Regulated 5V Charge Pump

PRODUCT SUMMARY

Input voltage range: 2.7V to 5.0V
Regulated output voltage of 5V ±4%
Output current: 100mA (V_{IN} = 3.3V)
110mA (V_{IN} = 3.6V)

FEATURES

Ultralow power: I_{IN} = 13µA
No inductors needed
Very low shutdown current: <1µA
Internal oscillator: 650KHz
Short-circuit and over-temperature protection

APPLICATIONS

White or Blue LED Backlighting
SIM Interface Supplies for Cellular Telephones
Li-Ion Battery Backup Supplies
Local 3V to 5V Conversion
Smart Card Readers
PCMCIA Local 5V Supplies

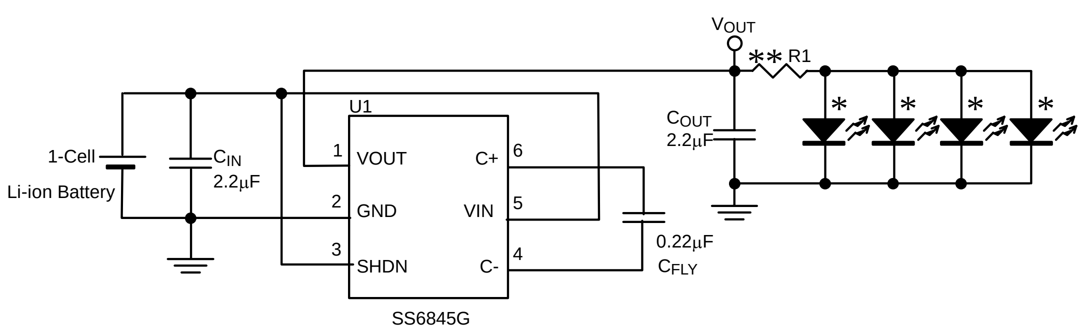
Pb-free; RoHS-compliant SOT-23-6 package

DESCRIPTION

The SS6845G is a micropower charge pump DC/DC converter that produces a regulated 5V output. The input voltage range is 2.7V to 5.0V. Extremely low operating current (13µA typical with no load) and a low external part count (one 0.22µF flying capacitor and two small bypass capacitors at the input and output) make the SS6845G ideally suitable for small, battery-powered applications.

The SS6845G operates as a PSM-mode (Pulse Skipping Modulation) switched capacitor voltage doubler to produce a regulated output and features thermal shutdown capability and short circuit protection.

TYPICAL APPLICATION CIRCUIT



Regulated 5V Output from 2.7V to 5.0V Input

* WLED series number: NSPW310BS, V_F=3.6V, I_F=20mA

** $R1 = \frac{V_{OUT} - V_F}{I_F \times N_{WLED}}$, where N_{WLED} is the number of WLEDs.

C_{IN}, C_{OUT}: CELMK212BJ225MG (X5R) (0805), TAIYO YUDEN

C_{FLY} : CEEMK212BJ224KG (X7R) (0805), TAIYO YUDEN

ORDERING INFORMATION

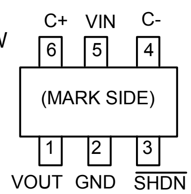
SS6845GG TR

Packing type:
TR: Tape and reel

Package type:
GG: RoHS-compliant SOT-23-6

PIN CONFIGURATION

SOT-23-6
TOP VIEW



SOT-23-6 Marking

Part No.	Marking
SS6845GG	BO50P

ABSOLUTE MAXIMUM RATINGS

VIN to GND 6V

VOUT to GND 6V

All other ins to GND 6V

VOUT short-circuit duration .... Continuous

Operating ambient temperature range .... -40°C to 85 °C

Junction temperature .... 125°C

Storage temperature range .... -65°C to 150 °C

Lead temperature (minimum 10 seconds) .... 260°C

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

TEST CIRCUIT

Refer to the TYPICAL APPLICATION CIRCUIT on page 1.

ELECTRICAL CHARACTERISTICS

(T_A=25°C, C_{FLY}=0.22μF, C_{IN}=2.2μF, C_{OUT}=2.2μF, unless otherwise specified.) (Note 1)

PARAMETER	TEST CONDITIONS	SYMBOL	MIN.	TYP.	MAX.	UNIT
Input voltage		V_{IN}	2.7		5.0	V
Output voltage	2.7V≤ V_{IN}< 3.3V, I_{OUT}≤ 30mA	V_{OUT}	4.8	5.0	5.2	V
	3.3V≤ V_{IN}≤ 5.0V, I_{OUT}≤ 60mA		4.8	5.0	5.2	
Continuous output current	V_{IN}=3V, V_{OUT}=5.0V $\overline{SHDN}$ =V_{IN}	I_{OUT}	60			mA
Supply current	2.7V≤ V_{IN}≤ 5.0V, I_{OUT}=0 , $\overline{SHDN}$ =V_{IN}	I_{CC}		13	30	μA
Shutdown current	2.7V≤ V_{IN}≤ 5.0V, I_{OUT}=0 , $\overline{SHDN}$ =0V	$I_{\overline{SHDN}}$		0.01	1.0	μA
Output ripple	V_{IN} =3V, I_{OUT}=50mA	V_R		60		mV
Efficiency	V_{IN} =2.7V , I_{OUT}=30mA	η		83		%
Switching frequency	Oscillator free-running	f_{OSC}		650		KHz
Shutdown input threshold (High)		V_{IH}	1.4			V
Shutdown input threshold (Low)		V_{IL}			0.3	V
Shutdown input current (High)	$\overline{SHDN}$ =V_{IN}	I_{IH}	-1		1	μA
Shutdown input current (Low)	$\overline{SHDN}$ = 0V	I_{IL}	-1		1	μA
Vout turn-on time	V_{IN} =3V, I_{OUT} = 0mA	t_{ON}		0.5		mS
Output short-circuit current	V_{IN}=3V, V_{OUT}= 0V, $\overline{SHDN}$ = V_{IN}	I_{SC}		170		mA

Note1: Specifications are production tested at T_A=25°C. Specifications over the -40°C to 85°C operating temperature range are assured by design, characterization and correlation with Statistical Quality Controls (SQC).

