SKI4056M

1A Linear Lithium-lin Battery Charger

Description

SKI4056M is a linear charger designed for constant current/constant voltage charging of single-cell lithium-ion batteries. Its ESOP-8 package with a bottom heatsink and minimal external component requirements make it an ideal choice for portable applications, such as USB power supplies and adapter power sources.

The SKI4056M adopts an internal PMOSFET architecture along with an anti-reverse charging circuit, eliminating the need for an external isolation diode. Thermal feedback automatically adjusts the charging current to limit the chip temperature during high-power operation or high ambient temperature conditions. The charging voltage is fixed at 4.2V, and the charging current can be set via an external PROG resistor. When the battery voltage reaches the final float voltage and the charging current drops to 1/10 of the set value, the SKI4056M automatically terminates the charging cycle.

When the input voltage (from an AC adapter or USB power supply) is disconnected, the SKI4056M automatically enters a low-current state, reducing the battery leakage current to less than 2μA. The SKI4056M can also be set to a shutdown state, minimizing the power supply current to 60μA.

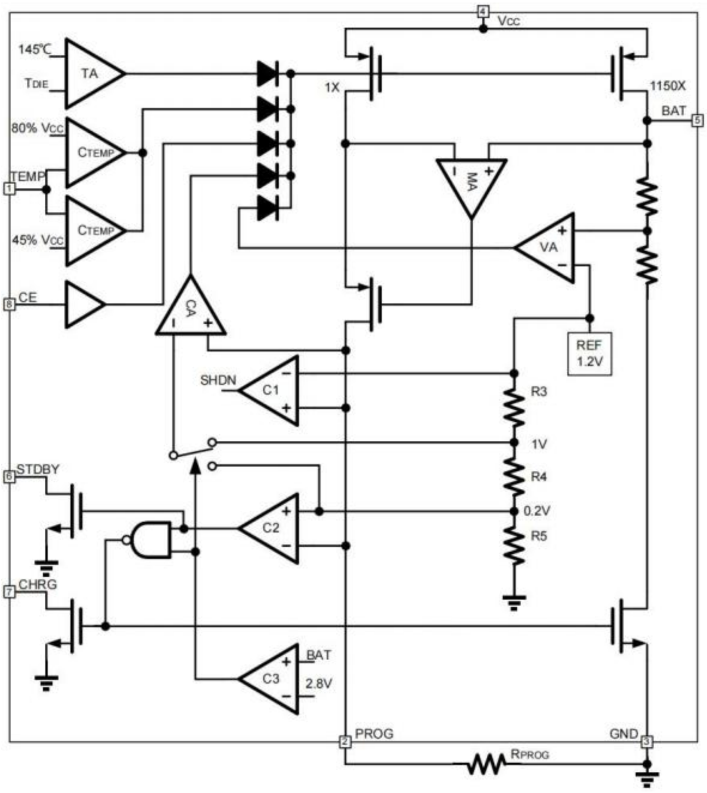
Features

- Programmable charging current up to 1200mA
- No need for MOSFET,current sensing resistor, or isolation diode
- Preset charging voltage: 4.2V ±1.5%
- C/10 current charge termination with automatic recharging
- Charging status indicator and full-charge status indicator
- 55μA current in standby mode
- 2.8V trickle charging threshold voltage
- Battery reverse polarity protection
- Package type: ESOP-8

