SK4156 28V/1A Single Cell, Lithium Battery Charger

General Description

The SK4156 is a complete constant-current & constant voltage linear charger, with Over Voltage Protection (OVP) built in, for single cell lithium-ion batteries. Its PSOP8 package and low external component count make the SK4156 ideally suited for portable applications. Further more, the SK4156 can work within USB and wall adapter.

No blocking diode is required due to the internal PMOSFET architecture and have prevent to negative Charge Current Circuit. Thermal feedback regulates the charge current to limit the die temperature during high power operation or high ambient temperature. The charge voltage is fixed at 4.2V and 4.35V, and the charge current can be programmed externally with a single resistor.

The SK4156 automatically terminates the charge cycle when the charge current drops to 1/10th the programmed value after the final float voltage is reached.

The SK4156 Other features include current monitor, under voltage lockout, automatic recharge and two status pin to indicate charge termination and the presence of an input voltage.

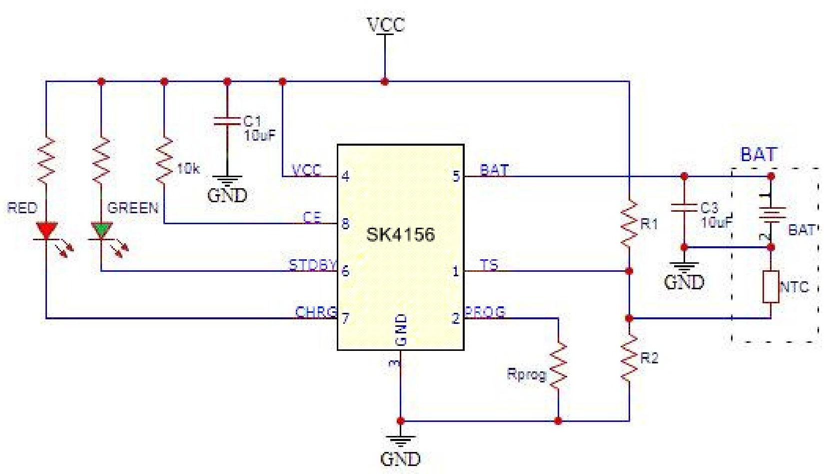
Features

- Programmable Charge Current Up to 1000mA
- Maximum power point tracking (MPPT) (Optional)
- OVP voltage at 6.5V
- No MOSFET, Sense Resistor or Blocking Diode Required
- Complete Linear Charger for Single Cell Lithium-Ion Batteries
- Constant-Current/Constant-Voltage
- Preset 4.2V and 4.35V Charge Voltage with 1.5% Accuracy
- Automatic Recharge
- Two Charge Status Output Pins
- C/10 Charge Termination
- 2.9V Trickle Charge Threshold
- Soft-Start Limits Inrush Current
- Available in PSOP8 and DFN2x2-8 Package

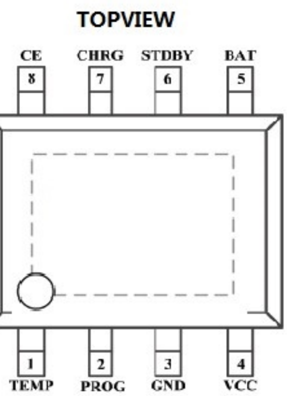
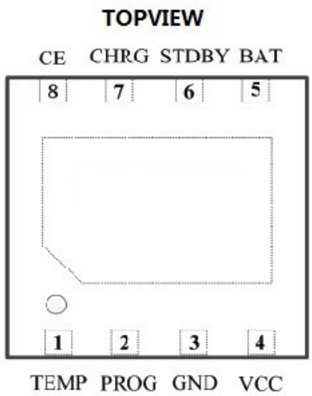
Application

- Charging Docks and Cradles
- Cellular Telephones, PDAs, GPS
- Digital Still Cameras, Portable Devices
- USB Bus-Powered Chargers, Chargers