TYPICAL PERFORMANCE CHARACTERISTICS

(C_N, C_{OUT}: CELMK212BJ225MG, C_{FLY}: CEEMK212BJ224KG)

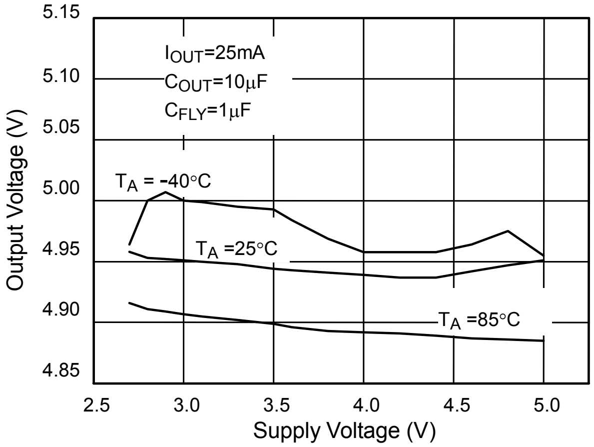


Fig. 1 Line Regulation

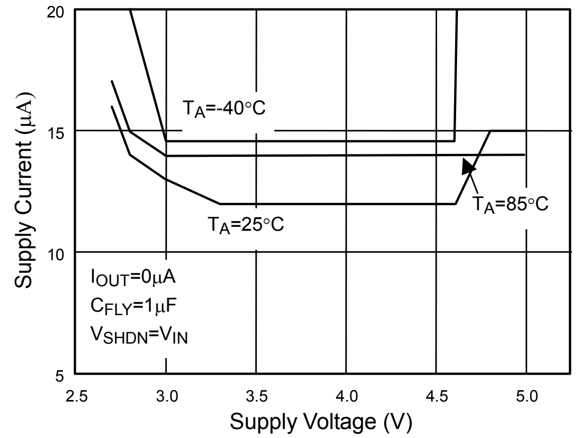


Fig. 2 No Load Supply Current vs. Supply Voltage

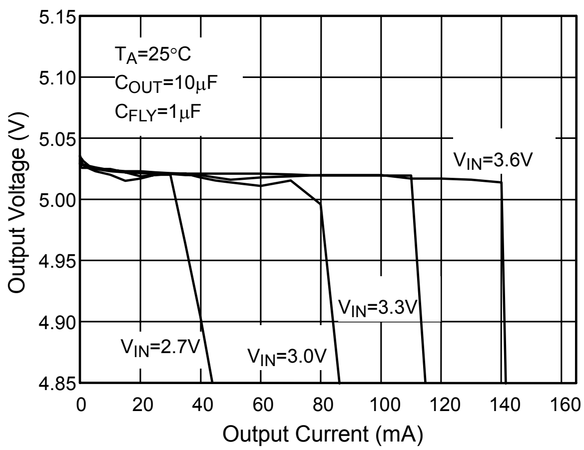


Fig. 3 Load Regulation

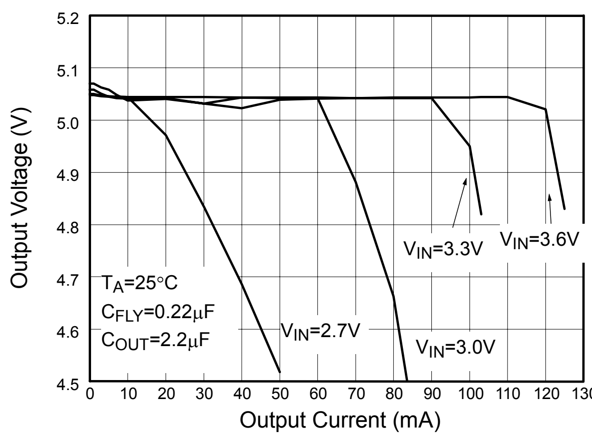


Fig. 4 Load Regulation

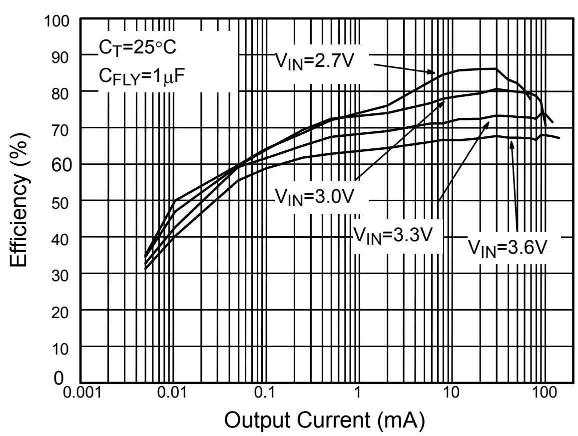


Fig. 5 Efficiency

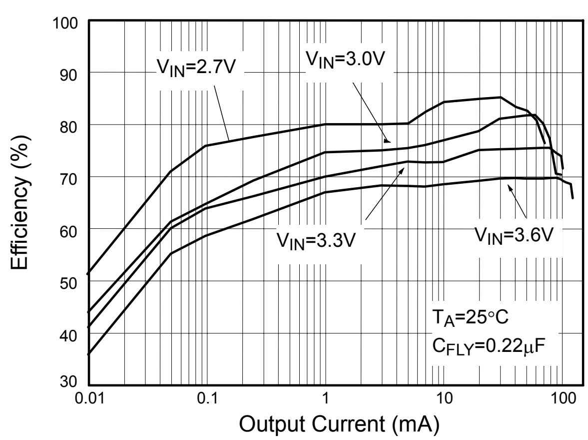


Fig. 6 Efficiency

TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

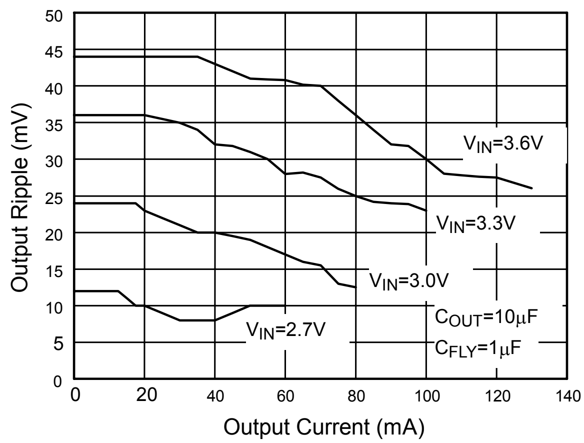


