

## LM2664 Switched Capacitor Voltage Converter

### General Description

The LM2664 CMOS charge-pump voltage converter inverts a positive voltage in the range of +1.8V to +5.5V to the corresponding negative voltage of -1.8V to -5.5V. The LM2664 uses two low cost capacitors to provide up to 40 mA of output current.

The LM2664 operates at 160 kHz oscillator frequency to reduce output resistance and voltage ripple. With an operating current of only 220  $\mu$ A (operating efficiency greater than 91% with most loads) and 1  $\mu$ A typical shutdown current, the LM2664 provides ideal performance for battery powered systems. The device is in SOT-23-6 package.

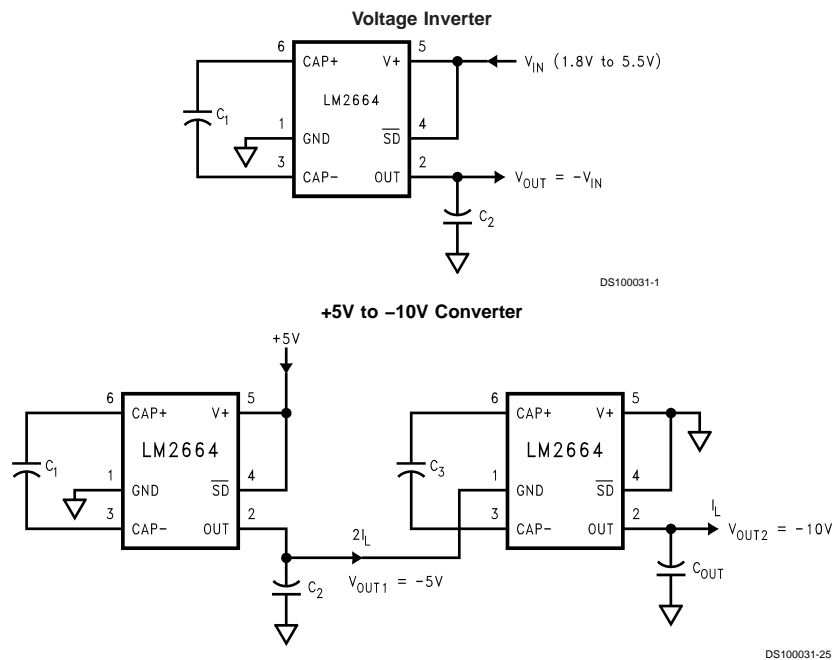
### Features

- Inverts Input Supply Voltage
- SOT23-6 Package
- 12 $\Omega$  Typical Output Impedance
- 91% Typical Conversion Efficiency at 40 mA
- 1 $\mu$ A Typical Shutdown Current

### Applications

- Cellular Phones
- Pagers
- PDAs
- Operational Amplifier Power Suppliers
- Interface Power Suppliers
- Handheld Instruments

### Basic Application Circuits



**Absolute Maximum Ratings** (Note 1)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage (V+ to GND, or GND to OUT)	5.8V
SD	(GND – 0.3V) to (V+ + 0.3V)
V+ and OUT Continuous Output Current	50 mA
Output Short-Circuit Duration to GND (Note 2)	1 sec.

Continuous Power	600 mW
Dissipation ( $T_A = 25^\circ\text{C}$ )(Note 3)	
$T_{J\text{Max}}$ (Note 3)	150°C
$\theta_{JA}$ (Note 3)	210°C/W
Operating Junction	–40° to 85°C
Temperature Range	
Storage Temperature Range	–65°C to +150°C
Lead Temp. (Soldering, 10 seconds)	300°C
ESD Rating	2kV

**Electrical Characteristics**

Limits in standard typeface are for  $T_J = 25^\circ\text{C}$ , and limits in **boldface** type apply over the full operating temperature range. Unless otherwise specified:  $V_+ = 5\text{V}$ ,  $C_1 = C_2 = 3.3\text{ }\mu\text{F}$ . (Note 4)

