEL ....(V_{LV} - 0.3V) to (V_{IN} + 0.3V)
OUT, CAP- ....-6V to 0.3V
Continuous Output Current 135mA
Output Short-Circuit Duration to GND (Note 1) 1sec

Continuous Power Dissipation (T_A = +70°C)
SO (derate 5.88mW/°C above +70°C)..........................471mW
Operating Temperature Range ....-40°C to +85°C
Junction Temperature ....+150°C
Storage Temperature Range ....-65°C to +160°C
Lead Temperature (soldering, 10sec) ....+300°C

Note 1: Shorting OUT to IN may damage the device and should be avoided.

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 Circuits* (inverter configuration), FSEL = LV = GND, V_{IN} = 5V, C1 = C2 = 10µF (MAX1680), C1 = C2 = 2.2µF (MAX1681), **T_A = 0°C to +85°C**, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS			MIN	TYP	MAX	UNITS
Input Voltage Range	V_{IN}	Inverter configuration, R_L = 1kΩ, LV = GND		MAX1680	2.0		5.5	V
				MAX1681	3.0		5.5	
		Doubler configuration, R_L = 1kΩ, LV = OUT		MAX1680	2.5		5.5	
				MAX1681	4.0		5.5	
Supply Current	I+	MAX1680	FSEL = IN (125kHz)	T_A = +25°C		2.5	4.5	mA
							5.4	
			FSEL = LV (250kHz)	T_A = +25°C		5	9	
							10.8	
		MAX1681	FSEL = IN (500kHz)	T_A = +25°C		10	18	
							21.6	
			FSEL = LV (1MHz)	T_A = +25°C		20	36	
							43.2	
Output Voltage Under Load (Note 2)	V_{LOAD}	I_{LOAD} = 125mA			-3.75	-4.56		V
Output Resistance (Note 2)	R_{OUT}	FSEL = IN or LV				3.5	10	Ω
Output Resistance to Ground in Shutdown	$R_{OUT(SHUT)}$	SHDN = IN				1	5	Ω
Shutdown Current	$I+_{SHDN}$	OUT = GND, SHDN = IN					1	µA
Input Bias Current (SHDN)	I_{SHDN}				-1		1	µA
Input Bias Current (FSEL)	I_{FSEL}				-1		1	µA
Shutdown, FSEL Thresholds	V_{IL}	LV = GND (Note 3)					1	V
	V_{IH}				4			
Switching Frequency	f_{OSC}	MAX1680	FSEL = LV	T_A = +25°C	187	250	313	kHz
					157		348	
			FSEL = IN	T_A = +25°C	94	125	156	
					79		174	
		MAX1681	FSEL = LV	T_A = +25°C	750	1000	1250	
					570		1490	
			FSEL = IN	T_A = +25°C	375	500	625	
					285		745	

ELECTRICAL CHARACTERISTICS (continued)

(*Typical Operating Circuits* (inverter configuration), FSEL = LV = GND, V_{IN} = 5V, C1 = C2 = 10µF (MAX1680), C1 = C2 = 2.2µF (MAX1681), **T_A = 0°C to +85°C**, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Power Efficiency		R_L = 100Ω to GND, FSEL = IN	MAX1680		90		%
Power Efficiency		R_L = 100Ω to GND, FSEL = IN	MAX1681		80		%

ELECTRICAL CHARACTERISTICS

(*Typical Operating Circuits* (inverter configuration), FSEL = LV = GND, V_{IN} = 5V, C1 = C2 = 10µF (MAX1680), C1 = C2 = 2.2µF (MAX1681), **T_A = -40°C to +85°C**, unless otherwise noted.) (Note 4)