Fig.7 Output Current vs. Output Ripple

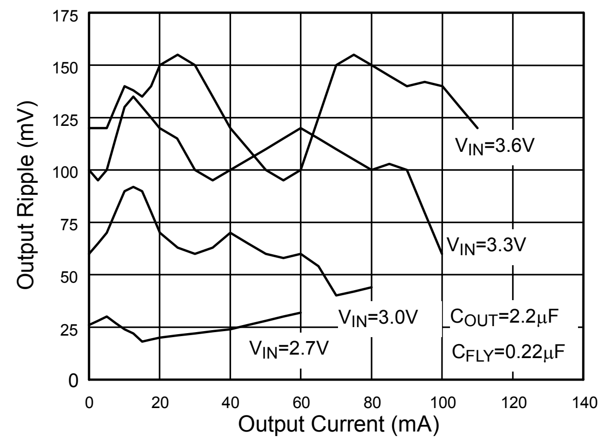


Fig. 8 Output Current vs. Output Ripple

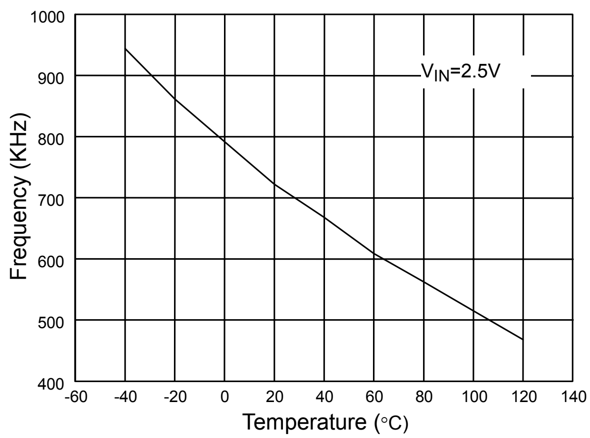


Fig. 9 Frequency vs. Temperature

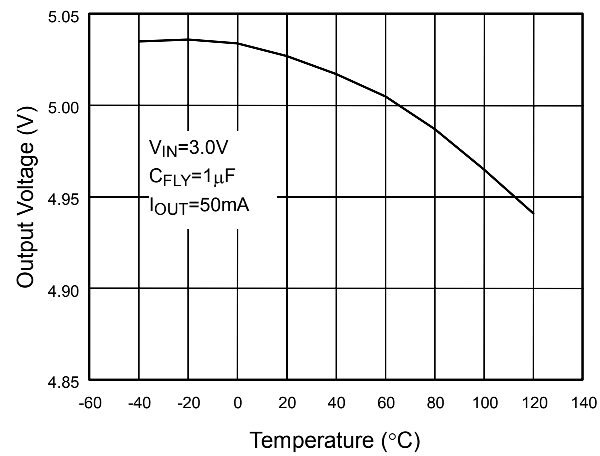


Fig. 10 Output Voltage vs. Temperature

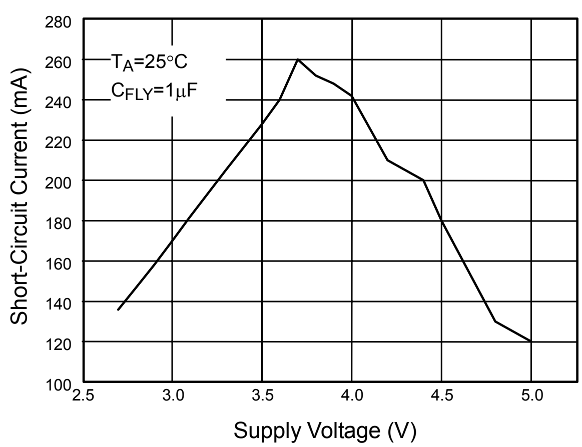


Fig. 11 Short-Circuit Current vs. Supply Voltage

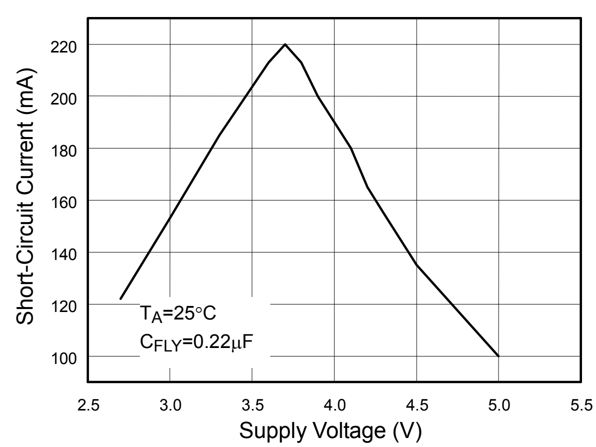


Fig. 12 Short-Circuit Current vs. Supply Voltage

TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

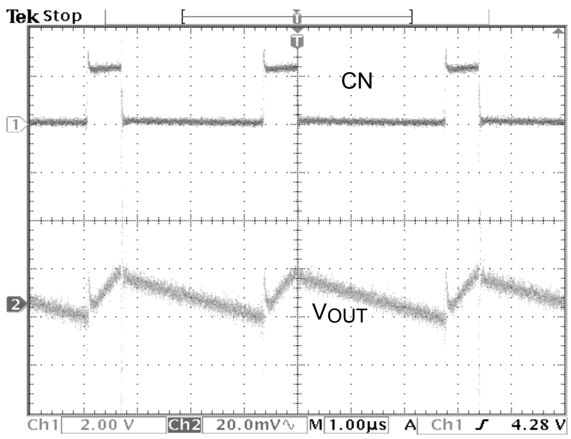


Fig. 13 Output Ripple
