

Low Noise, Regulated Charge Pump DC/DC Converter

Description

The SC4004 is a low noise, constant frequency (400kHz) switched capacitor voltage doubler. It produce a regulated output voltage from a 2.5V to 4.5V input with up to 250mA of output current. Low external parts count (one flying capacitor and two small bypass capacitors at V_{IN} and V_{OUT}) make the SC4004 ideally suited for small, battery-powered applications.

A new charge-pump architecture maintains constant switching frequency to zero load and reduces both output and input ripple. The SC4004 have thermal shutdown capability and can survive a continuous short circuit from V_{OUT} to GND. Built-in soft-start circuitry prevents excessive inrush current during start-up.

High switching frequency enables the use of small ceramic capacitors. A low current shutdown feature disconnects the load from V_{IN} and reduces quiescent current to $<1\mu A$.

The SC4004 is available in the industry standard SOT-23-6 power packages.

Features

- V_{IN} Range: 2.5V to 5V
- Fixed 5V $\pm 4\%$ Output
- Output Current: Up to 250mA
- Low Noise Constant Frequency (400kHz) Operation
- Constant Frequency Operation at All Loads
- Automatic Soft-Start Reduces Inrush Current
- Shutdown Current $<1\mu A$
- Short-Circuit Protection
- No Inductors
- Available in Low Profile 6-Lead SOT23 Package

Applications

- White LED Backlighting
- Li-Ion Battery Backup Supplies
- Local 3V to 5V Conversion
- Smart Card Readers
- PCMCIA Local 5V Supplies