PARAMETER	SYMBOL	CONDITIONS		MIN	TYP	MAX	UNITS
Input Voltage Range	V_{IN}	Inverter configuration, R_L = 1kΩ, LV = GND	MAX1680	2.0		5.5	V
Input Voltage Range	V_{IN}	Inverter configuration, R_L = 1kΩ, LV = GND	MAX1681	3.0		5.5	V
Input Voltage Range	V_{IN}	Doubler configuration, R_L = 1kΩ, LV = OUT	MAX1680	2.5		5.5	V
Input Voltage Range	V_{IN}	Doubler configuration, R_L = 1kΩ, LV = OUT	MAX1681	4.0		5.5	V
Supply Current	I+	MAX1680	FSEL = IN (125kHz)			5.4	mA
Supply Current	I+	MAX1680	FSEL = LV (250kHz)			10.8	mA
Supply Current	I+	MAX1681	FSEL = IN (500kHz)			21.6	mA
Supply Current	I+	MAX1681	FSEL = LV (1MHz)			43.2	mA
Output Voltage Under Load (Note 2)	V_{LOAD}	I_{LOAD} = 125mA		-3.75			V
Output Resistance (Note 2)	R_{OUT}	FSEL = IN or LV				10	Ω
Output Resistance in Shutdown	$R_{OUT(SHUT)}$	SHDN = IN				5	Ω
Shutdown Current	$I+_{SHDN}$	OUT = GND, SHDN = IN				1	µA
Input Bias Current (SHDN)	I_{SHDN}					1	µA
Input Bias Current (FSEL)	I_{FSEL}			-1		1	µA
Shutdown, FSEL Thresholds	V_{IL}	LV = GND (Note 3)		-1		1	V
Shutdown, FSEL Thresholds	V_{IH}	LV = GND (Note 3)		4			V
Switching Frequency	f_{OSC}	MAX1680	FSEL = LV	157		348	kHz
Switching Frequency	f_{OSC}	MAX1680	FSEL = IN	79		174	kHz
Switching Frequency	f_{OSC}	MAX1681	FSEL = LV	570		1490	kHz
Switching Frequency	f_{OSC}	MAX1681	FSEL = IN	285		745	kHz

Note 2: C1 and C2 are low-ESR (<0.2Ω) capacitors. Capacitor ESR adds to the circuit's output resistance. Using capacitors with higher ESR reduces output voltage and efficiency. The specified output resistance includes the C1 and C2 0.2Ω ESR.

Note 3: The typical threshold for V_{INPUT} other than +5V is $0.35V_{INPUT}$ (V_{IL} = V_{IH}).

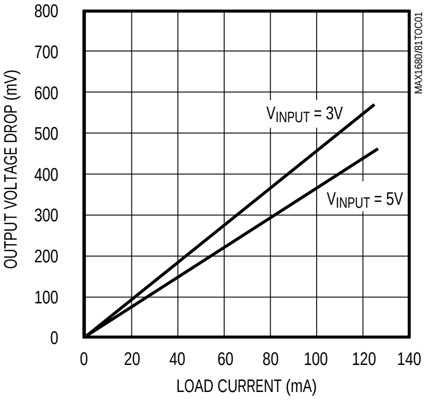
Note 4: Specifications to -40°C are guaranteed by design, not production tested.

125mA, Frequency-Selectable, Switched-Capacitor Voltage Converters

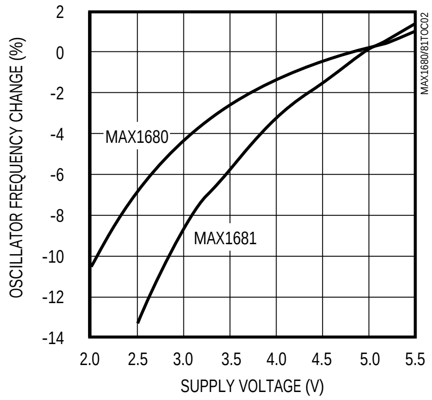
Typical Operating Characteristics

(All curves generated using the inverter configuration shown in the *Typical Operating Circuits* with LV = GND, FSEL = IN or LV, C1 = C2 = 10µF (MAX1680), C1 = C2 = 2.2µF (MAX1681), and T_A = +25°C, unless otherwise noted. Test results are also valid for the doubler configuration with LV = OUT and T_A = +25°C.)

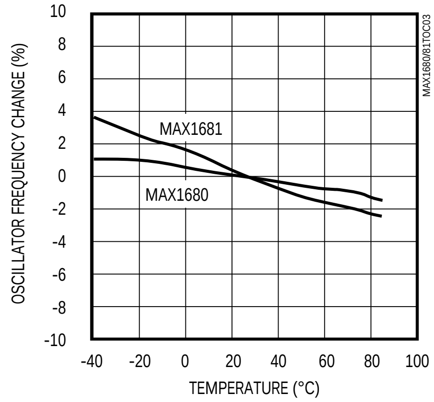
OUTPUT VOLTAGE DROP vs. LOAD CURRENT



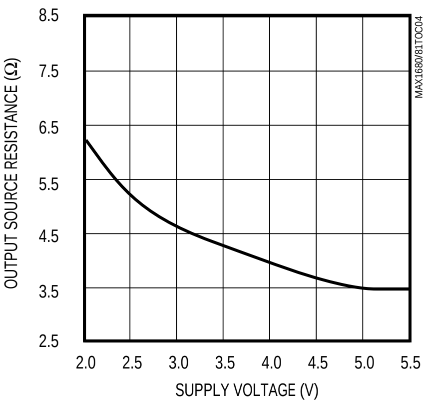
OSCILLATOR FREQUENCY CHANGE vs. SUPPLY VOLTAGE