V_{IN}=3.0V, I_{OUT}=50mA, C_{OUT}=10µF,C_{FLY}=1µF

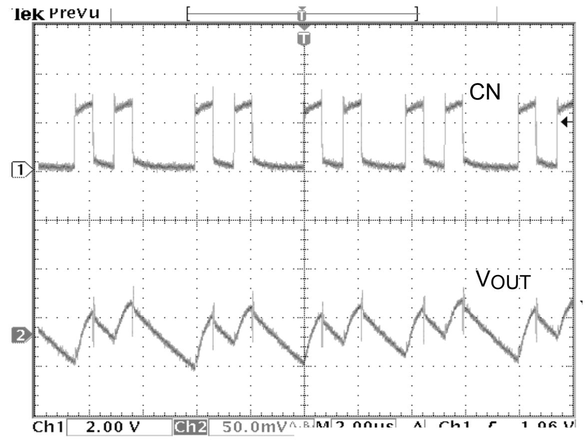


Fig. 14 Output Ripple
V_{IN}=3.0V, I_{OUT}=50mA, C_{OUT}=2.2µF, C_{FLY}=0.22µF

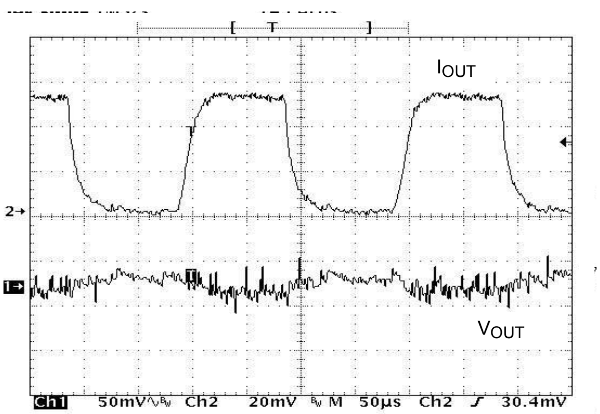


Fig. 15 Load Transient Response
V_{IN}=3.0V, I_{OUT}=0mA~50mA,C_{OUT}=10µF, C_{FLY}=1µF

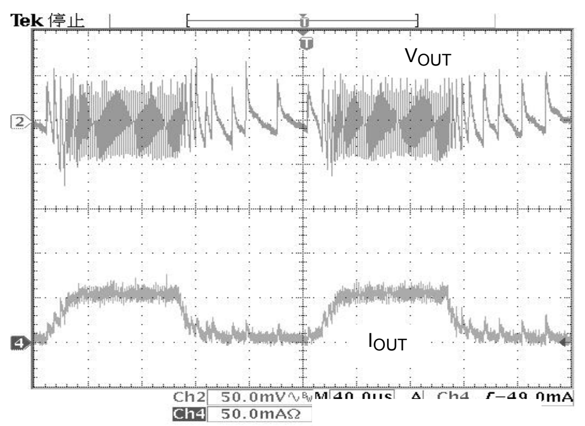


Fig. 16 Load Transient Response
V_{IN}=3.0V, I_{OUT}=0mA~50mA,C_{OUT}=2.2µF, C_{FY}=0.22µF

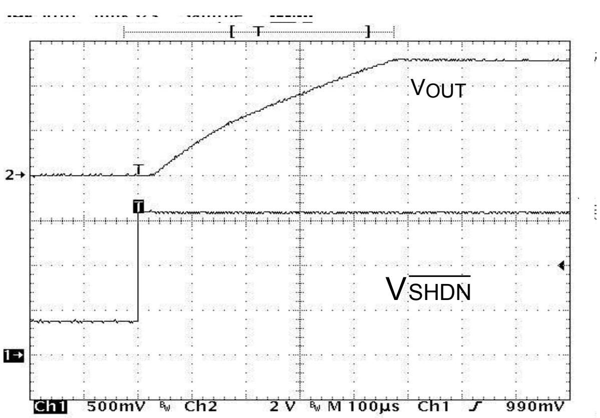


Fig. 17 Start-Up Time
V_{IN}=3.0V, I_{OUT}=0A, C_{OUT}=10µF

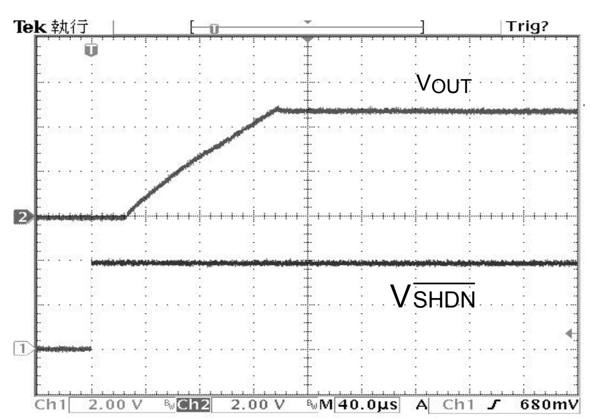
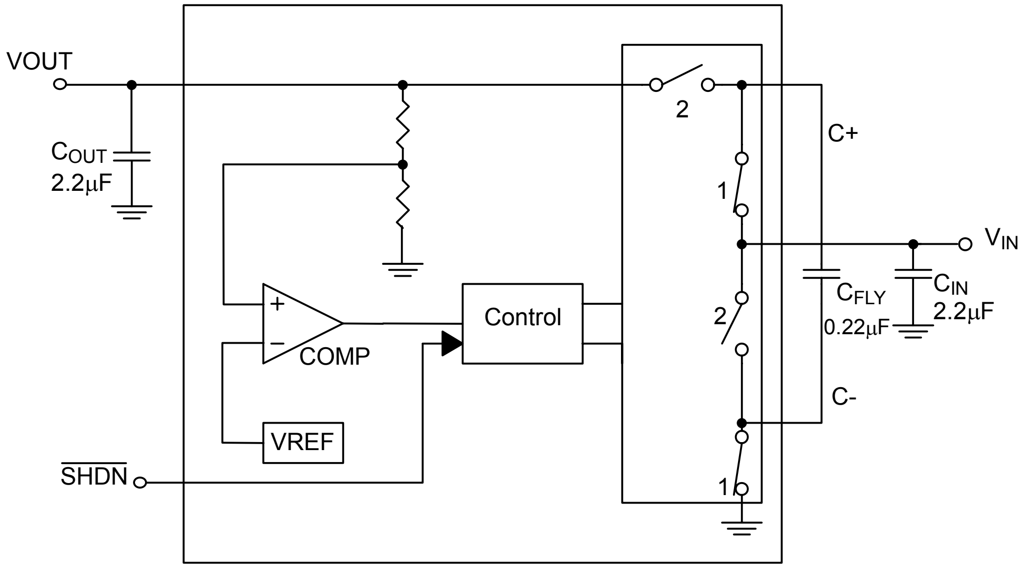