Typical Application Circuit

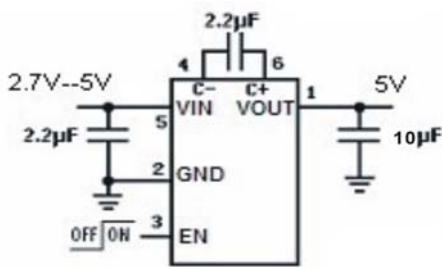


Figure 1: Regulated 5V Output

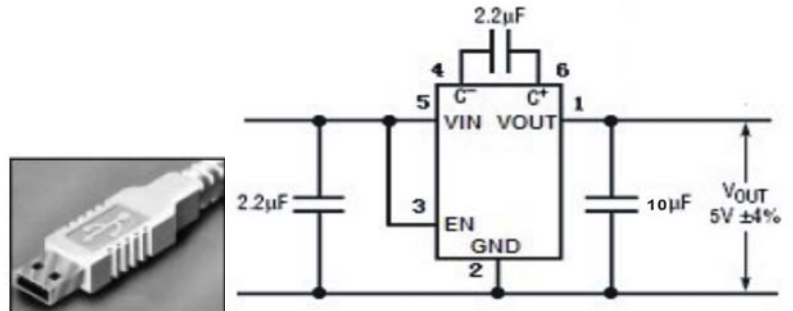


Figure 2: USB Port to Regulated 5V Power Supply

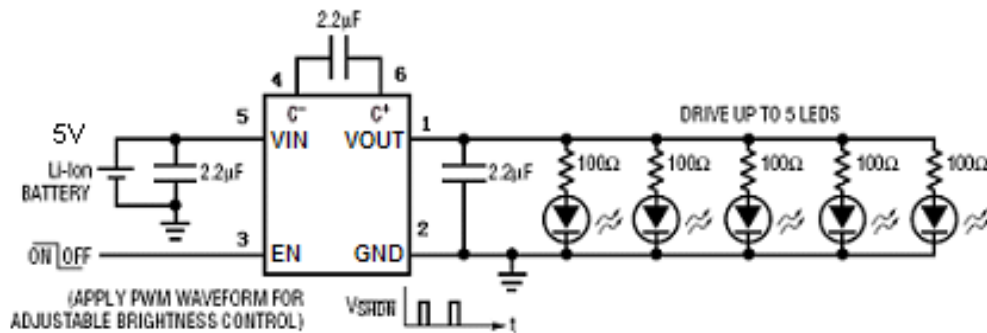


Figure 3: Lithium-Ion Battery to 5V White or Blue LED Drivers

Pin Configuration

Package Type	Pin Configurations
SC4004 SOT-23-6L	

Pin	Name	Pin Description
1.	VOUT	Regulated Output Voltage. V_{OUT} should be bypassed with a low ESR ceramic capacitor providing at least $2\mu F$ of capacitance as close to the pin as possible for best performance.
2.	GND	Ground. These pins should be tied to a ground plane for best performance. The exposed pad must be soldered to PCB ground to provide electrical contact and optimum thermal performance.
3.	EN	Active Low Shutdown Input. This pin must not be allowed to float.
4.	C-	Flying Capacitor Negative Terminal.
5.	VIN	Input Supply Voltage. V_{IN} should be bypassed with a $1\mu F$ to $4.7\mu F$ low impedance ceramic capacitor.
6.	C+	Flying Capacitor Positive Terminal.

Pin Description

Absolute Maximum Ratings (Note 1)

- Input Supply Voltage (V_{IN}) ----- $-0.3V$ to $6V$
- V_{EN} ----- $-0.3V$ to $V_{IN} + 0.3V$
- I_{OUT} (Note 2) ----- $250mA$
- V_{OUT} ----- $-0.3V$ to $5.5V$
- V_{OUT} Short-circuit Duration ----- indefinite
- Maximum Junction Temperature ----- $125^{\circ}C$
- Operating Ambient Temperature Range (Note 3)----- $-40^{\circ}C$ to $85^{\circ}C$
- Storage Temperature Range ----- $-65^{\circ}C$ to $125^{\circ}C$
- Lead Temperature (Soldering, 10 sec) ----- $300^{\circ}C$

Note 1: Absolute Maximum Ratings are those values beyond which the life of a device may be impaired.

Note 2: Based on long term current density limitations.