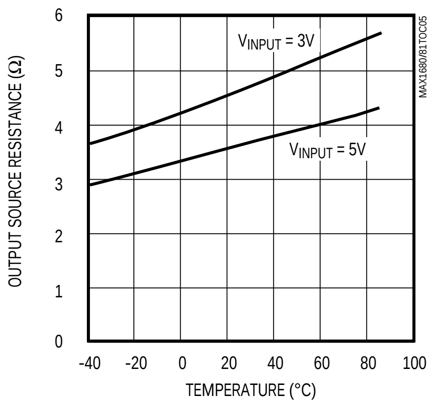
OSCILLATOR FREQUENCY CHANGE vs. TEMPERATURE



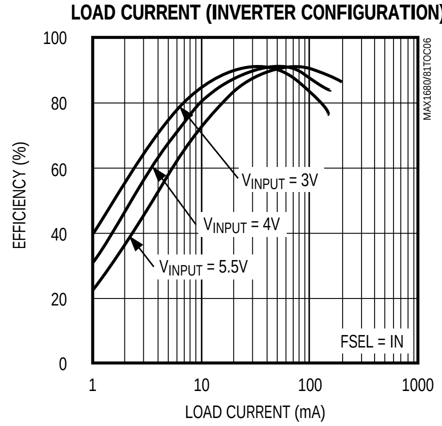
OUTPUT SOURCE RESISTANCE vs. SUPPLY VOLTAGE



OUTPUT SOURCE RESISTANCE vs. TEMPERATURE



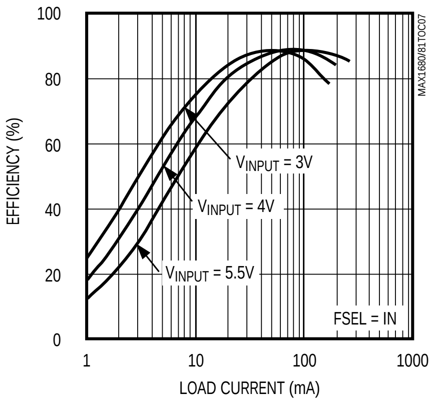
MAX1680 EFFICIENCY vs. LOAD CURRENT (INVERTER CONFIGURATION)



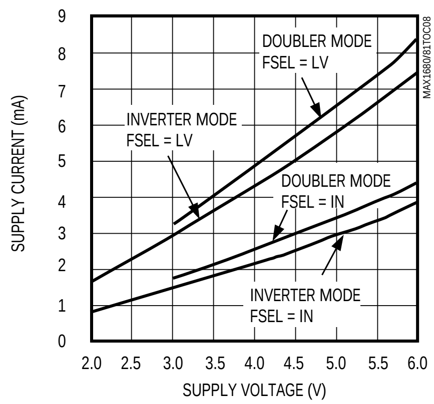
Typical Operating Characteristics (continued)

(All curves generated using the inverter configuration shown in the *Typical Operating Circuits* with LV = GND, FSEL = IN or LV, C1 = C2 = 10µF (MAX1680), C1 = C2 = 2.2µF (MAX1681), and T_A = +25°C, unless otherwise noted. Test results are also valid for the doubler configuration with LV = OUT and T_A = +25°C.)

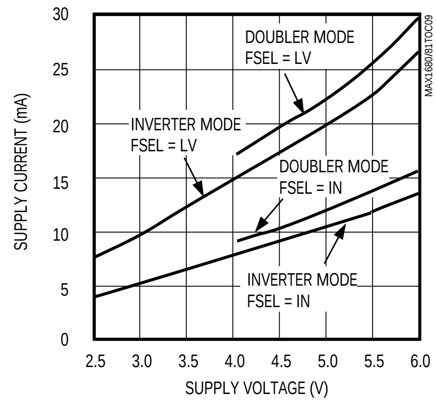
MAX1681 EFFICIENCY vs. LOAD CURRENT (DOUBLER CONFIGURATION)