Fig. 18 Start-Up Time
V_{IN}=3.0V, I_{OUT}=0A, C_{OUT}=2.2µF

BLOCK DIAGRAM



PIN DESCRIPTIONS

PIN 1:VOUT - Regulated output voltage. For the best performance, V_{OUT} should be bypassed with a 2.2µF (min) low ESR capacitor with the shortest possible leads.

PIN 2: GND - Ground. Should be tied to a ground plane for best performance.

PIN 3: $\overline{\text{SHDN}}$ - Active-low shutdown input. A low voltage on $\overline{\text{SHDN}}$ disables the SS6845G. $\overline{\text{SHDN}}$ is not allowed to float.

PIN 4: C- - Flying capacitor negative terminal.

PIN 5: VIN - Input supply voltage. V_{IN} should be bypassed with a 2.2µF (min) low ESR capacitor.

PIN 6: C+ - Flying capacitor positive terminal.

APPLICATION INFORMATION

Introduction

The SS6845G is a micropower charge pump DC/DC converter that produces a regulated 5V output with an input voltage range from 2.7V to 5.0V. It utilizes the charge pump topology to boost V_{IN} to a regulated output voltage. Regulation is obtained by sensing the output voltage through an internal resistor divider. A switched doubling circuit enables the charge pump when the feedback voltage is lower than the trip point of the internal comparator, and vice versa. When the charge pump is enabled, a two-phase non-overlapping clock activates the charge pump switches. To maximize battery life for a battery-use application, quiescent current is limited to no more than 13µA.

Operation

This kind of converter uses capacitors to store and transfer energy. Since the capacitors can't change their voltage level abruptly, the voltage ratio of V_{OUT} over V_{IN} is limited to some range. Capacitive voltage conversion is obtained by switching a capacitor periodically. It first charges the capacitor by connecting it across a voltage source and then connects it to the output. Referring to Fig. 19, during the on state of internal clock, Q_1 and Q_4 are closed, which charges C_1 to V_{IN} level. During the off state, Q_3 and Q_2 are closed. The output voltage is V_{IN} plus V_{C1}, that is, $2V_{IN}$.

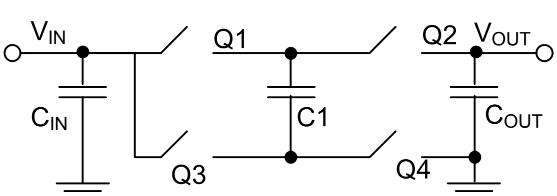


Fig. 19 The circuit of charge pump

Short Circuit/Thermal Protection

The SS6845G includes built-in short circuit current limiting as well as over-temperature protection. During a short circuit condition, the output current is automatically constrained to approximately 170mA. This short circuit current will cause a rise in the internal IC junction temperature. When the die temperature exceeds 150°C, the thermal protection will shut down the charge pump switching operation and the die temperature will then reduce. Once the die temperature drops below 135°C, the charge pump switching circuit will restart. If the fault has not been eliminated, the this protection mechanism will repeat again and again, allowing the SS6845G to work continuously in a short circuit condition without damaging the device.

Shutdown

In shutdown mode, the output is disconnected from the input. The input current is extremely low since most of the circuitry is turned off. Due to high impedance, the shutdown pin cannot float.

Efficiency

The diagrams, Fig. 20 and Fig. 21 show the operation of the charge pump in the on and off states. R_{DS-ON} is the resistance of the switching element during conduction. ESR is the equivalent series resistance of the flying capacitor C_1. I_{ON-AVE} and $I_{OFF-AVE}$ are the average current during the on-state and off-state, respectively. D is the duty-cycle, which means the ratio of the on-state time to the total cycle time. Let's look at capacitor C_1 - assuming that capacitor C_1, has reached its steady state, then the amount of charge flowing into C_1 during the on-state is equal to that flowing out of C_1 during the off-state.

$$I_{ON-AVE} \times DT = I_{OFF-AVE} \times (1-D)T \text{ ....(1)}$$

$$I_{ON\text{-}AVE} \times D = I_{OFF\text{-}AVE} \times (1-D) \text{ ....(2)}$$

$$\begin{aligned} I_{IN} &= I_{ON\text{-}AVE} \times D + I_{OFF\text{-}AVE} \times (1-D) \\ &= 2 \times I_{ON\text{-}AVE} \times D \quad \text{.........(3)} \\ &= 2 \times I_{OFF\text{-}AVE} \times (1\text{-}D) \end{aligned}$$

$$I_{OUT} = I_{OFF\text{-}AVE} \times (1-D)$$

$$I_{IN} = 2I_{OUT} \text{ ....(4)}$$

For the SS6845G, the controller uses the PSM (Pulse Skipping Modulation) control strategy. When the duty cycle is limited to 0.5, then:

$$I_{ON\text{-}AVE} \times 0.5 \times T = I_{OFF\text{-}AVE} \times (1-0.5) \times T$$

$$I_{ON\text{-}AVE} = I_{OFF\text{-}AVE} \text{ ....(5)}$$

According to the equation (4), we know that as long as the flying capacitor C1 is at steady state, the input current is twice the output current. The efficiency of charge pump is given below:

$$\eta = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times I_{IN}} = \frac{V_{OUT} \times I_{OUT}}{V_{IN} \times 2I_{OUT}} = \frac{V_{OUT}}{2V_{IN}} \text{ ..(6)}$$