Typical Application Circuit



Pin Configuration

PSOP8	DFN2x2-8
	

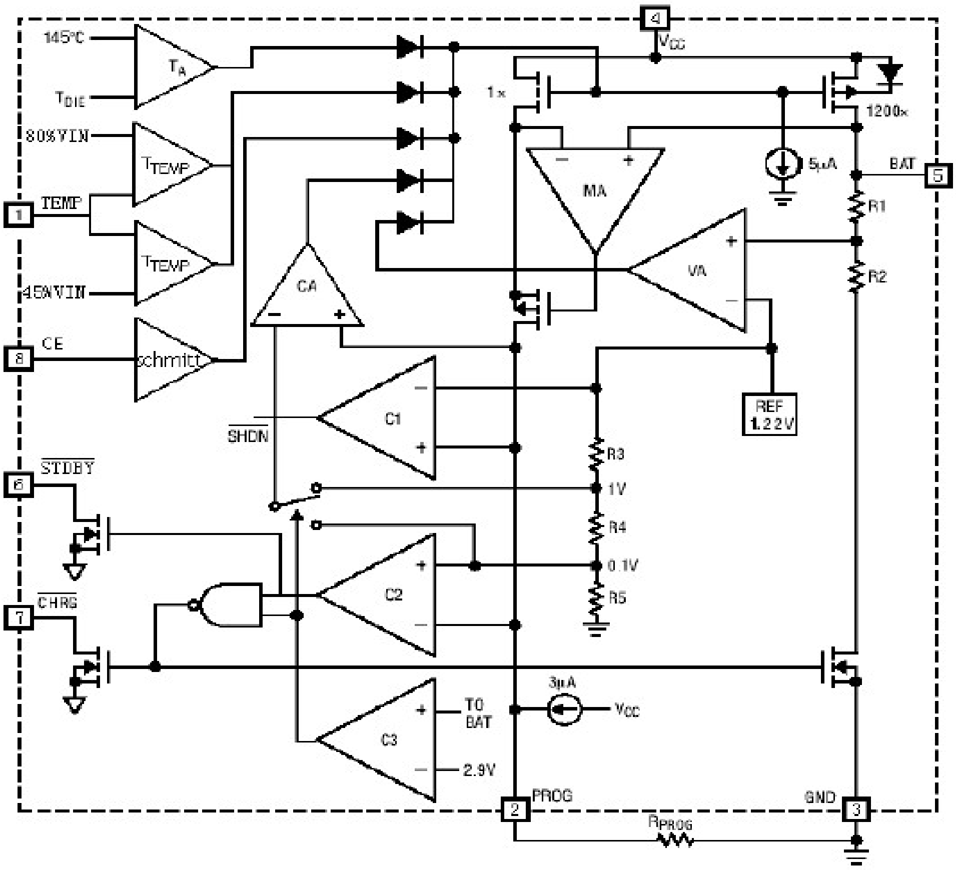
Pin Description

Pin	Function Description	Pin	Function Description
TEMP	Connecting TEMP pin to NTC thermistor’s output in Lithium ion battery pack. When Temp is tied to GND, this function is disabled. The other functions remain unchanged.	BAT	Connect the positive terminal of the battery to BAT pin
PROG	Constant charge current setting and charge current monitor pin	STDBY	Open Drain Charge Status Output
GND	Ground pin	CHRG	Open Drain Charge Status Output
VCC	Input Voltage pin	CE	Chip Enable Input

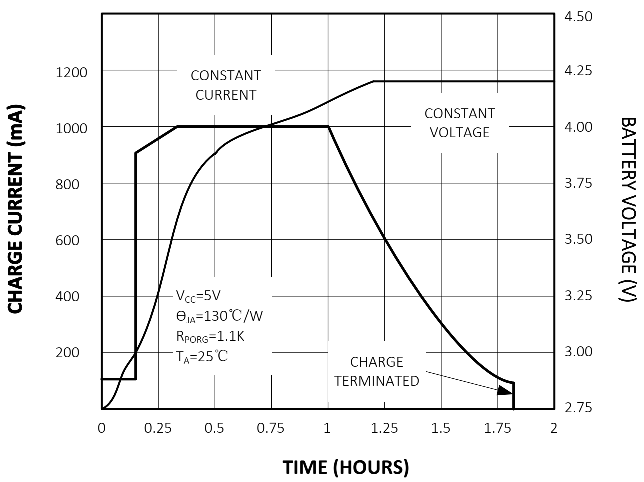
Ordering Information

Part No.	MPPT Function	Package	Tape/Reel
SK4156P8-42	Y	PSOP8	4000
SK4156P8-435	Y		
SK4156D8-42	Y	DFN2x2-8	3000
SK4156D8-435	Y		
SK4156P8-42-N	N	PSOP8	4000