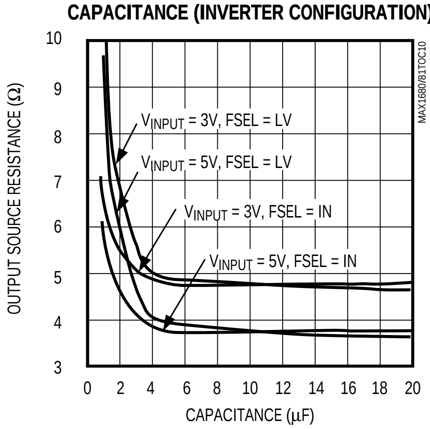
MAX1680 SUPPLY CURRENT vs. SUPPLY VOLTAGE



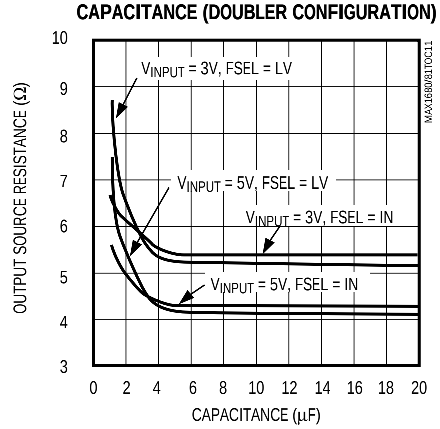
MAX1681 SUPPLY CURRENT vs. SUPPLY VOLTAGE



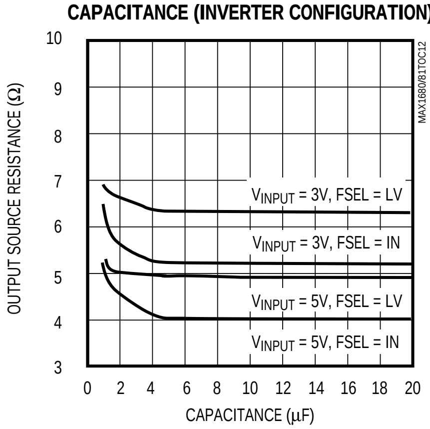
MAX1680 OUTPUT SOURCE RESISTANCE vs. CAPACITANCE (INVERTER CONFIGURATION)



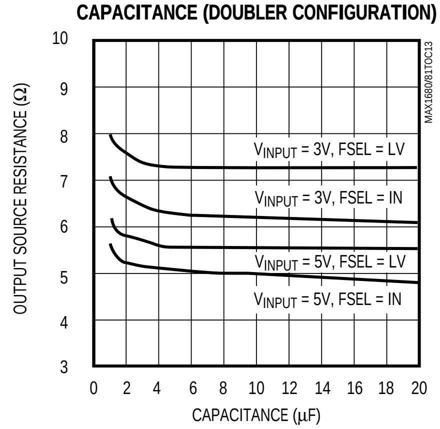
MAX1680 OUTPUT SOURCE RESISTANCE vs. CAPACITANCE (DOUBLER CONFIGURATION)



MAX1681 OUTPUT SOURCE RESISTANCE vs. CAPACITANCE (INVERTER CONFIGURATION)



MAX1681 OUTPUT SOURCE RESISTANCE vs. CAPACITANCE (DOUBLER CONFIGURATION)



Pin Description

PIN	NAME	FUNCTION	
		INVERTER	DOUBLER
1	FSEL	Selects operating frequency. MAX1680: 250kHz when FSEL is low, 125kHz when FSEL is high. MAX1681: 1MHz when FSEL is low, 500kHz when FSEL is high.	
2	CAP+	Positive Charge-Pump Capacitor Connection	
3	GND	Power-Supply Ground Input	Power-Supply Positive Voltage Input
4	CAP-	Negative Charge-Pump Capacitor Connection	
5	OUT	Negative Voltage Output	Power-Supply Ground Connection
6	LV	Logic Voltage Input. Connect LV to GND.	Connect LV to OUT.
7	SHDN	Shutdown Input. Driving SHDN high disables the charge pump, and the output goes to 0V. SHDN is a CMOS input.	Not available; connect to OUT.
8	IN	Power-Supply Positive Voltage Input	Positive Voltage Output

Detailed Description

The MAX1680/MAX1681 switched-capacitor voltage converters either invert or double the input voltage. They have low output resistance (3.5Ω) and can deliver up to 125mA output current. These devices operate at one of two selectable frequencies: 125kHz/250kHz (MAX1680) and 500kHz/1MHz (MAX1681). This provides the flexibility to optimize capacitor size, operating supply current, and overall circuit efficiency. Frequency selection also allows for minimizing coupling into other sensitive circuits. These devices contain no internal divider; the oscillator frequency equals the switching frequency. The devices can easily be cascaded to produce a higher output voltage, or paralleled to deliver more current.