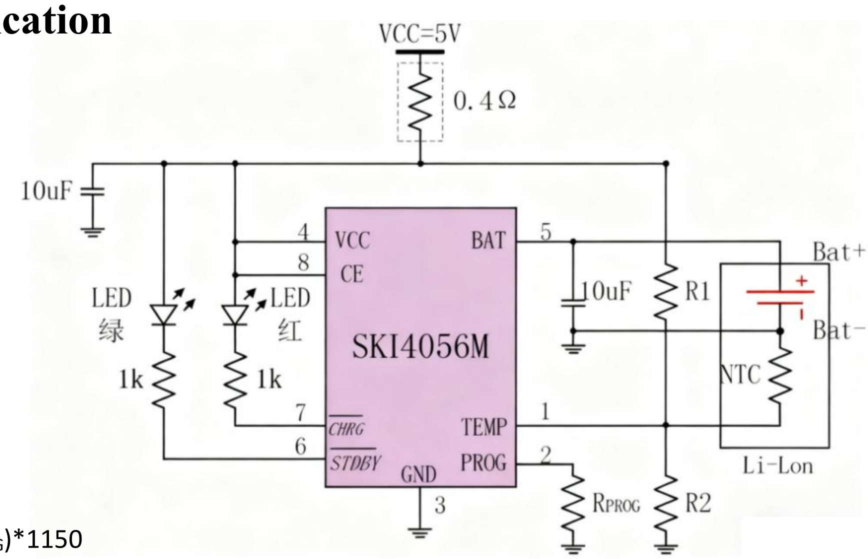
Applications

- Mobile phones,PDAs,MP3 players,MP4 players
- Digital cameras, electronic dictionaries
- Portable devices, various chargers

Block Diagram

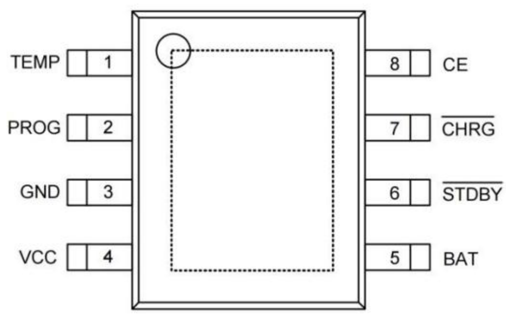


Typical Application



Note: $I_{BAT}=(V_{PROG}/R_{PROG})*1150$

Pin Description

Pin Number	Pin Name	I/O	Description	Pin Configuration Diagram
1	TEMP	I	Temperature detection input	
2	PROG	I	Charging current setting pin	
3	GND	P	Ground	
4	VCC	P	Input power supply	
5	BAT	O	Battery connection pin	
6	STDBY	O	Battery full charge indication pin	
7	CHRG	O	Battery charging indication pin	
8	CE	I	Chip enable input	

Absolute Maximum Ratings (T_A=25℃ unless otherwise noted)

Parameter	Symbol	Value	Unit
Supply Voltage	V_{CC}	-0.3~6.0	V
Battery Voltage	V_{BAT}	-4.5~6.0	V
Voltage on Other Pins	V_{IN}	-0.3~6.0	V
BAT Pin Current	I_{BAT}	1200	mA
Junction Temperature	T_J	150	℃
Storage Temperature	T_{STG}	-65~+150	℃
Soldering Temperature(10s)	T_W	260	℃

Recommended Operating Conditions (T_A=25℃ unless otherwise noted)

Parameter	Symbol	Min	Max	Unit
Supply Voltage	V_{CC}	4.5	5.5	V
Continuous Output Current	I_{BAT}		1000	mA
Operating Temperature	T_A	-20	85	℃

Electrical Characteristics(T_A=25°C, V_{CC}=5.0V unless otherwise noted)