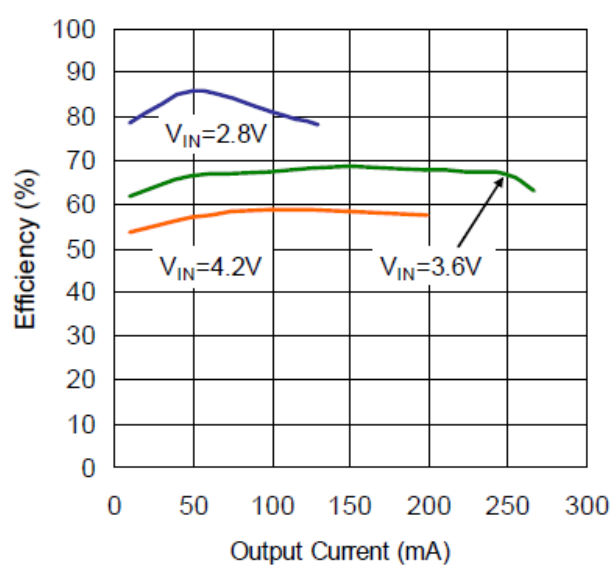
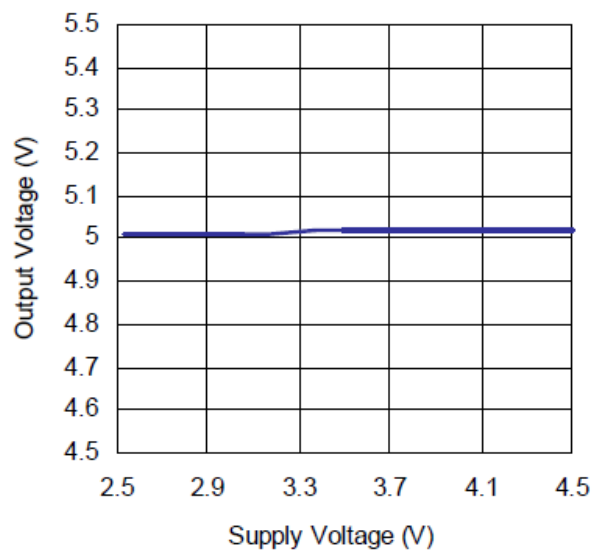
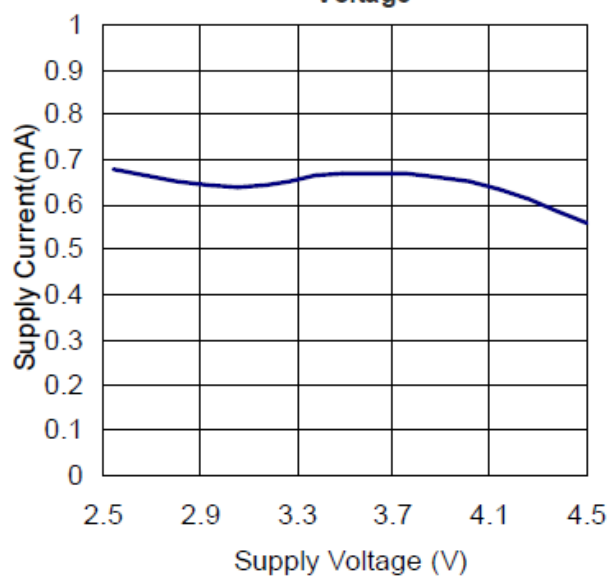
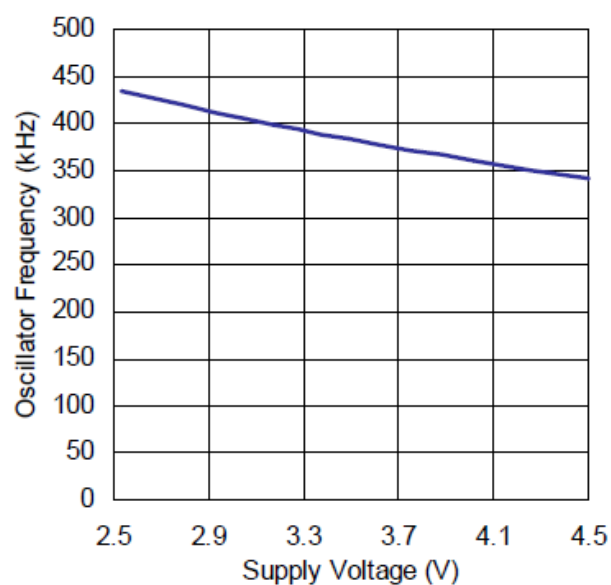
Note 3: The SC4004 are guaranteed to meet performance specifications from $0^{\circ}C$ to $70^{\circ}C$. Specifications over the $-40^{\circ}C$ to $85^{\circ}C$ operating temperature range are assured by design, characterization and correlation with statistical process controls.

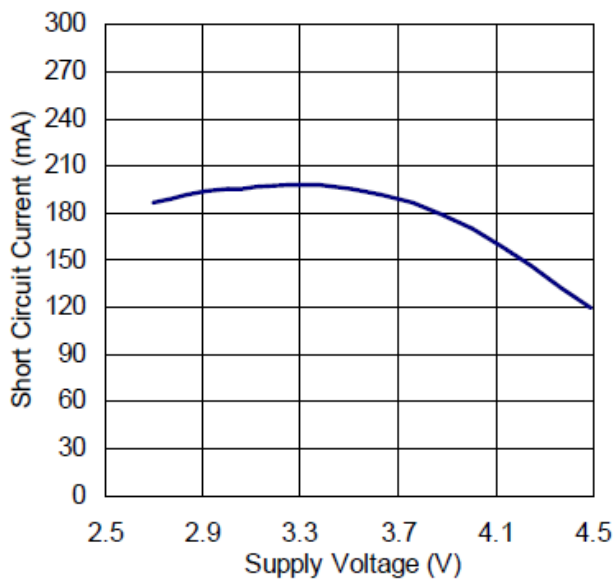
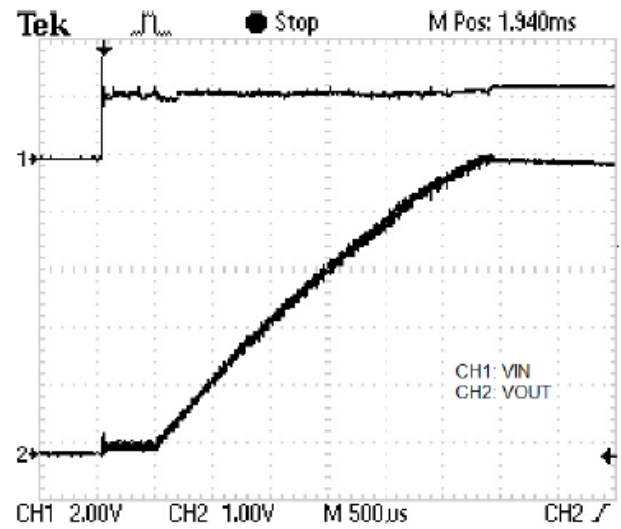
Electrical Characteristics