The MAX1680/MAX1681 feature a shutdown mode that reduces supply current to <1µA (SHDN = high). OUT, in the inverter configuration, pulls to ground in shutdown mode. Shutdown is not available in the doubler configuration; connect SHDN to OUT.

Applications Information

Voltage Inverter

A simple voltage inverter is the most common MAX1680/MAX1681 application. It requires three external capacitors (including the input bypass capacitor) as shown in the *Typical Operating Circuits* (inverter configuration). Although the output is not regulated, low output resistance produces a typical drop of only 0.44V with a 125mA load. This low output resistance makes the devices fairly insensitive to changes in load (see the graphs for Output Source Resistance vs. Temperature and Supply Voltage in the *Typical Operating Characteristics* section).

Voltage Doubler

The MAX1680/MAX1681 can be configured as a voltage doubler with two external capacitors as shown in the *Typical Operating Circuits* (doubler configuration). When loaded, the output voltage drop is similar to that of the voltage inverter. The minimum input supply range is slightly higher than in the inverter configuration. Calculate ripple voltage using the equation in the *Capacitor Selection* section.

Frequency Control

A frequency-control pin, FSEL, provides design flexibility. Each device has two selectable frequencies: 125kHz/250kHz (MAX1680) and 500kHz/1MHz (MAX1681). This allows optimization of capacitor size and supply current for a given output load. Table 1 summarizes the frequency options .

Table 1. Nominal Switching Frequencies

FSEL CONNECTION	FREQUENCY (kHz)	
	MAX1680	MAX1681
FSEL = LV	250	1000
FSEL = IN	125	500

Operating Frequency Trade-Offs

It is important to recognize the trade-offs between switching frequency, power consumption, noise, cost, and performance. Higher frequency switching reduces capacitor size while maintaining the same output impedance, thus saving capacitor cost and board space. Lower frequency designs use less supply current. Table 2 summarizes the relative trade-offs.

Table 2. Switching-Frequency Trade-Offs

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

Capacitor Selection

The MAX1680/MAX1681 are tested with capacitor values of 10µF and 2.2µF, respectively. Capacitor size and switching speed determine output resistance. Larger C1 values decrease the output resistance until the internal switch resistance (3.5Ω typ) becomes the dominant term. Low-ESR capacitors minimize output resistance and ripple voltage. The entire circuit's output resistance can be approximated by the following equation:

$$R_{OUT} \cong R_O + 4 \times ESR_{C1} + ESR_{C2} + [1 / (f_{OSC} \times C1)] + [1 / (f_{OSC} \times C2)]$$

where R_O is the device's internal effective switch resistance and f_{OSC} is the switching frequency. Output resistance is a critical circuit component, as it determines the voltage drop that will occur at the output from the ideal value of $-V_{INPUT}$ (or $2V_{INPUT}$ when doubling).

To optimize performance, minimize overall resistance in the system. In particular, equivalent series resistance (ESR) in the capacitors produces significant losses as large currents flow through them. Therefore, choose a low-ESR capacitor for highest efficiency. Table 3 lists recommended capacitors and their suppliers.

Calculate the output ripple voltage as follows:

$$V_{RIPPLE} = [(I_{OUT}) / (2 \times f_{OSC} \times C2)] + 2 \times (I_{OUT} \times ESR_{C2})$$

where I_{OUT} is the load current, f_S is the charge pump's operating frequency, C2 is the output capacitor, and ESR_{C2} is the output capacitor's ESR.

Table 4 lists the minimum recommended capacitances that allow for the maximum output current. The output capacitor, C2, is normally equal to or greater than the charge-pump capacitor, C1. Capacitor values can be scaled directly proportional to the input voltage, frequency, and load current. For example, for V_{INPUT} = 5V, I_{LOAD} = 125mA at f_{OSC} = 125kHz, a 6.4µF minimum capacitor is recommended. For an output of only 62.5mA, a 3.2µF capacitor is recommended. C1's value can be estimated as follows:

$$C1 = 6.4\mu F \times (V_{INPUT} / 5.0V) \times (125kHz / f_{OSC}) \times (I_{LOAD} / 125mA)$$

where f_{OSC} is the switching frequency (kHz) and I_{LOAD} is the output current (mA) required.