Symbol	Parameter	Condition	Min	Typ	Max	Units
V+	Supply Voltage		<b>1.8</b>		<b>5.5</b>	V
I <sub>Q</sub>	Supply Current	No Load		220	<b>500</b>	$\mu\text{A}$
I <sub>SD</sub>	Shutdown Supply Current			1		$\mu\text{A}$
V <sub>SD</sub>	Shutdown Pin Input Voltage	Normal Operation	<b>2.0</b> (Note 5)			V
		Shutdown Mode			<b>0.8</b> (Note 6)	
I <sub>L</sub>	Output Current		<b>40</b>			mA
R <sub>SW</sub>	Sum of the R <sub>ds(on)</sub> of the four internal MOSFET switches	I <sub>L</sub> = 40 mA		4	<b>8</b>	$\Omega$
R <sub>OUT</sub>	Output Resistance (Note 7)	I <sub>L</sub> = 40 mA		12	<b>25</b>	$\Omega$
f <sub>OSC</sub>	Oscillator Frequency	(Note 8)	<b>80</b>	160		kHz
f <sub>SW</sub>	Switching Frequency	(Note 8)	<b>40</b>	80		kHz
P <sub>EFF</sub>	Power Efficiency	R <sub>L</sub> (1.0k) between GND and OUT	<b>90</b>	94		%
		I <sub>L</sub> = 40 mA to GND		91		
V <sub>OEFF</sub>	Voltage Conversion Efficiency	No Load	<b>99</b>	99.96		%

**Note 1:** Absolute maximum ratings indicate limits beyond which damage to the device may occur. Electrical specifications do not apply when operating the device beyond its rated operating conditions.

**Note 2:** OUT may be shorted to GND for one second without damage. However, shorting OUT to V+ may damage the device and should be avoided. Also, for temperatures above 85°C, OUT must not be shorted to GND or V+, or device may be damaged.

**Note 3:** The maximum allowable power dissipation is calculated by using  $P_{D\text{Max}} = (T_{J\text{Max}} - T_A)/\theta_{JA}$ , where  $T_{J\text{Max}}$  is the maximum junction temperature,  $T_A$  is the ambient temperature, and  $\theta_{JA}$  is the junction-to-ambient thermal resistance of the specified package.

**Note 4:** In the test circuit, capacitors C<sub>1</sub> and C<sub>2</sub> are 3.3  $\mu\text{F}$ , 0.3 $\Omega$  maximum ESR capacitors. Capacitors with higher ESR will increase output resistance, reduce output voltage and efficiency.

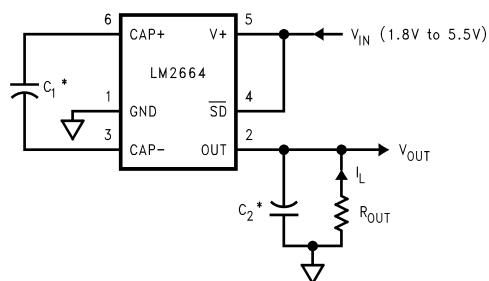
**Note 5:** The minimum input high for the shutdown pin equals 40% of V+.

**Note 6:** The maximum input low for the shutdown pin equals 20% of V+.

**Note 7:** Specified output resistance includes internal switch resistance and capacitor ESR. See the details in the application information for simple negative voltage converter.

**Note 8:** The output switches operate at one half of the oscillator frequency,  $f_{\text{OSC}} = 2f_{\text{SW}}$ .

## Test Circuit



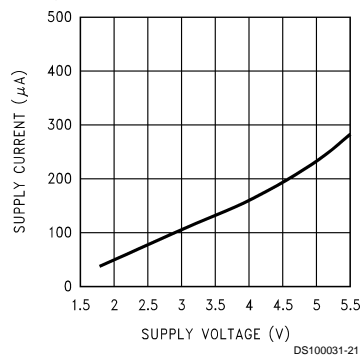
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\*C<sub>1</sub> and C<sub>2</sub> are 3.3  $\mu$ F, SC series OS-CON capacitors.