Functional Block Diagram



Typical Completed Charging Curve



Absolute Maximum Rating

Parameter	Symbol	Value	Units
Input Supply Voltage	V_{CC}	28	V
BAT Voltage	V_{BAT+}	11	V
TEMP/CE	V_{TEMP}	6.0	V
CHRG/STDBY	V_{CHRG}	28	V
BAT Pin Current	I_{BAT}	1500	mA
PROG Pin Current	I_{PROG}	2	mA
TEMP/CE Pin Current	I_{Temp}/I_{CE}	5	mA
Thermal Resistance (PSOP8)	Θ_{JA}	70	℃/W
Storage Temperature		-40℃~150	℃
Lead Temperature (Soldering, 10 sec)		260±5	℃

Note: Even if the characteristics of CE pins can't be changed itself, there does not cause problems with the product if it is used with the application below adding 100 kohm is added to CE pins.

Recommended Operating Rating

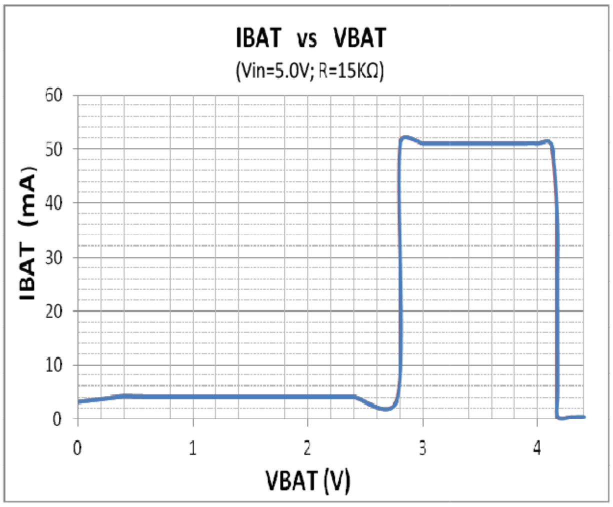
Parameter	Value	Units
Input voltage operating range	4.6 ~ 6.5	V
Junction Temperature	-20 ~ 85	℃