Table 3. Low-ESR Capacitor Suppliers

SUPPLIER	PHONE	FAX	DEVICE TYPE
AVX	(803) 946-0690 (800) 282-4975	(803) 626-3123	Surface mount, TPS series
Marcon/United Chemi-Con	(847) 696-2000	(847) 696-9278	Ceramic capacitors
Matsuo	(714) 969-2491	(714) 960-6492	Surface mount, 267 series
Nichicon	USA: (847) 843-7500 Japan: 81-7-5231-8461	USA: (847) 843-2798 Japan: 81-7-5256-4158	Through-hole, PL series
Sanyo	USA: (619) 661-6835 Japan: 81-7-2070-6306	USA: (619) 661-1055 Japan: 81-7-2070-1174	Through-hole, OS-CON series
Sprague	(603) 224-1961	(603) 224-1430	Surface mount, 595D series
TDK	(847) 390-4373	(847) 390-4428	Ceramic capacitors
United Chemi-Con	(714) 255-9500	(714) 255-9400	Through-hole, LXF series
Vishay/Vitramon	(203) 268-6261	(203) 452-5670	SMT ceramic chip capacitors

Table 4. Minimum Recommended Capacitances for Maximum Output Current

f_{OSC} (kHz)	CAPACITANCE (µF) (C1 = C2)			
	V_{IN} = 2V	V_{IN} = 3V	V_{IN} = 4V	V_{IN} = 5V
125	2.5	3.8	5.1	6.4
250	1.2	1.9	2.5	3.2
500	0.6	0.9	1.2	1.6
1000	0.3	0.4	0.6	0.8

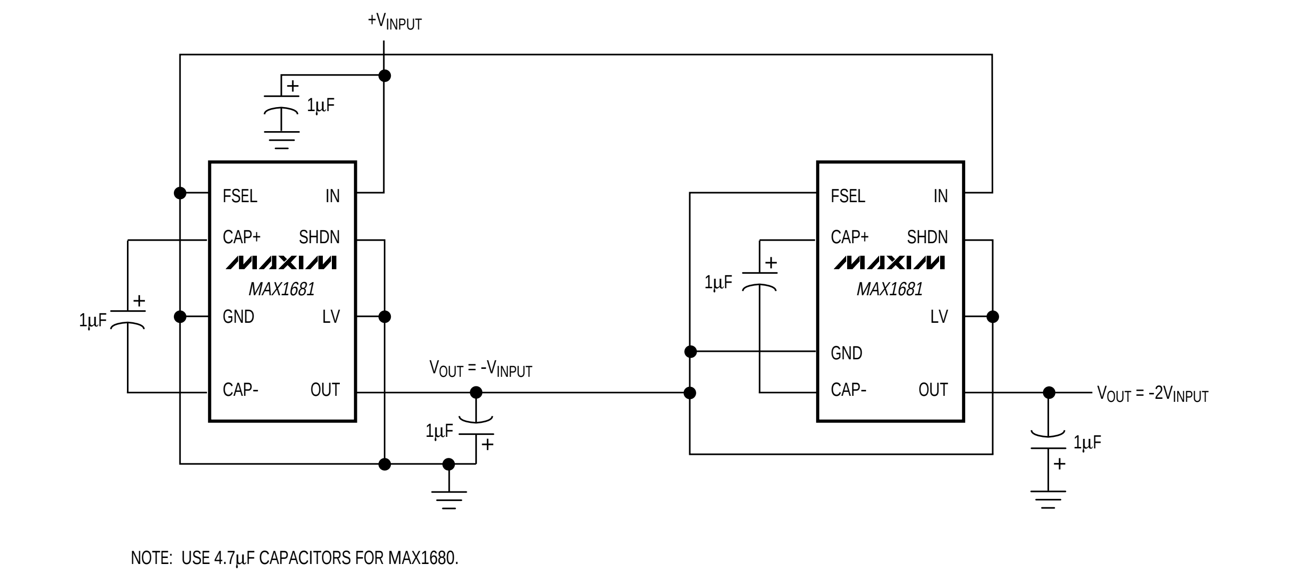


Figure 1. Cascading MAX1680/MAX1681s to Increase Output Voltage

Bypass Capacitor

Bypass the input voltage to reduce AC impedance and to prevent internal switching noise. Bypassing depends on the source impedance location. The AC ripple current is 2 x I_{OUT} for the doubler and the inverter. Use a large bypass capacitor (equal to C1) if the supply has high AC impedance.

Cascading Devices

To produce larger negative voltages, cascade two devices (Figure 1). For two devices, the unloaded output voltage is approximately -2 x V_{INPUT}, but this value is reduced slightly by the first device's output resistance multiplied by the second device's quiescent current. The effective output resistance for a cascaded device is larger than that for an individual device (20Ω for two devices). Cascading several devices increases output resistance and reduces efficiency. If a large negative voltage is required for several stages, an inductive inverting switching regulator such as the MAX629 or MAX774 may offer more advantages.