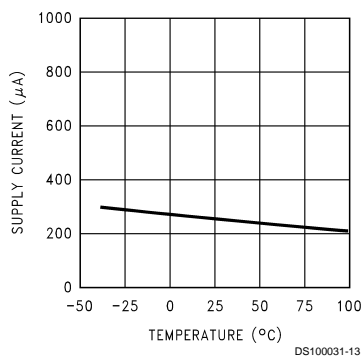
FIGURE 1. LM2664 Test Circuit

## Typical Performance Characteristics (Circuit of Figure 1, V<sub>+</sub> = 5V unless otherwise specified)

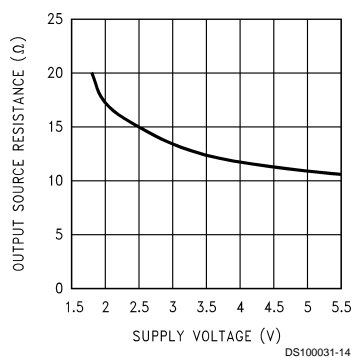
### Supply Current vs Supply Voltage



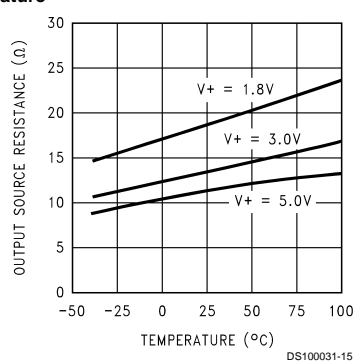
### Supply Current vs Temperature



### Output Source Resistance vs Supply Voltage

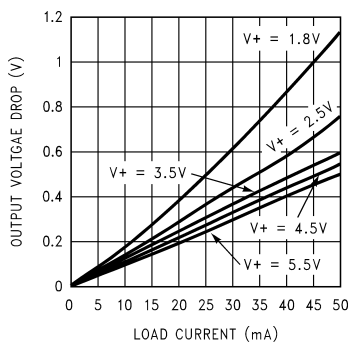


### Output Source Resistance vs Temperature

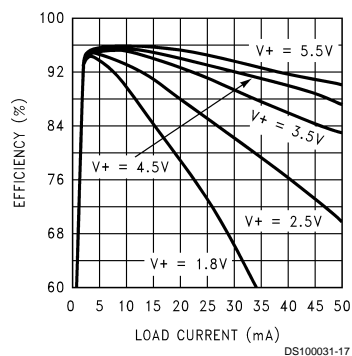


## Typical Performance Characteristics (Circuit of Figure 1, $V_+ = 5V$ unless otherwise specified) (Continued)

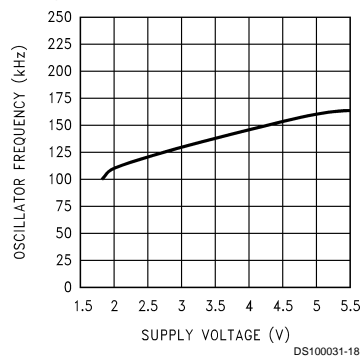
**Output Voltage Drop vs Load Current**



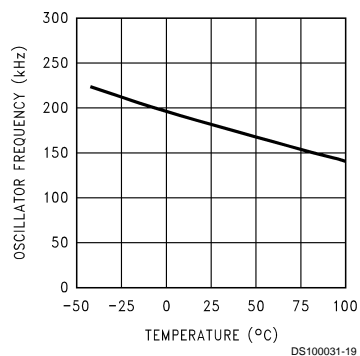
**Efficiency vs Load Current**



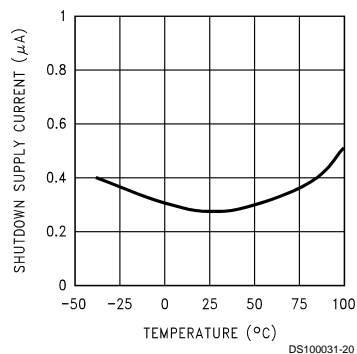
**Oscillator Frequency vs Supply Voltage**