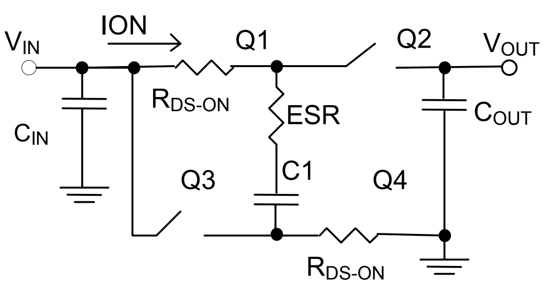


Fig. 20 The on-state of charge pump circuit

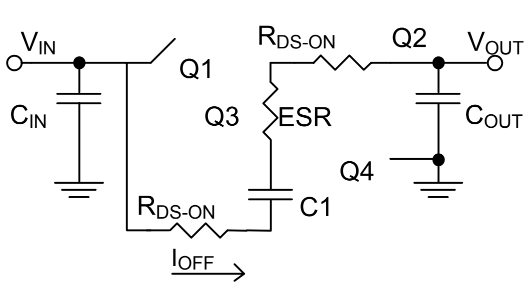


Fig. 21 The off-state of charge pump circuit

External Capacitor Selection

Three external capacitors, C_{IN}, C_{OUT} and C_{FLY}, determine SS6845G performance, in the area of output ripple voltage, charge pump strength and transients. Optimum performance can be obtained by the use of ceramic capacitors with low ESR. Due to their high ESR, tantalum and aluminum capacitors are not recommended for charge-pump applications.

To reduce noise and ripple, a low ESR ceramic capacitor, ranging from 2.2µF to 10µF, is recommended for C_{IN} and C_{OUT}. The value of C_{OUT} determines the amount of output ripple voltage. An output capacitor with a larger value results in smaller ripple.

C_{FLY} is critical to the performance of a charge pump. The larger C_{FLY} is, the larger the output current and the smaller the resulting ripple voltage. However, a large C_{FLY} requires large C_{IN} and C_{OUT}.
The ratio of C_{IN} (as well as C_{OUT}) to C_{FLY} should be approximately 10:1.

The values of the capacitors used under operating conditions, determine the performance of the charge pump converter, and two factors, described below, affect the value of the capacitors.

1. **Material:** Ceramic capacitors of different materials, such as X7R, X5R, Z5U and Y5V, have different tolerances to temperature and capacitance can vary significantly. For example, X7R or X5R types of capacitor retain their capacitance over temperatures from -40°C to 85°C, but a Z5U or Y5V type will change a lot over that temperature range.

2. **Package Size:** A ceramic capacitor with large volume (0805), gets a lower ESR than a small one (0603). Therefore, larger devices provide improved transient response over smaller ones.

Table 1 lists the recommended components for use with the SS6845G.

Table.1 Bill of Material

Design-ator	Part Type	Description	Vendor
C_{IN}	2.2μ	CELMK212BJ-225MG (X5R)	TAIYO YUDEN
C_{FLY}	0.22μ	CEEMK212BJ-224KG (X7R)	TAIYO YUDEN
C_{OUT}	2.2μ	CELMK212BJ-225MG (X5R)	TAIYO YUDEN

Power Dissipation

Now, let's look at the power dissipation in $R_{DS\text{-}ON}$ and ESR. Assume that the $R_{DS\text{-}ON}$ of each internal switching element in the SS6845G is equal and ESR is the equivalent series resistance of C_{FLY} (refer to Fig. 20 and Fig. 21). The approximation of the power losses of $R_{DS\text{-}ON}$ and ESR are given below:

$$P_{R_{DS-ON}} \cong I^2_{ON\text{-}AVE} \times 2R_{DS-ON} \times D + I^2_{OFF\text{-}AVE} \times 2R_{DS-ON} \times (1-D)$$
$$= (\frac{I_{IN}}{2D})^2 \times 2R_{DS\text{-}ON} \times D + (\frac{I_{OUT}}{1\text{-}D})^2 \times 2R_{DS\text{-}ON} \times (1\text{-}D)$$
$$= (\frac{2I_{OUT}}{2D})^2 \times 2R_{DS\text{-}ON} \times D + (\frac{I_{OUT}}{1\text{-}D})^2 \times 2R_{DS\text{-}ON} \times (1\text{-}D)$$
$$= I^2_{OUT} \times (\frac{2}{D} R_{DS\text{-}ON}) + I^2_{OUT} \times (\frac{2}{1\text{-}D} R_{DS\text{-}ON})$$
$$= I^2_{OUT} \times \frac{2}{D(1\text{-}D)} \times R_{DS\text{-}ON} \qquad ....(7)$$

$$P_{ESR} \cong I^2_{ON-AVE} \times ESR \times D + I^2_{OFF-AVE} \times ESR \times (1-D)$$
$$= (\frac{I_{IN}}{2D})^2 \times ESR \times D + (\frac{I_{OUT}}{1-D})^2 \times ESR \times (1-D)$$
$$= I^2_{OUT} \times ESR \times \frac{1}{D} + I^2_{OUT} \times ESR \times \frac{1}{1\text{-}D}$$
$$= I^2_{OUT} \times ESR \times \frac{1}{D(1\text{-}D)}$$

With a duty-cycle of 0.5, the power loss of $R_{DS\text{-}ON}$ is

$$P_{R_{DS-ON}} \cong I^2_{OUT} \times \frac{2}{0.5(1-0.5)} \times R_{DS\text{-}ON}$$
$$= I^2_{OUT} \times 8R_{DS-ON}$$

$$P_{ESR} \cong I^2_{OUT} \times ESR \times \frac{1}{0.5(1-0.5)}$$
$$= I^2_{OUT} \times 4ESR$$

In fact, whether the current is the on-state or the off-state, it decays exponentially rather than flows steadily, and as the root mean square value of exponential decay is not equal to that of steady flow, then we must use an approximation.