Paralleling Devices

Parallel two or more MAX1680/MAX1681s to reduce output resistance voltage drop under a given load. With reduced output resistance, paralleled devices deliver higher load currents. Figure 2 shows two MAX1680/MAX1681s connected in parallel. Output resistance is inversely proportional to the number of devices.

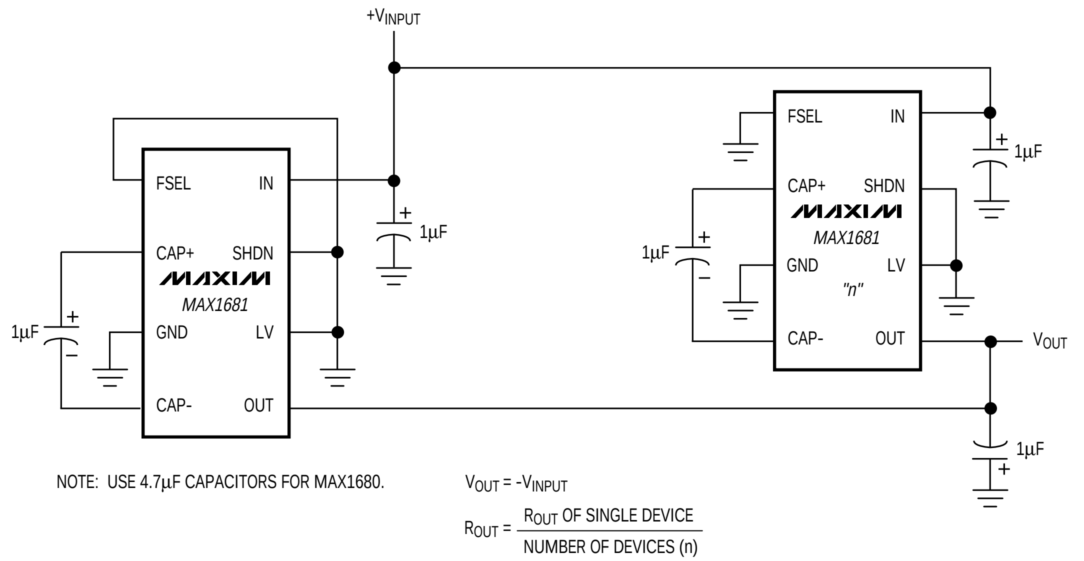


Figure 2. Paralleling MAX1680/MAX1681s to Increase Output Current

Combined Doubler and Inverter

Figure 3 shows a single MAX1680/MAX1681 as an inverter and a doubler. The maximum output current is the sum of the loads on the two outputs and is still limited to 125mA. As the device is loaded, the output voltages move toward ground. In this particular configuration, connect LV to GND (inverter). The diodes used in the circuit cause a drop of approximately 0.7V in the doubler's output voltage, impacting efficiency.

Compatibility with the MAX660 and MAX860/MAX861

The MAX1680/MAX1681 can be used in place of the MAX860/MAX861, except for the SHDN and FSEL pins. The MAX1680/MAX1681 shut down with a high input voltage, compared with the MAX860/MAX861. The MAX1680/MAX1681 have only two frequency choices.

Replacing the MAX660 with the MAX1680/MAX1681 involves a wiring change, as the external oscillator pin is replaced by the shutdown feature. Table 5 compares the devices.

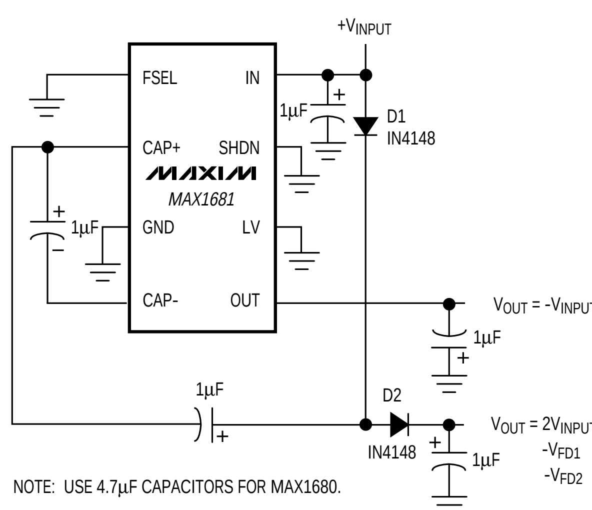
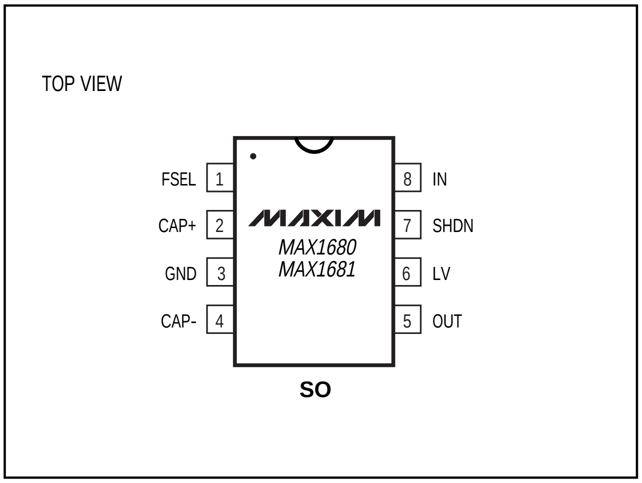