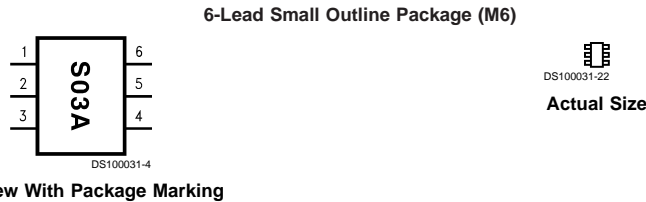
**Oscillator Frequency vs Temperature**



**Shutdown Supply Current vs Temperature**



Connection Diagram



Ordering Information

Order Number	Package Number	Package Marking	Supplied as
LM2664M6	MA06A	SO3A (Note 9)	Tape and Reel (1000 units/rail)
LM2664M6X	MA06A	SO3A (Note 9)	Tape and Reel (3000 units/rail)

**Note 9:** The first letter “S” identifies the part as a switched capacitor converter. The next two numbers are the device number. The fourth letter “A” indicates the grade. Only one grade is available. Larger quantity reels are available upon request.

Pin Description

Pin	Name	Function
1	GND	Power supply ground input.
2	OUT	Negative voltage output.
3	CAP–	Connect this pin to the negative terminal of the charge-pump capacitor.
4	SD	Shutdown control pin, tie this pin to V+ in normal operation, and to GND for shutdown.
5	V+	Power supply positive voltage input.
6	CAP+	Connect this pin to the positive terminal of the charge-pump capacitor.

Circuit Description

The LM2664 contains four large CMOS switches which are switched in a sequence to invert the input supply voltage. Energy transfer and storage are provided by external capacitors. *Figure 2* illustrates the voltage conversion scheme. When  $S_1$  and  $S_3$  are closed,  $C_1$  charges to the supply voltage  $V_+$ . During this time interval, switches  $S_2$  and  $S_4$  are open. In the second time interval,  $S_1$  and  $S_3$  are open; at the same time,  $S_2$  and  $S_4$  are closed,  $C_1$  is charging  $C_2$ . After a number of cycles, the voltage across  $C_2$  will be pumped to  $V_+$ . Since the anode of  $C_2$  is connected to ground, the output at the cathode of  $C_2$  equals  $-(V_+)$  when there is no load current. The output voltage drop when a load is added is determined by the parasitic resistance ( $R_{ds(on)}$ ) of the MOSFET switches and the ESR of the capacitors and the charge transfer loss between capacitors. Details will be discussed in the following application information section.

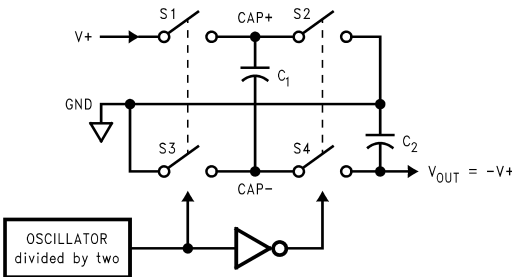


FIGURE 2. Voltage Inverting Principle

Application Information

Simple Negative Voltage Converter

The main application of LM2664 is to generate a negative supply voltage. The voltage inverter circuit uses only two external capacitors as shown in the Basic Application Circuits. The range of the input supply voltage is 1.8V to 5.5V.