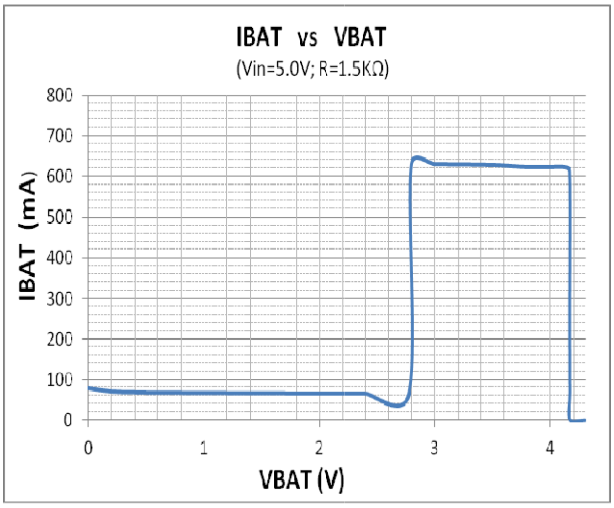
Electrical Characteristics

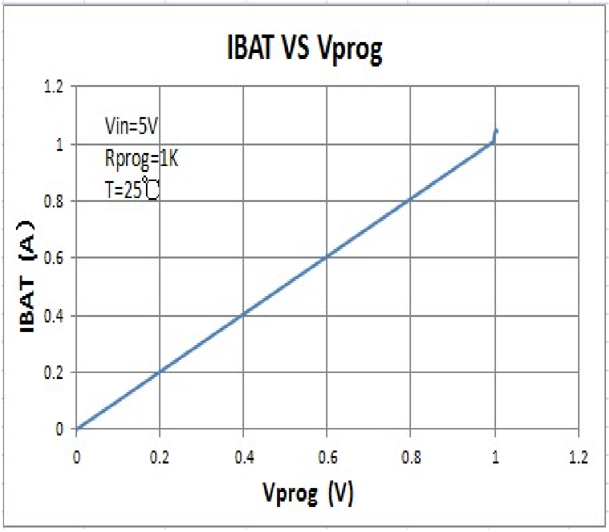
V_{CC}=5V, Tj=25℃, unless otherwise stated.

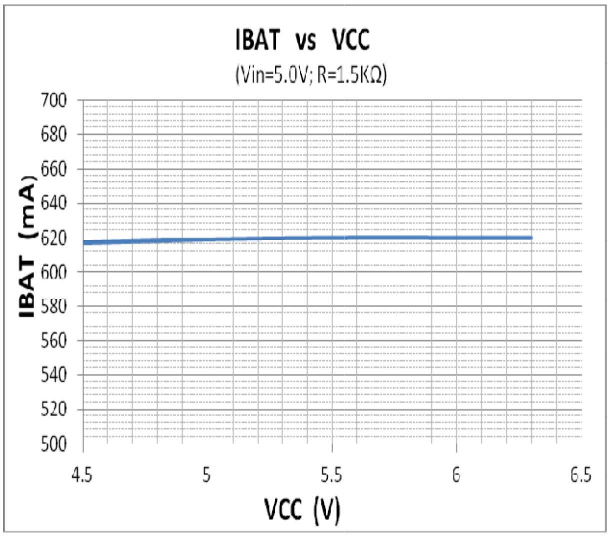
Symbol	Parameter	Conditions	Min	Typ	Max	Unit
V_{IN_OP}	Input voltage operating		4.5		6.5	V
I_{CC}	Input Current	Charging, R_{PROG}=2K		1000		µA
		Standby		170		
		Shut off		3		
V_{FLOAT}	Floating voltage	I_{BAT} = 30mA, R_{PROG}=10K	4.158	4.2	4.242	V
			4.306	4.35	4.394	
I_{BAT}	BAT PIN Current:	Charging (R_{PROG}=2K)		500		mA
		Charging (R_{PROG}=1K)		1000		mA
		Standby, V_{BAT}=4.3V		2		uA
		Shut off		2		uA
I_{TRIKL}	Trickle Charge Current	V_{BAT}<V_{TRIKL}, R_{PROG}=2K		50		mA
V_{TRIKL}	Trickle Charge Threshold	R_{PROG}=2K, V_{BAT} Rising		2.9		V
V_{TRHYS}	Trickle charger hysteresis	R_{PROG}=2K		100		mV
V_{UV}	V_{CC} UVLO	V_{CC} Low to High		3.7		V
V_{UVHYS}	V_{CC} UVLO hysteresis			150		mV
V_{ASD}	V_{CC}-V_{BAT} Lockout voltage threshold	Vcc Rising		150		mV
		Vcc Falling		100		mV
I_{TERM}	C/10 Termination	R_{PROG}=2K		60		mA
		R_{PROG}=1K		100		mA
V_{PROG}	PROG Voltage	R_{PROG}=2K, CC mode		1.0		V
V_{CHRG}	CHRG Sink voltage	I_{CHRG} = 5mA			0.4	V
V_{STDBY}	STDBY Sink voltage	I_{STDBY} =5mA			0.4	V
V_{TEMP-H}	TEMP Voltage High			80		%Vcc
V_{TEMP-L}	TEMP Voltage Low			45		%Vcc
ΔV_{RECHRG}	Recharge Threshold	V_{FLOAT} - V_{RECHRG}		150		mV
T_{LIM}	Constand CC Temp			120		°C
$T_{RECHARGE}$	Recharge Filter Delay	V_{BAT} High to Low		1		ms
T_{TERM}	Charger Terminal Delay	I_{BAT} Falling Below I_{CHG}/10		1		ms
I_{PROG}	PROG Pull Up Current			0.5		µA
OVP	Over Voltage Protection			6.5		V
	OVP Hysteresis			200		mV