Parameter	Symbol	Test Condition	Min	Typ	Max	Unit
Input Supply Voltage	V_{CC}		4.5	5.0	6.0	V
Input Supply Current	I_{CC}	Charging mode,R_{PROG}=1K		55	200	μA
		Standby mode(charge termination)		55	150	μA
		Shutdown mode (R_{PROG} disconnection, V_{CC}<V_{BAT},V_{CC}<V_{UV})		60	150	μA
Output Float Voltage	V_{FLOAT}		4.137	4.2	4.263	V
BAT Pin Current	I_{BAT}	Current mode,R_{PROG}=2K		575		mA
		Current mode,R_{PROG}=1K		1150		mA
		Standby mode,V_{BAT}=4.2V	-6	-2.5	0	μA
		Reverse connection mode, V_{BAT}=-4V		-0.34		mA
		Shutdown mode,P_{ROG} floating		±2	±4	μA
		Sleep mode, V_{CC}=0V	-2	-1		μA
Trickle Charging Current	I_{TRIKL}	V_{BAT}<B_{TRIKL},R_{PROG}=1K		230		mA
Trickle Charging Threshold Voltage	V_{TRIKL}	R_{PROG}=1K,V_{BAT} rising		2.8		V
Trickle Charging Hysteresis Voltage	V_{TRHYS}	R_{PROG}=1K		180		mV
VCC Undervoltage Lockout Threshold	V_{UV}	V_{CC} rising	3.7	3.8	3.99	V
VCC Undervoltage Lockout Hysteresis	V_{UVHYS}	V_{CC} falling		150		mV
Manual Shutdown Threshold Voltage	V_{MSD}	P_{ROG} pin voltage rising/falling	0.9	1.0	1.1	V
VCC-BAT Lockout Threshold Voltage	V_{ASD}	V_{CC} rising		120		mV
		V_{CC} falling		100		mV
C/10 Termination Threshold Current	I_{TERM}	R_{PROG}=2K		57		mA
		R_{PROG}=1K		115		mA
PROG Pin Voltage	V_{PROG}	Current mode,R_{PROG}=1K	0.9	1.0	1.1	V

PROG Pin Pull Up Current	I_{PROG}			3		μA
CHRG Pin Output Low Level	V_{CHRG}	I_{CHRG}=5mA	0.1	0.3	0.6	V
STDBY Pin Output Low Level	V_{STDBY}	I_{STDBY}=5mA	0.1	0.3	0.6	V
TEMP Pin High Threshold Voltage	V_{TEMP_H}			80	83	%VCC
TEMP Pin Low Threshold Voltage	V_{TEMP-L}		42	45		%VCC
Recharge Battery Threshold Voltage	ΔV_{RECHRG}	V_{FLOAT}-V_{RECHEG}		120		mV
Recharge Comparator Filter Time	$t_{TRCHARGE}$	V_{BAT} falling		1.8		ms
Termination Comparator Filter Time	t_{TERM}	I_{BAT} dropping below I_{CHG}/10		1.8		ms
Soft Start Time	t_{ss}	I_{BAT}=0 to I_{BAT}=1300V/R_{PROG}		100		μs
Power FET on Resistance	R_{ON}			500		mΩ
Junction Temperature In Current Limiting Mode	T_{LIM}			145		℃

Operating Principle

Overview

The SKI4056M is a linear charger specifically designed for lithium-ion or lithium-polymer batteries. It uses an internal power transistor to charge the battery with constant current/constant voltage. The charging current can be programmed via an external resistor, with a maximum continuous charging current of up to 1A. The internal power management circuit of the chip automatically reduces the charging current when the chip junction temperature exceeds 145 ℃, thereby maximizing the power handling capacity of the chip without the risk of overheating damage to the chip or external components. Therefore, when designing the charging current, customers only need to design according to typical conditions without considering the worst-case scenario, as the chip will automatically reduce the charging current in the worst case.

When the input voltage is higher than the power supply under-voltage detection threshold and the chip enable input is at a high level, the SKI4056M starts charging the battery, and the CHRG pin outputs a low level to indicate that charging is in progress. If the battery voltage is below 3V, the charger pre-charges the battery with a small current; when the battery voltage exceeds 3V, the charger charges the battery in constant current mode, and the charging current is programmed by R_{PROG}. When the battery voltage approaches 4.2V, the charging current gradually decreases, and the SKI4056M enters constant voltage charging mode. When the charging current drops below the C/10 termination threshold current, the charging cycle ends, the CHRG pin becomes high-impedance, and STDBY outputs a low level. When the battery voltage drops below the recharge threshold voltage, a new charging cycle starts automatically.

The high-precision voltage reference, error amplifier, and resistor divider network inside the chip ensure that the battery float voltage accuracy is within 1.5%, meeting the requirements of lithium-ion batteries and lithium-polymer batteries.