Operating Conditions: $T_A=25\text{ }^{\circ}\text{C}$, $EN=V_{IN}$, $C_{IN}=C_{OUT}=2.2\text{ }\mu\text{F}$, unless otherwise specified.

SYMBO L	PARAMETER	CONDITIONS	SC4004			UNITS
			MIN .	TYP.	MAX.	
V_{IN}	Input Supply Voltage		2.5	5.0	5.5	V
V_{OUT}	Output Voltage Range		4.7	5	5.2	V
I_{SHDN}	Shutdown Current	$EN=0V, V_{OUT}=0V$		0.3		μA
I_S	No load input current	$I_{OUT}=0\text{mA}, V_{IN}=2.7V$		0.65		mA
I_{OUT}	Output current limit			250		mA
V_R	Output Ripple	$V_{IN}=2.7V, I_{OUT}=100\text{mA}$		150		mVP-P
EFFI	Efficiency	$V_{IN}=2.7V, I_{OUT}=100\text{mA}$		82		%
R_{OL}	Open-Loop Output Resistance $R_{OL}=(2V_{IN}-V_{OUT})/I_{OUT}$	$V_{IN}=2.7V, I_{OUT}=100\text{mA}$		4		Ω
fosc	Switching Frequency			400		kHz

Typical Performance Characteristics

Efficiency vs. Output Current

Output Voltage vs. Supply Voltage

No Load Supply Current vs. Supply Voltage

Oscillator Frequency vs. Supply Voltage


Short Circuit Current vs. Supply Voltage

VOUT Soft-Start Ramp (VIN=3V)


Application Information

Operation

The SC4004 use a switched capacitor charge pump to boost V_{IN} to a regulated output voltage. Regulation is achieved by sensing the output voltage through an internal resistor divider and modulating the charge pump output current based on the error signal. A 2-phase nonoverlapping clock activates the charge pump switches. The flying capacitor is charged from V_{IN} on the first phase of the clock. On the second phase of the clock it is stacked in series with V_{IN} and connected to V_{OUT} . This sequence of charging and discharging the flying capacitor continues at a free running frequency of 0.4MHz (typ).

In shutdown mode all circuitry is turned off and the

SC4004 draw only leakage current from the V_{IN} supply. Furthermore, V_{OUT} is disconnected from V_{IN} . The EN pin is a CMOS input with a threshold voltage of approximately 0.8V. The SC4004 is in shutdown when a logic low is applied to the EN pin. Since the EN pin is a high impedance CMOS input it should never be allowed to float. To ensure that its state is defined it must always be driven with a valid logic level.

Short-Circuit Protection

The SC4004 have built-in short-circuit current limiting. During short-circuit conditions; they will automatically limit their output current to approximately 200mA.