The output characteristics of this circuit can be approximated by an ideal voltage source in series with a resistance. The voltage source equals  $-(V_+)$ . The output resistance  $R_{out}$  is a function of the ON resistance of the internal MOSFET switches, the oscillator frequency, the capacitance and ESR of  $C_1$  and  $C_2$ . Since the switching current charging and discharging  $C_1$  is approximately twice as the output current, the

## Application Information (Continued)

effect of the ESR of the pumping capacitor  $C_1$  will be multiplied by four in the output resistance. The output capacitor  $C_2$  is charging and discharging at a current approximately equal to the output current, therefore, its ESR only counts once in the output resistance. A good approximation of  $R_{OUT}$  is:

$$R_{OUT} \cong 2R_{SW} + \frac{2}{f_{OSC} \times C_1} + 4ESR_{C1} + ESR_{C2}$$

where  $R_{SW}$  is the sum of the ON resistance of the internal MOSFET switches shown in *Figure 2*.

High capacitance, low ESR capacitors will reduce the output resistance.

The peak-to-peak output voltage ripple is determined by the oscillator frequency, the capacitance and ESR of the output capacitor  $C_2$ :

$$V_{RIPPLE} = \frac{I_L}{f_{OSC} \times C_2} + 2 \times I_L \times ESR_{C2}$$

Again, using a low ESR capacitor will result in lower ripple.

### Shutdown Mode

A shutdown ( $\overline{SD}$ ) pin is available to disable the device and reduce the quiescent current to 1 $\mu$ A. Applying a voltage less than 20% of  $V+$  to the  $\overline{SD}$  pin will bring the device into shutdown mode. While in normal operating mode, the pin is connected to  $V+$ .

## Low ESR Capacitor Manufacturers

Manufacturer	Phone	Capacitor Type
Nichicon Corp.	(708)-843-7500	PL & PF series, through-hole aluminum electrolytic
AVX Corp.	(803)-448-9411	TPS series, surface-mount tantalum
Sprague	(207)-324-4140	593D, 594D, 595D series, surface-mount tantalum
Sanyo	(619)-661-6835	OS-CON series, through-hole aluminum electrolytic
Murata	(800)-831-9172	Ceramic chip capacitors
Taiyo Yuden	(800)-348-2496	Ceramic chip capacitors
Tokin	(408)-432-8020	Ceramic chip capacitors

## Other Applications

### Paralleling Devices

Any number of LM2664s can be paralleled to reduce the output resistance. Each device must have its own pumping capacitor  $C_1$ , while only one output capacitor  $C_{OUT}$  is needed as shown in *Figure 3*. The composite output resistance is:

$$R_{OUT} = \frac{R_{OUT} \text{ of each LM2664}}{\text{Number of Devices}}$$

### Capacitor Selection

As discussed in the *Simple Negative Voltage Converter* section, the output resistance and ripple voltage are dependent on the capacitance and ESR values of the external capacitors. The output voltage drop is the load current times the output resistance, and the power efficiency is

$$\eta = \frac{P_{OUT}}{P_{IN}} = \frac{I_L^2 R_L}{I_L^2 R_L + I_L^2 R_{OUT} + I_Q (V+)}$$

Where  $I_Q(V+)$  is the quiescent power loss of the IC device, and  $I_L^2 R_{OUT}$  is the conversion loss associated with the switch on-resistance, the two external capacitors and their ESRs.

The selection of capacitors is based on the specifications of the dropout voltage (which equals  $I_{OUT} R_{OUT}$ ), the output voltage ripple, and the converter efficiency. Low ESR capacitors (Table 1) are recommended to maximize efficiency, reduce the output voltage drop and voltage ripple.