Charging Current Setting

The charging current is set by the resistance value between the PROG pin and GND:

$$I_{BAT}=1150*V_{PROG}/R_{PROG}\text{(error ±15%)}$$

The relationship between RPROG and charging current can be referred to the following table:

R_{PROG}(k)	I_{BAT}(mA)
20	57
10	115
5	230
3	380
2	575
1	1150

Charge Termination

When the charging current drops to 1/10 of the set value after reaching the final floating charging voltage, the charging cycle is terminated. This condition is monitored and detected by an internal filter comparator that is monitoring the PROG pin.When the PROG pin voltage drops below 100mV for a duration exceeding t_{TERM}(approximately 1.8ms), charging is terminated, the charging current is turned off, and SKI4056M enters the standby mode. At this point, the power current drops to 55μA (note: C/10 termination fails in the constant current charging and thermal limit mode).

Transient loads on the BAT pin during charging can cause the PROG pin voltage to briefly drop below 100mV. The 1.8ms filter time (t_{TERM}) of the termination comparator ensures that such transient loads do not cause premature termination of the charging cycle. Once the average charging current drops below 1/10 of the set value, the SKI4056M immediately terminates the charging cycle and stops supplying any current through the BAT pin. In this state, all loads on the BAT pin must be powered by the battery.

In standby mode, the SKI4056M continuously monitors the BAT pin voltage. If the voltage of this pin drops below the 4.1V recharge threshold (VRECHRG), another charging cycle starts and current is supplied to the battery again.

The SKI4056M has two open-drain status indicator outputs. When the charger is in charging state, CHRG is pulled low; in other states, CHRG is in high-impedance state. When the battery temperature is outside the normal temperature range, both CHRG and STDBY pins output high-impedance.

Typical connection of the TEMP pin: when the battery is not connected to the charger, neither the red light nor the green light is on, indicating a fault state. Connecting the TEMP pin to GND disables the battery temperature detection function. When the battery is not connected to the charger, CHRG outputs a pulse signal indicating no battery installed. When the external capacitor of the BAT pin is 10μF, the flashing frequency is approximately 1-4 seconds.

When the status indication function is not used, connect the unused status indication output to ground.

Charging Status	CHRG Pin	STDBY Pin
	Red Light	Green Light
Charging in progress	On	Off
Battery fully charged	Off	On
Power under voltage/No battery connected/Battery temperature too high or to low	Off	Off
BAT connected to 10μF capacitor, no Battery(TEMP=GND)	Flashing(T=1-4S)	On

Thermal Limiting

If the internal temperature of the chip rises above the preset value of approximately 125°C, the internal thermal feedback loop will reduce the set charging current until the current is reduced to 0 when the temperature exceeds 145°C. This function prevents the SKI4056M from overheating and allows users to increase the upper limit of the power handling capacity of a given circuit board without the risk of damaging the SKI4056M. On the premise that the charger can automatically reduce the current under worst-case conditions, the charging current can be set according to the typical (rather than worst-case) ambient temperature.

Battery Temperature Monitoring

To prevent damage to the battery caused by excessively high or low temperatures, the SKI4056M integrates a battery temperature monitoring circuit. The battery temperature monitoring function is realized by measuring the voltage of the TEMP pin. The voltage of the TEMP pin is realized by an NTC thermistor inside the battery and a resistor divider network. The SKI4056M compares the voltage of the TEMP pin with two internal thresholds V_{LOW} and V_{HIGH} to confirm whether the battery temperature is outside the normal range. Inside the SKI4056M, V_{LOW} is fixed at 45%*V_{CC}, and V_{HIGH} is fixed at 80%*V_{CC}. If the voltage of the TEMP pin $V_{TEMP}<V_{LOW}$ or $V_{TEMP}>V_{HIGH}$, it indicates that the battery temperature is too high or too low, and the charging process will be suspended; if the voltage of the TEMP pin V_{TEMP} is between V_{LOW} and V_{HIGH}, charging continues.

If the TEMP pin is connected to the ground, the battery temperature monitoring function is disabled.

Determining the Values of R1 and R2

The values of R1 and R2 should be determined according to the battery temperature monitoring range and the resistance value of the thermistor. An example is given as follows:

Assume that the set temperature range of the battery is T_L to T_H (where $T_L < T_H$); the thermistor used in the battery is a negative temperature coefficient thermistor (NTC), with R_{TL} being its resistance value at temperature T_L and R_{TH} being its resistance value at temperature T_H. Then, $R_{TL} > R_{TH}$.