Soft-Start

The SC4004 have built-in soft-start circuitry to prevent excessive current flow at V_{IN} during start-up. The soft-start time is preprogrammed to approximately 1ms, so the start-up current will be primarily dependent upon the output capacitor.

V_{IN} , V_{OUT} Capacitor Selection

The style and value of capacitors used with the SC4004 determine several important parameters such as regulator control loop stability, output ripple, charge pump strength and minimum start-up time.

To reduce noise and ripple, it is recommended that low ESR ($< 0.1\Omega$) ceramic capacitors be used for both C_{IN} and C_{OUT} . These capacitors should be 0.47uF or greater. Tantalum and aluminum capacitors are not recommended because of their high ESR.

The value of C_{OUT} directly controls the amount of output ripple for a given load current. Increasing the size of C_{OUT} will reduce the output ripple at the expense of higher minimum turn on time and higher start-up current. The peak-to-peak output ripple is approximately given by the expression:

$$V_{RIPPLE-P} \cong \frac{I_{OUT}}{2f_{OSC} \cdot C_{OUT}}$$

Where f_{OSC} is the SC4004 oscillator frequency (typically 0.4MHz) and C_{OUT} is the output charge storage capacitor.

Both the style and value of the output capacitor can significantly affect the stability of the SC4004. The SC4004 use a linear control loop to adjust the strength of the charge pump to match the current required at the output. The error signal of this loop is stored directly on the output charge storage capacitor. The charge storage capacitor also serves to form the

dominant pole for the control loop. To prevent ringing or instability on the SC4004 it is important for the output capacitor to maintain at least 0.47uF of capacitance over all conditions.

Likewise excessive ESR on the output capacitor will tend to degrade the loop stability of the SC4004. Ceramic capacitors typically have exceptional ESR performance and combined with a tight board layout should yield very good stability and load transient performance.

As the value of C_{OUT} controls the amount of output ripple, the value of C_{IN} controls the amount of ripple present at the input pin (V_{IN}). The input current to the SC4004 will be relatively constant while the charge pump is on either the input charging phase or the output charging phase but will drop to zero during the clock nonoverlap times. Since the nonoverlap time is small ($\sim 25ns$), these missing “notches” will result in only a small perturbation on the input power supply line. Note that a higher ESR capacitor such as tantalum will have higher input noise due to the input current change times the ESR. Therefore ceramic capacitors are again recommended for their exceptional ESR performance.

Flying Capacitor Selection

Warning: A polarized capacitor such as tantalum or aluminum should never be used for the flying capacitor since its voltage can reverse upon start-up of the SC4004. Low ESR ceramic capacitors should always be used for the flying capacitor.

The flying capacitor controls the strength of the charge pump. In order to achieve the rated output current it is necessary to have at least 0.68uF of capacitance for the flying capacitor. For very light load applications the flying capacitor may be reduced to save space or cost. The theoretical minimum output resistance of a voltage doubling charge pump is given by:

$$R_{OL(MIN)} \equiv \frac{2V_{IN} - V_{OUT}}{I_{OUT}} \cong \frac{1}{f_{OSC} C_{FLY}}$$

Where f_{OSC} is the switching frequency (0.4Hz typ) and C_{FLY} is the value of the flying capacitor. The charge pump will typically be weaker than the theoretical limit due to additional switch resistance, however for very light load applications the above expression can be used as a guideline in determining a starting capacitor value.

Power Efficiency

The power efficiency of the SC4004 is similar to that of a linear regulator with an effective input voltage of twice the actual input voltage. This occurs because the input current for a voltage doubling charge pump is approximately twice the output current. In an ideal regulating voltage double the power efficiency would be given by: 、

$$\eta \equiv \frac{P_{OUT}}{P_{IN}} = \frac{V_{OUT} \cdot I_{OUT}}{V_{IN} \cdot 2I_{OUT}} = \frac{V_{OUT}}{2V_{IN}}$$

At moderate to high output power the switching losses

Packaging Information

SOT-23-6L Package Outline Dimension

and quiescent current of the SC4004 are negligible and the expression above is valid. For example with $V_{IN} = 3V$, $I_{OUT} = 50mA$ and $V_{OUT} = 5V$ the measured efficiency is 80% which is in close agreement with the theoretical 83.3% calculation.