## Other Applications (Continued)

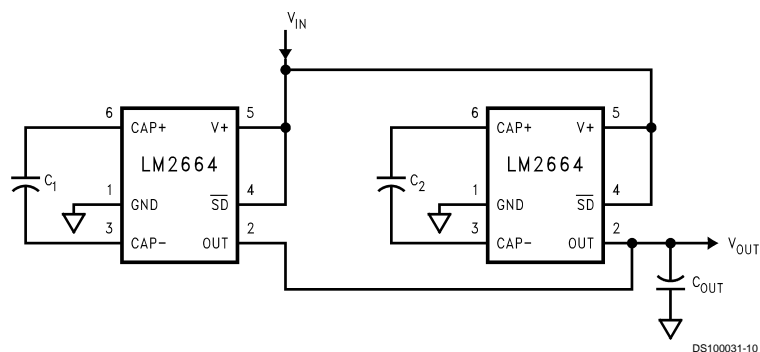


FIGURE 3. Lowering Output Resistance by Paralleling Devices

### Cascading Devices

Cascading the LM2664s is an easy way to produce a greater negative voltage (e.g. A two-stage cascade circuit is shown in Figure 4).

If  $n$  is the integer representing the number of devices cascaded, the unloaded output voltage  $V_{out}$  is  $(-nV_{in})$ . The effective output resistance is equal to the weighted sum of each individual device:

$$R_{out} = nR_{out,1} + n/2 R_{out,2} + \dots + R_{out,n}$$

Note that, the number of  $n$  is practically limited since the increasing of  $n$  significantly reduces the efficiency, and increases the output resistance and output voltage ripple.

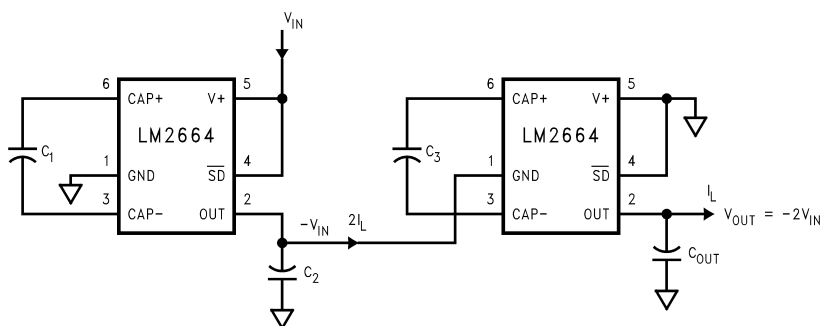
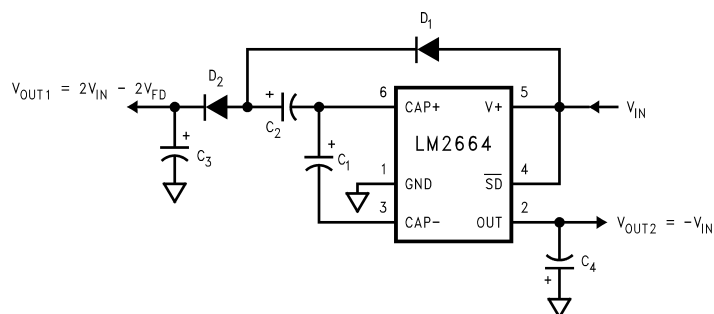


FIGURE 4. Increasing Output Voltage by Cascading Devices

### Combined Doubler and Inverter

In Figure 5, the LM2664 is used to provide a positive voltage doubler and a negative voltage converter. Note that the total current drawn from the two outputs should not exceed 50 mA.

## Other Applications (Continued)



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FIGURE 5. Combined Voltage Doubler and Inverter

### Regulating $V_{OUT}$

It is possible to regulate the negative output of the LM2664 by use of a low dropout regulator (such as LP2980). The whole converter is depicted in Figure 6. This converter can give a regulated output from  $-1.8V$  to  $-5.5V$  by choosing the proper resistor ratio:

$$V_{out} = V_{ref} (1 + R_1/R_2)$$

where,  $V_{ref} = 1.23V$

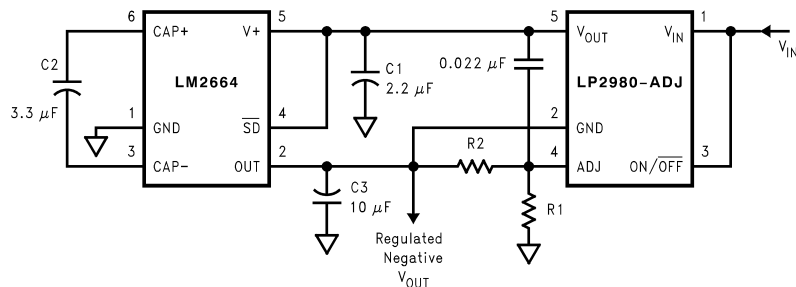
Note that, the following conditions must be satisfied simultaneously for worst case design:

$$V_{in\_min} > V_{out\_min} + V_{drop\_max} \text{ (LP2980)}$$

$$+ I_{out\_max} \times R_{out\_max} \text{ (LM2664)}$$

$$V_{in\_max} < V_{out\_max} + V_{drop\_min} \text{ (LP2980)}$$

$$+ I_{out\_min} \times R_{out\_min} \text{ (LM2664)}$$



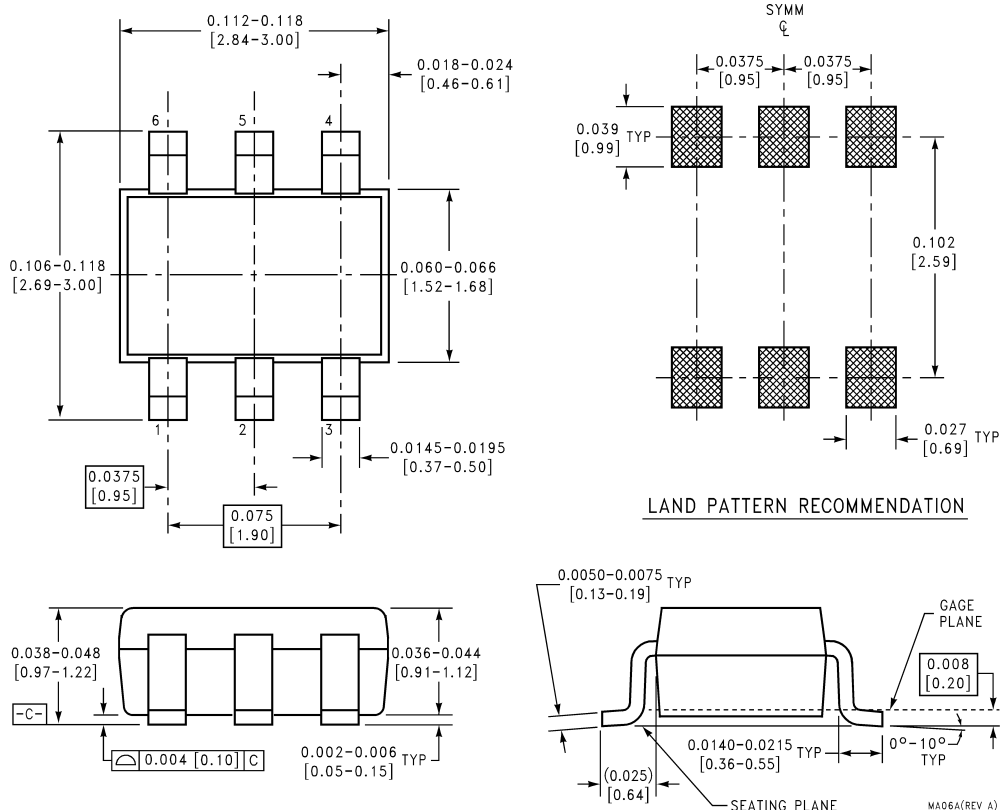
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FIGURE 6. Combining LM2664 with LP2980 to Make a Negative Adjustable Regulator



# Physical Dimensions

inches (millimeters) unless otherwise noted



**6-Lead Small Outline Package (M6)**  
**NS Package Number MA06A**

For Order Numbers, refer to the table in the "Ordering Information" section of this document.

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