Let's use another approach to look at the charge pump circuit and focus on the flying capacitor C_1. Referring to Fig. 20, when the circuit is in the on state, the voltage across C_1 is:

$$V_{C\text{-}ON}(t) = V_{IN} - 2R_{DS-ON} \times I_{ON}(t) - ESR \times I_{ON}(t) \quad ...(9)$$

The average of V_{C1} during the on-state is:

$$V_{C-ON-AVE} = V_{IN} - 2R_{DS-ON} \times I_{ON-AVE} - ESR \times I_{ON-AVE} \quad ....(10)$$

Similarly, referring to Fig. 21, when the circuit is in the off-state, the voltage of C1 is:

$$V_{C\text{-}OFF}(t) = V_{OUT} - V_{IN} + 2R_{DS\text{-}ON} \times I_{OFF}(t) + ESR \times I_{OFF}(t) \quad ....(11)$$

The average of V_{C1} during the off-state is:

$$V_{C-OFF-AVE} = V_{OUT} - V_{IN} + 2R_{DS-ON} \times I_{OFF-AVE} + ESR \times I_{OFF-AVE} \quad ....(12)$$

The difference in charge stored in C_1 between the on-state and off-state is the net charge transferred to the output in one cycle.

$$\begin{aligned}\Delta Q &= Q_{ON} - Q_{OFF} \\ &= C_1 \times (V_{C1-ON-AVE} - V_{C1-OFF-AVE}) \\ &= C_1 \times (2V_{IN} - V_{OUT} - 2R_{DS\text{-}ON} \times I_{ON\text{-}AVE} - 2R_{DS\text{-}ON} \times I_{OFF\text{-}AVE} - ESR \times I_{ON\text{-}AVE} - ESR \times I_{OFF\text{-}AVE}) \quad \text{.........(13)} \\ &= C_1 \times (2V_{IN} - V_{OUT} - 2R_{DS-ON} \times \frac{I_{OUT}}{D} - 2R_{DS-ON} \times \frac{I_{OUT}}{1-D} - ESR \times \frac{I_{OUT}}{D} - ESR \times \frac{I_{OUT}}{1-D}) \\ &= C_1 \times [2V_{IN} - V_{OUT} - (2R_{DS-ON} + ESR) \times I_{OUT} \times \frac{1}{D(1-D)}]\end{aligned}$$

Thus the output current can be written as

$$\begin{aligned}I_{OUT} &= f \times \Delta Q = f \times (Q_{ON} - Q_{OFF}) \\ &= f \times C_1 \times [2V_{IN} - V_{OUT} - (2R_{DS-ON} + ESR) \times I_{OUT} \times \frac{1}{D(1-D)}] \quad \text{.......... (14)}\end{aligned}$$

When the duty cycle is 0.5, the output current can be written as:

$$\begin{aligned}I_{OUT} &= f \times C_1 \times [2V_{IN} - V_{OUT} - (2R_{DS-ON} + ESR) \times I_{OUT} \times \frac{1}{0.5(1-0.5)}] \quad \text{.......... (15)} \\ &= fC_1 \times [2V_{IN} - V_{OUT} - (8R_{DS-ON} + 4ESR) \times I_{OUT}]\end{aligned}$$

And equation (15) can be re-written as:

$$2V_{IN} - V_{OUT} = \frac{1}{fC_1} \times I_{OUT} + (8R_{DS-ON} + 4ESR) \times I_{OUT} \quad \text{.......... (16)}$$

According to equation (16), when the duty cycle is 0.5, the equivalent circuit of the charge pump is shown in Fig. 22. The term $8R_{DS\text{-}ON}$ is the total effect of switching resistance, $1/fC_1$ is the effect of flying capacitor and 4ESR is its equivalent resistance.

From the equivalent circuit shown in Fig. 22, it is seen that the terms $1/fC_1$, 4ESR and $8R_{DS\text{-}ON}$ should be as small as possible to get large output current. However, since the $R_{DS\text{-}ON}$ is internal to the SS6845G, all that can be done is to lower the values of $1/fC_1$ and ESR. However even if the values of $1/fC_1$ and ESR can be kept as small as possible, the term $8R_{DS\text{-}ON}$ still dominates the limit of the maximum output current.

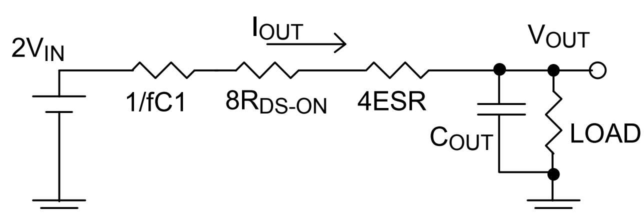


Fig. 22 The equivalent circuit of charge pump

Layout Considerations

With the high switching frequency and transient currents of the SS6845G, careful consideration of PCB layout is important. To achieve the best performance, it is necessary to minimize the distance between every component and also to minimize the length of every connection and maximize the trace width. Make sure each device connects to an immediate ground plane. Fig. 23 to Fig. 25 show a recommended layout.

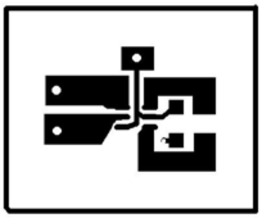


Fig. 23 Top layer

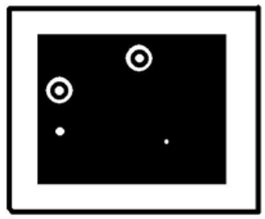


Fig. 24 Bottom layer

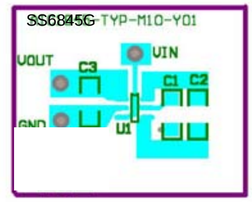
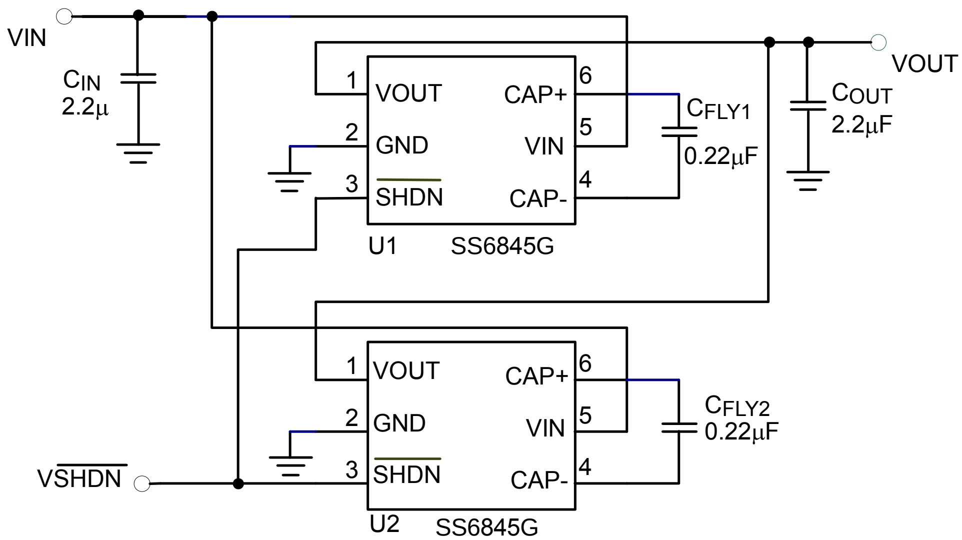