Layout Considerations

Due to its high switching frequency and the high transient currents produced by the SC4004, careful board layout is necessary. A true ground plane and short connections to all capacitors will improve performance and ensure proper regulation under all conditions. Figure 4 shows an example layout for the SC4004.

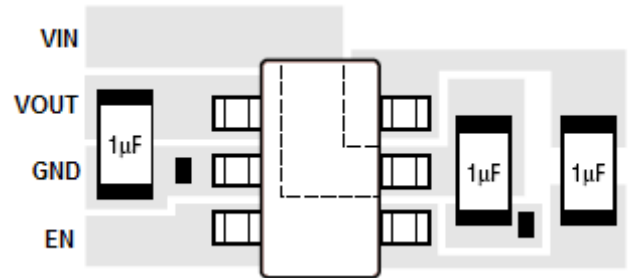
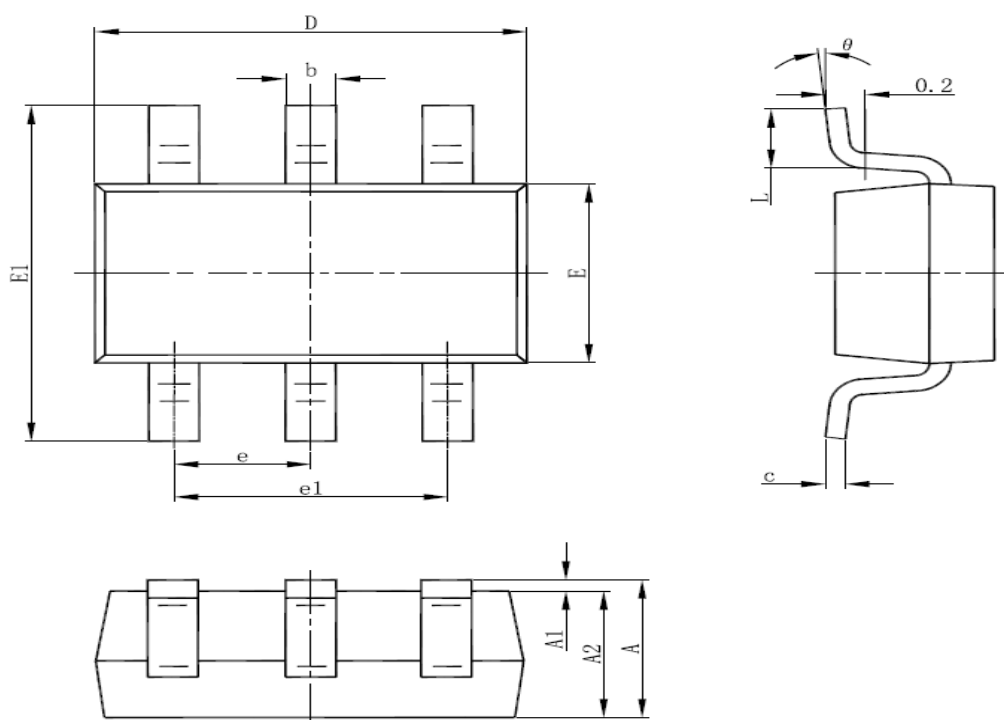


Figure 4: Recommended Layout



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	1.050	1.250	0.041	0.049
A1	0.000	0.100	0.000	0.004
A2	1.050	1.150	0.041	0.045
b	0.300	0.500	0.012	0.020
c	0.100	0.200	0.004	0.008
D	2.820	3.020	0.111	0.119
E	1.500	1.700	0.059	0.067
E1	2.650	2.950	0.104	0.116
e	0.950(BSC)		0.037(BSC)	
e1	1.800	2.000	0.071	0.079
L	0.300	0.600	0.012	0.024
θ	0°	8°	0°	8°