At temperature T_L, the voltage of the TEMP pin is:

$$V_{TEMPL} = \frac{R2||R_{TL}}{R1+R2||R_{TL}} * V_{CC}$$

At temperature T_H, the voltage of the TEMP pin is:

$$V_{TEMPH} = \frac{R2||R_{TH}}{R1+R2||R_{TH}} * V_{CC}$$

Then, from $\mathbf{V_{TEMPL}= V_{HIGH} = K_2 * V_{CC}(K_2=0.8)}$

$\mathbf{V_{TEMPH}= V_{LOW} = K_1 * V_{CC}(K_1=0.45)}$

we can solve for: **R1** = $\frac{R_{TL}R_{TH}(K_2-K_1)}{(R_{TL}-R_{TH})K_1K_2}$

$$\mathbf{R2} = \frac{R_{TL}R_{TH}(K_2-K_1)}{R_{TL}(K_1-K_1K_2)-R_{TH}(K_2-K_1K_2)}$$

Similarly, if the thermistor inside the battery is a positive temperature coefficient (PTC) thermistor, then $R_{TH} > R_{TL}$, and we can calculate:

$$\mathbf{R1} = \frac{R_{TL}R_{TH}(K_2-K_1)}{(R_{TH}-R_{TL})K_1K_2}$$

$$\mathbf{R2} = \frac{R_{TL}R_{TH}(K_2-K_1)}{R_{TH}(K_1-K_1K_2)-R_{TL}(K_2-K_1K_2)}$$

From the above derivation, it can be seen that the set temperature range is independent of the power supply voltage V_{CC} and only related to R1, R2, R_{TH}, and R_{TL}; among them, R_{TH} and R_{TL} can be obtained by referring to the relevant battery manual or through experimental testing.

In practical applications, if only the temperature characteristic of one end is concerned, such as overheat protection, R2 can be omitted and only R1 can be used. The derivation of R1 also becomes simple, which will not be repeated here.

Under-voltage Lockout

An internal under-voltage lockout circuit monitors the input voltage and keeps the charger in shutdown mode until V_{CC} rises above the under-voltage lockout threshold. If the UVLO comparator toggles, the charger will exit shutdown mode after V_{CC} rises 150mV above the battery voltage.

Manual Shutdown

At any time during the charging cycle, the SKI4056M can be placed in shutdown mode by setting the CE terminal to low level or removing PROG (PROG pin floating), which reduces the battery leakage current to 2μA and the power supply current to below 60μA. Setting the CE terminal to high level again or connecting a setting resistor can start a new charging cycle.

Automatic Recharging

Once the charging cycle is terminated, the SKI4056M immediately uses a comparator with a 1.8ms filter time ($t_{RECHARGE}$) to continuously monitor the voltage on the BAT pin. When the battery voltage drops below 4.1V (approximately 90% of the battery capacity), the charging cycle restarts. This ensures that the battery is maintained at (or near) full charge and eliminates the need for periodic charging cycle initiation. During the recharge cycle, the CHRG pin output enters a strong pull-down state. Figure 1 shows the state diagram of a typical charging cycle.