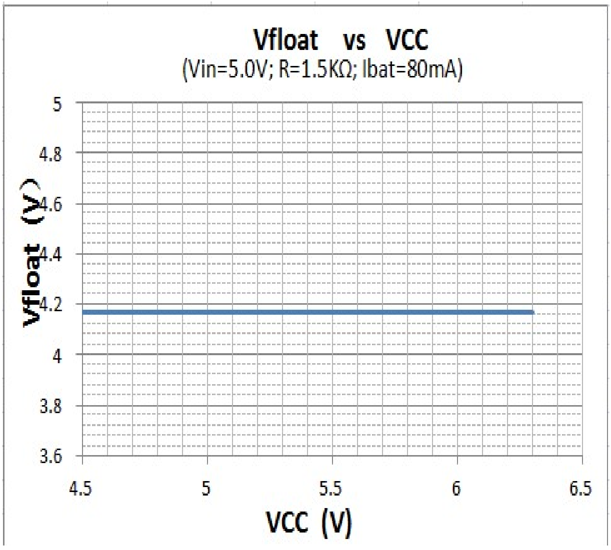
Typical Characteristics

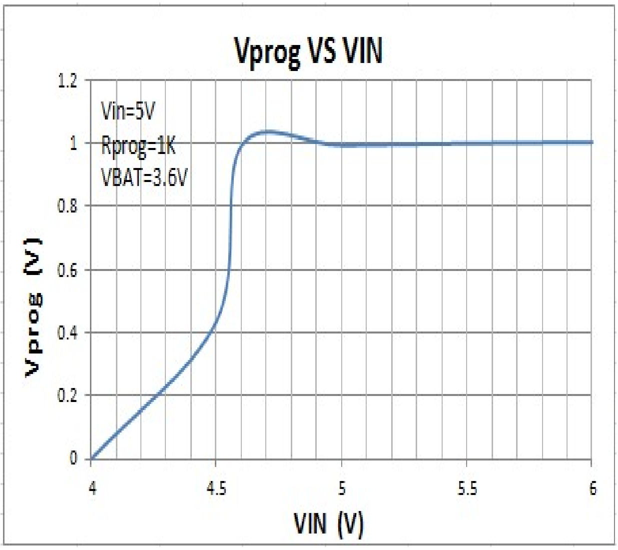












Application Information

The SK4156 is a constant-current & constant-voltage linear charger for single cell lithium-ion batteries. Constant-current & constant-voltage to charger batter by internal MOSFET. It can deliver up to 1A of charge current. No blocking diode or external current sense resistor is required. SK4156 include two Open-Drain charge status Pins: Charge status indicator and battery failure status output .The internal thermal regulation circuit reduces the programmed charge current if the die temperature attempts to rise above a preset value of approximately 120℃. This feature protects the SK4156 from excessive temperature, and allows the user to push the limits of the power handling capability of a given circuit board without risk of damaging the SK4156 or the external components. Another benefit of adopting thermal regulation is that charge current can be set according to typical, not worst-case, ambient temperatures for a given application with the assurance that the charger will automatically reduce the current in worst-case conditions.

The charge cycle begins when the voltage at the VCC pin rises above the UVLO level, a current set resistor is connected from the PROG pin to ground, and the CE pin is pulled above the chip enable threshold. The CHRG pin outputs a logic low to indicate that the charge cycle is on going. At the beginning of the charge cycle, if the battery voltage is below 2.9V, the charge is in recharge mode to bring the cell voltage up to a safe level for charging. The charger goes into the fast charge constant-current mode once the voltage on the BAT pin rises above 2.9V. In constant current mode, the charge current is set by RPROG. When the battery approaches the regulation voltage 4.2V, the charge current begins to decrease as the SK4156 enters the constant-voltage mode. When the current drops to charge termination threshold, the charge cycle is terminated, and CHRG pin assumes a high impedance state to indicate that the charge cycle is terminated and STDBY pin is pulled low. The charge termination threshold is 10% of the current in constant current mode. To restart the charge cycle, remove the input voltage and reapply it, or momentarily force CE pin to 0V.