Figure 3. Combined Doubler and Inverter

Table 5. Device Comparison

PART NUMBER	TYPICAL QUIESCENT CURRENT (mA)	OUTPUT CURRENT (mA)	OUTPUT RESISTANCE (Ω)	SWITCHING FREQUENCY (kHz)
MAX660	0.12/1.0	100	6.5	5/40
MAX665	0.20/1.0	100	6.5	5/40
MAX860	0.20/0.60/1.40	50	12	6/50/130
MAX861	0.30/1.10/2.50	50	12	13/100/250
MAX1680	2.5/5.0	125	3.5	125/250
MAX1681	10/20	125	3.5	500/1000
ICL7660	0.080	10	55	5

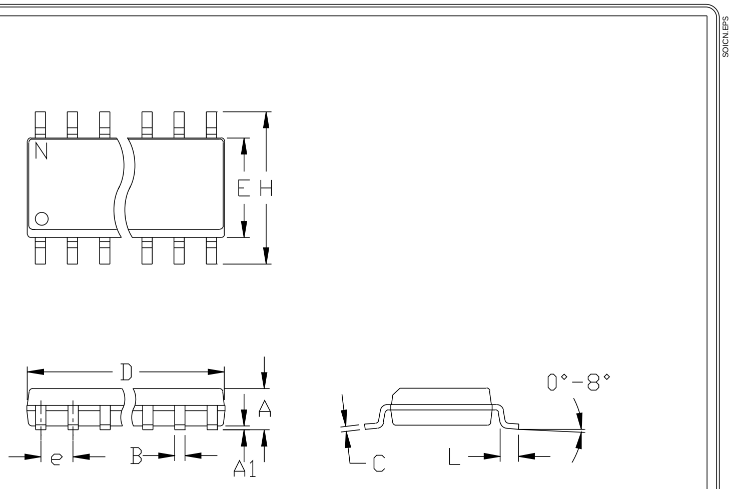
Pin Configuration



Chip Information

TRANSISTOR COUNT: 171

SUBSTRATE CONNECTED TO IN



	INCHES		MILLIMETERS	
	MIN	MAX	MIN	MAX
A	0.053	0.069	1.35	1.75
A1	0.004	0.010	0.10	0.25
B	0.014	0.019	0.35	0.49
C	0.007	0.010	0.19	0.25
e	0.050		1.27	
E	0.150	0.157	3.80	4.00
H	0.228	0.244	5.80	6.20
h	0.010	0.020	0.25	0.50
L	0.016	0.050	0.40	1.27

	INCHES		MILLIMETERS			
	MIN	MAX	MIN	MAX	N	MS012
D	0.189	0.197	4.80	5.00	8	A
D	0.337	0.344	8.55	8.75	14	B
D	0.386	0.394	9.80	10.00	16	C

NOTES:
1. D&E DO NOT INCLUDE MOLD FLASH
2. MOLD FLASH OR PROTRUSIONS NOT TO EXCEED .15mm (.006")
3. LEADS TO BE COPLANAR WITHIN .102mm (.004")
4. CONTROLLING DIMENSION: MILLIMETER
5. MEETS JEDEC MS012-XX AS SHOWN IN ABOVE TABLE
6. N = NUMBER OF PINS

MAXIM 120 SAN GABRIEL DR SUNNYVALE CA 94086 FAX (408) 737 7194 PROPRIETARY INFORMATION	TITLE: PACKAGE FAMILY OUTLINE: SOIC .150"	1/1	DOCUMENT CONTROL NUMBER: 21-0041	REV: A

NOTES