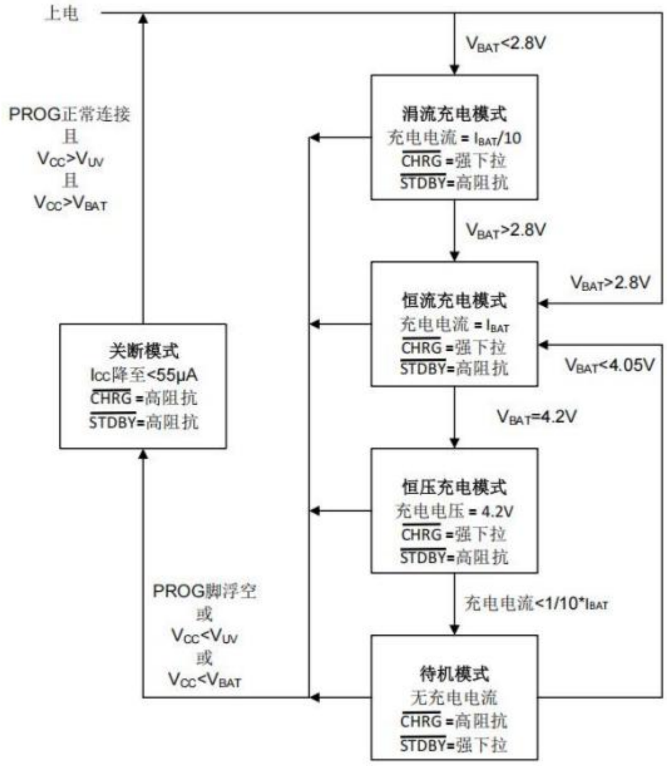


Figure 1: Typical charging cycle state diagram

Stability Considerations

In constant current mode, the PROG pin is in the feedback loop instead of the battery, and the stability of constant current mode is affected by the impedance of the PROG pin. The absence of an additional capacitor on the PROG pin will reduce the maximum allowable resistance value of the setting resistor.The threshold frequency on the PROG pin should be set to C_{PROG}. Then, the maximum resistance value of RPROG can be calculated using the following formula:

$$R_{PROG} \leq \frac{1}{2\pi * 10^5 * C_{PROG}}$$

For users, they may be more interested in the charging current rather than the transient current. For example, if a switching power supply operating in low current mode is connected in parallel with the battery, the average current flowing out of the BAT pin is usually more important than the transient current pulse. In this case, a simple RC filter can be used on the PROG pin to measure the average battery current (as shown in Figure 2). A 10k resistor is added between the PROG pin and the filter capacitor to ensure stability.

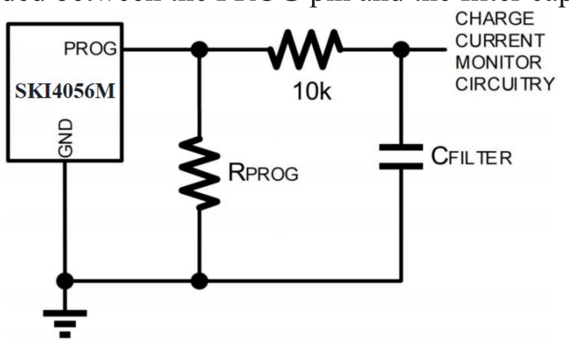


Figure 2: Isolating capacitive loads and filter circuit on the PROG pin

Power Dissipation

The condition for the SKI4056M to reduce the charging current due to thermal feedback can be estimated by the power dissipation in the IC. This power dissipation is almost entirely generated by the internal MOSFET, which can be approximately calculated by the following formula:

$$P_D = (V_{CC}-V_{BAT})*I_{BAT}$$

Where: P_D is the dissipated power, V_{CC} is the input power supply voltage, V_{BAT} is the battery voltage, and I_{BAT} is the charging current.

When thermal feedback starts to protect the IC, the ambient temperature is approximately:

$$TA=140°C-PD*\theta_{JA}=140°C-(V_{CC}-V_{BAT})*I_{BAT}*\theta_{JA}$$

Example: A SKI4056M operating at 5V is programmed to provide a full-scale current of 800mA to a discharged lithium-ion battery with a voltage of 3.75V. Assuming θ_{JA} is 150°C/W, the ambient temperature when the SKI4056M starts to reduce the charging current is approximately:

$$T_A=140°C-(5.0V-3.75V)*(800mA)*150°C/W$$

$$T_A=65°C$$

The SKI4056M can be used at ambient temperatures above 65°C, but the charging current will be reduced below 800mA. For a given ambient temperature, the charging current can be approximately calculated by the following formula:

$$IBAT = \frac{145°C-T_A}{(V_{CC}-V_{BAT})*\theta_{JA}}$$

As discussed in the operating principle section, when thermal feedback reduces the charging current, the voltage of the PROG pin will also decrease proportionally.