The charge cycle can also be automatically restarted if the BAT pin voltage falls below the recharge threshold. The on-chip reference voltage, error amplifier and the resistor divider provide regulation voltage with 1% accuracy which can meet the requirement of lithium-ion and lithium polymer batteries. When the input voltage is not present, or input voltage is below V_{BAT}, the charger goes into a sleep mode, dropping battery drain current to less than 3μA. This greatly reduces the current drain on the battery and increases the standby time. The charger can be shutdown by forcing the CE pin to GND.

Programming Charge Current

The charge current is programmed using a single resistor from the PROG pin to ground. The program resistor and the charge current are calculated using the following equations.

$$R_{PROG} = \frac{1000}{I_{BAT}} \quad (\pm 10\%)$$

In application, according the charge current to determine RPROG, the relation between RPROG and charge current can reference the following chart:

R_{PROG} (k)	I_{BAT} (mA)
25	40
16.6	60
8.33	120
4.2	240
3.33	300
2.5	400
1.67	600
1.39	720
1.2	800
1.11	900
1.0	1000

Charge Termination

A charge cycle is terminated when the charge current falls to 1/10th the programmed value after the final float voltage is reached. This condition is detected by using an internal filtered comparator to monitor the PROG pin. When the PROG pin voltage falls below 100mV for longer than t_{TERM} (typically 1mS), charging is terminated. The charge current is latched off and the SK4156 enters standby mode, where the input supply current drops to 55µA (Note：C/10 termination is disabled in trickle charging and thermal limiting modes).

When charging, transient loads on the BAT pin can cause the PROG pin to fall below 100mV for short periods of time before the DC charge current has dropped to 1/10th the programmed value. The 1mS filter time (t_{TERM}) on the termination comparator ensures that transient loads of this nature do not result in premature charge cycle termination. Once the average charge current drops below 1/10th the programmed value, the SK4156 terminated the charge cycle and ceases to provide any current through the BAT pin. In this state all loads on the BAT pin must be supplied by the battery.

The SK4156 constantly monitors the BAT pin voltage in standby mode. If this voltage drops below the 4.05V recharge threshold (V_{RECHRG}), another charge cycle begins and current is once again supplied to the battery. To manually restart a charge cycle when in standby mode, the input voltage must be removed and reapplied or the charger must be shut down and restarted using the PROG pin. Figure 1 shows the state diagram of a typical charge cycle.

Charge Status Indicator

The SK4156 has two open-drain status indicator output CHRG and STDBY. CHRG is pull-down when the SK4156 in a charge cycle. In other status CHRG in high impedance. CHRG and STDBY are all in high impedance when the battery out of the normal temperature.

Represent in failure state, when TEMP pin in typical connecting, or the charger with no battery: red LED and green LED all don’t light. The battery temperature sense function is disabled by connecting TEMP pin to GND. If battery is not connected to charger, CHRG pin outputs a PWM level to indicate no battery. If BAT pin connects a 10µF capacitor, the frequency of CHRG flicker about 1-4S, If not use status indicator should set status indicator output connected to GND

Charger's Status	Red LED	Green LED
Charging	light	dark
Battery in full state	dark	light
Under-voltage, battery's temperature is to high or too low, or not connect to battery (use TEMP)	dark	dark
BAT pin is connected to 10µF capacitor, No battery mode(TEMP=GND)	Green LED bright, Red LED flicker F=1-4S	

Temperature Limits

The SK4156 has an internal temperature control of 120℃ during charging. Typically, SK4156 will charge the battery according to the user pre-set CC current. When the IC temperature reaches 120℃, SK4156 will automatically reduce charging current to maintain the 120℃ control temperature will not be exceeded.