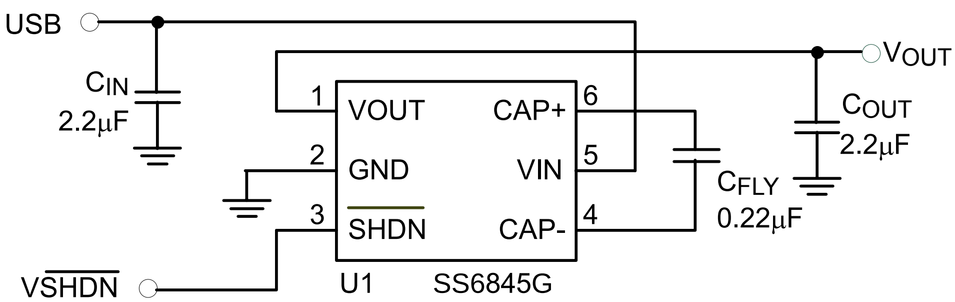
Fig. 25 Topover layer

APPLICATION EXAMPLES



C_{IN}, C_{OUT} : TAIYO YUDEN Ceramic Capacitor, CELMK212BJ225MG (X5R) (0805)
C_{FLY1}, C_{FLY2}: TAIYO YUDEN Ceramic Capacitor, CEEMK212BJ224KG (X7R) (0805)

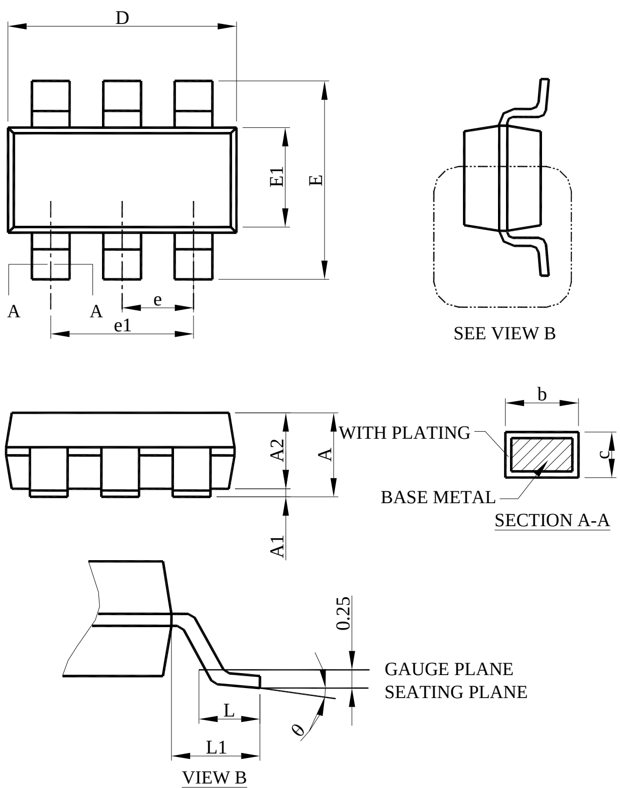
Fig. 26 Using two SS6845G in parallel to provide larger output current.



C_{IN}, C_{OUT}: TAIYO YUDEN Ceramic Capacitor, CELMK212BJ225MG (X5R) (0805)
C_{FLY1} : TAIYO YUDEN Ceramic Capacitor, CEEMK212BJ224KG (X7R) (0805)

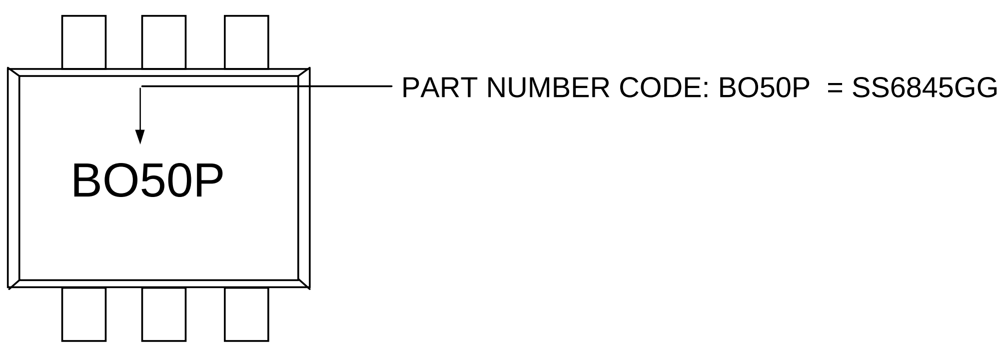
Fig. 27 Regulated 5V from USB

PHYSICAL DIMENSIONS (unit: mm)



SYMBOL	SOT-23-6	
	MILLIMETERS	
	MIN.	MAX.
A	0.95	1.45
A1	0.05	0.15
A2	0.90	1.30
b	0.30	0.50
c	0.08	0.22
D	2.80	3.00
E	2.60	3.00
E1	1.50	1.70
e	0.95 BSC	
e1	1.90 BSC	
L	0.30	0.60
L1	0.60 REF	
θ	0°	8°

PART MARKING



PACKING: Moisture sensitivity level MSL3

3000 pcs in antistatic tape on a reel packed in a moisture barrier bag (MBB).