Thermal Considerations

Due to the small form factor of the ESOP8 package, it is very important to adopt a PCB layout with excellent thermal design to maximize the usable charging current. The heat dissipation path for dissipating the heat generated by the IC is from the chip to the lead frame, and through the bottom heat sink to the PCB copper surface. The PCB copper surface serves as a heat sink, and the copper foil area connected to the heat sink should be as wide as possible and extended to a larger copper area to dissipate heat to the surrounding environment. Through-holes to internal or back copper circuit layers are also useful in improving the overall thermal performance of the charger. When designing the PCB layout, other heat sources on the circuit board unrelated to the charger must also be considered, as they will affect the overall temperature rise and maximum charging current.

In general practical applications (ambient temperature approximately 25°C), under the maximum charging current condition, it is optimal to control the surface dissipation temperature of the 4056M chip below 65°C through design optimization such as PCB heat dissipation layout.

Increasing Thermal Regulation Current

Reducing the voltage drop across the internal MOSFET can significantly reduce the power consumption in the IC, which has the effect of increasing the current delivered to the battery terminal during thermal regulation. One countermeasure is to dissipate part of the power through an external component (such as a resistor or diode).

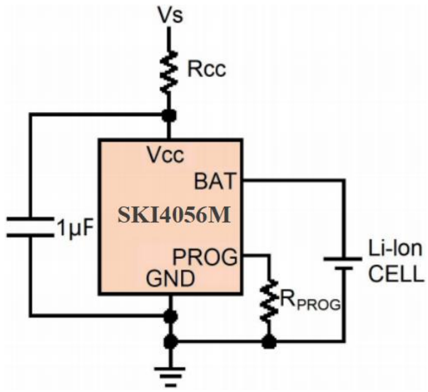


Figure 3: A circuit to maximize the charging current in thermal regulation mode

Although this application can deliver more energy to the battery in thermal regulation mode and shorten the charging time, in voltage mode, if VCC becomes low enough to put the SKI4056M in a low dropout state, it may actually extend the charging time. Figure 4 shows how the circuit causes a voltage drop as R_{CC} increases.

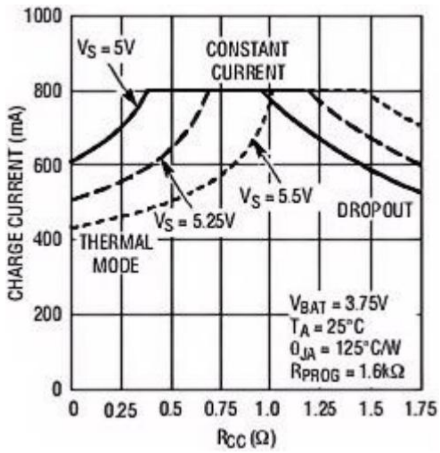


Figure 4: Relationship curve between charging current and RCC

This technique works best when the RCC value is minimized to keep the component size small and avoid voltage drop. Remember to select a resistor with sufficient power handling capacity.

V_{CC} Bypass Capacitor

Various types of capacitors can be used for input bypass; however, caution must be exercised when using multilayer ceramic capacitors. Due to the self-resonance and high Q characteristics of some types of ceramic capacitors, high voltage transients may be generated under certain start-up conditions (such as connecting the charger input to an active power supply). Adding a 1.5Ω resistor in series with the ceramic capacitor will minimize the start-up voltage transients.

Charging Current Soft Start

The SKI4056M includes a soft-start circuit to minimize inrush current at the start of the charging cycle. When a charging cycle is initiated, the charging current will rise from 0 to the full-scale value in approximately 20μs. During start-up, this can minimize the transient current load on the power supply.

USB and AC Adapter Power Supplies

The SKI4056M allows charging from an AC adapter or a USB port. Figure 5 shows an example of how to combine AC adapter and USB power inputs. A P-channel MOSFET (MP1) is used to prevent reverse signal transmission to the USB port when the AC adapter is connected, and a Schottky diode (D1) is used to prevent power loss in the USB power through the 1K pull-down resistor. In general, an AC adapter can provide much more current than a USB port with a current limit of 500mA. When the AC adapter is connected, an N-channel MOSFET (MN1) and an additional 10K setting resistor can be used to increase the charging current to 600mA.