If the user needs additional temperature control, such as setting min and max temperature limits for charging, SK4156 provides an additional TEMP pin to allow users to set min and/or max limits. The following calculations provide the details on how to obtain the correct external resistors for the desired min and max limits.

Temperature Monitoring

This is to provide additional temperature control to prevent the possible battery overheating. The SK4156 monitors the external temperature information through the voltage on TEMP pin. The typical set up is shown the typical applications as R1 and R2. The SK4156 compares voltage on TEMP with internal voltages V_{TEMPL} and V_{TEMPH}. V_{TEMPL} is internally set at 45%*Vcc (K1). V_{TEMPH} is internally set at 80%*Vcc. If the voltage on TEMP, V_{TEMP}, is higher than V_{TEMPH} or lower than V_{TEMPL}, charging will stop. When TEMP function is not used. TEMP pin should be connected to GND.

Choose R1 and R2 Values

The following examples shows how to set the values of R1 and R2 according to the desired Min and Max temperature limits.

Assuming we use Negative temperature Coefficient (NTC) resistor, and let V_{TEMPL} stands for voltage for TEMP at low temperature limit, V_{TEMPH} stands for high temperature limit, let RTL stands for NTC resistor value at low temperature limit, and RTH for resistor value at high temperature limit. Then we have:

$$V_{TEMPL} = \frac{R_2||R_{TL}}{R_1 + R_2||R_{TL}} \times VIN$$

$$V_{TEMPH} = \frac{R_2||R_{TH}}{R_1 + R_2||R_{TH}} \times VIN$$

We also know

$V_{TEMPL} = K2 \times V_{CC}$ (K2=0.8)

$V_{TEMPH} = K1 \times V_{CC}$ (K1=0.45)

Then we can calculate them as:

$$R_1 = \frac{R_{TL}R_{TH}(K_2 - K_1)}{(R_{TL} - R_{TH})K_1K_2}$$

$$R_2 = \frac{R_{TL}R_{TH}(K_2 - K_1)}{R_{TL}(K_1 - K_1K_2) - R_{TH}(K_2 - K_1K_2)}$$

Consequently, if PTC resistor is used, we will get the following results:

$$R_1 = \frac{R_{TL}R_{TH}(K_2 - K_1)}{(R_{TH} - R_{TL})K_1K_2}$$

$$R_2 = \frac{R_{TL}R_{TH}(K_2 - K_1)}{R_{TH}(K_1 - K_1K_2) - R_{TL}(K_2 - K_1K_2)}$$

From the above calculations, we can see that the temperature control and monitoring is independent of the Vcc. Additionally, if we are only interested one-sided temperature control such as overheating, we can use R1 only, and the related calculations are further simplified and will not repeated here.

Examples of TEMP Resistance Calculation:

TEMPL=-7℃, TEMPH=50℃, As known:

TS1 (K_1)	0.45	Inner Set
TS2 (K_2)	0.8	Inner Set

Entry the values of NTC resistance:

(Check the manual of MuRata NCP15XH103F03RC)

R_{TL}	37, 073.00	-7℃
R_{TH}	4, 161.00	50℃
R25℃	10, 000.00	

Calculation Results:

R_1	4, 556.87
R_2	35, 857.20

One note is that TEMP has an internal Zener diode with a fixed voltage of 6V for TEMP protection purposes. The Zener diode has a sinking ability of about 5mA. Consequently it is suggested the voltage of R1 is no less than 4.4K.

Under Voltage Lock Out (UVLO)

When V_{CC} is below UVLO, SK4156 will remain in the standby mode. Furthermore, to make sure the normal charging, UVLO will keep SK4156 in standby mode until V_{CC} is 100mV higher than the battery voltage.