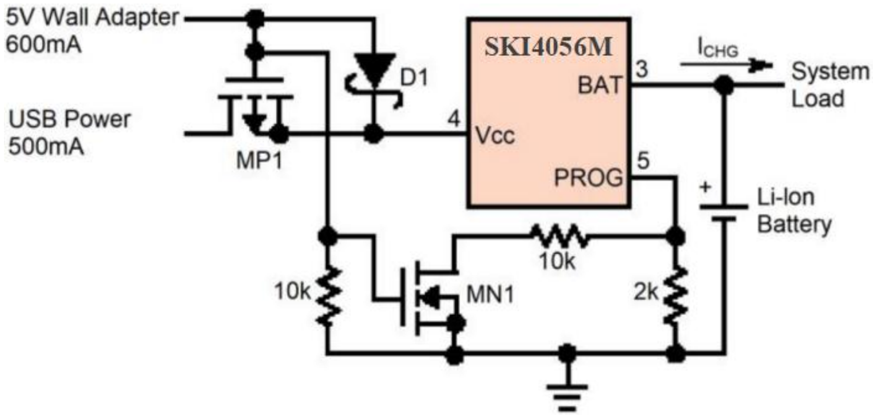
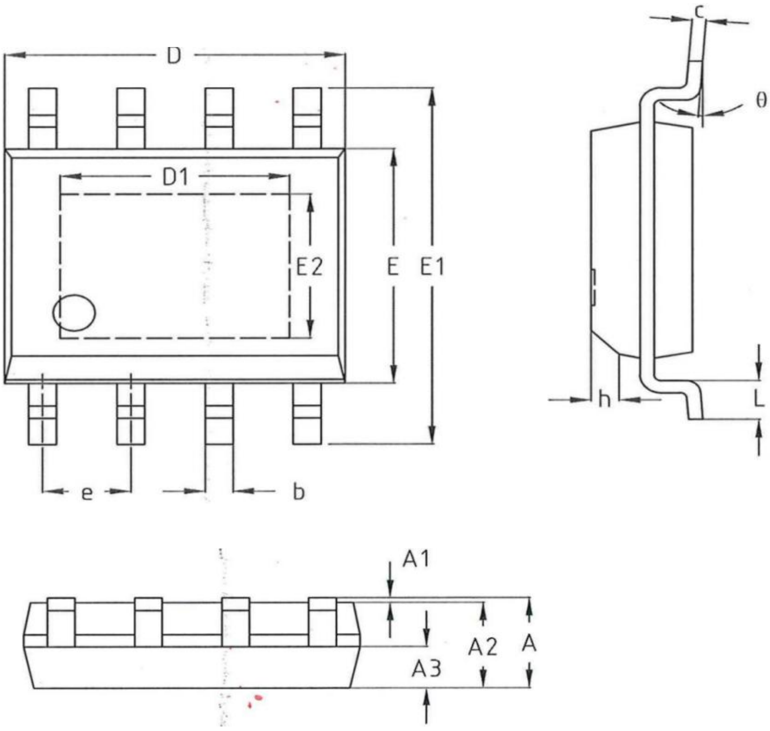


Figure 5: Combination of AC adapter and USB power supply

Package Information

ESOP-8

Dimensions in mm



Symbol	Dimensions In Millimeters			Symbol	Dimensions In Millimeters		
	Min	Nom	Max		Min	Nom	Max
A	1.50	1.60	1.70	E	3.80	3.90	4.00
A1	0.10	-	0.25	E1	5.80	6.00	6.20
A2	1.35	1.45	1.55	E2	2.30	2.40	2.50
A3	0.65	0.70	0.75	e	1.27 BSC		
b	0.35	-	0.50	h	0.30	-	0.50
c	0.19	-	0.25	L	0.50	-	0.80
D	4.80	4.90	5.00	θ	0°	-	8°
D1	3.20	3.30	3.40				

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