Manually Stop Charging

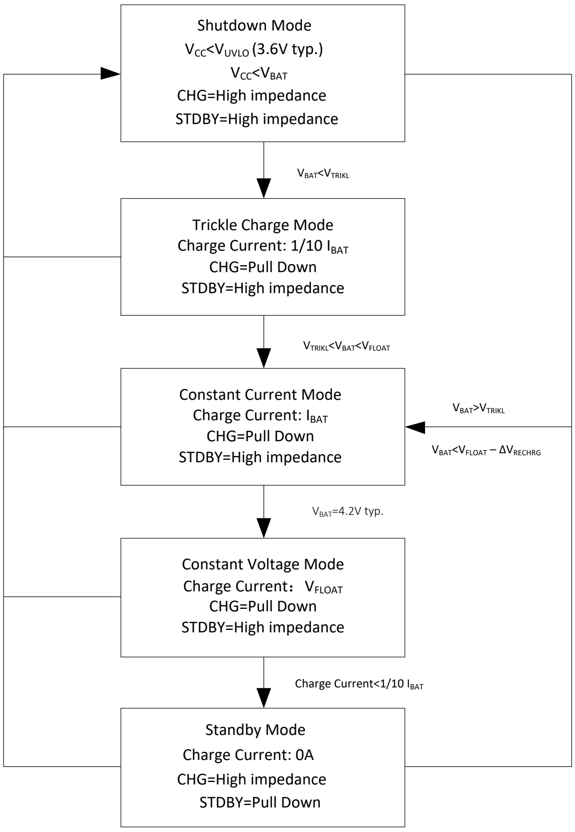
Charging can be stopped by forcing a voltage at CE, or floating R_{PROG} pin. Both methods will push SK4156 into shutdown mode and reduce the I_Q to 1µA.

Recharge

To maximize battery life, SK4156 has a recharge functions built in. When battery is fully charged, the SK4156 will stop charging and BAT pin will be set to high impedance mode and reduce battery drain. Furthermore, SK4156 will continue monitoring the voltage on battery. If the battery voltage drops before 4.05V for roughly 1mS, the SK4156 will automatically re-start and recharge the battery. The 1mS delay will effectively filtering out any environmental noise that might falsely start recharging.

If recharging battery is intended regardless of the battery voltage, the SK4156 can be powered off and powered back on again, then the normal charging will continue.

The following diagram shows the typical charging cycle:



Power Dissipation and CC

When the IC temperature reaches 120℃, the the Charging Current (CC) will be automatically reduced to ensure that the IC temperature will not continue rising into Over Temperature Protection (OTP). The value of actual CC can be calculated as follows. The power dissipation of the IC is set as follows:

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

The allowed temperature difference between 120℃ and ambient is then presented as:

$$T_A=120^{\circ}\mathrm{C}-P_D*\theta_{JA}$$
$$T_A=120^{\circ}\mathrm{C}-(V_{CC}-V_{BAT})*I_{BAT}*\theta_{JA}$$

Assuming θ_{JA} for PSOP8 is 70℃/W, the battery voltage is presently at 3.6V, and CC is reduced to 800mA, the T_A can then be calculated as:

$$T_A=120^{\circ}\mathrm{C}-(5V-3.6V)*800mA*70^{\circ}\mathrm{C}/W$$
$$T_A= 120^{\circ}\mathrm{C} - 1.12W*70^{\circ}\mathrm{C}/W$$
$$T_A=120^{\circ}\mathrm{C} - 78.4^{\circ}\mathrm{C} = 41.6^{\circ}\mathrm{C}$$

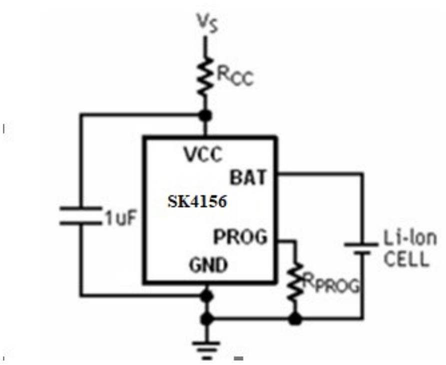
In other words, the charging current CC will be reduced automatically to around 800mA with a constant IC temperature of 120℃ for maximum charging, if the ambient temperature is limited to 41.6℃.

The amount charging current can also be calculated if the TA known, such as 35℃, as follows:

$$I_{BAT}=(120^{\circ}\mathrm{C}-35)/((5V-3.6V)*70^{\circ}\mathrm{C}/W)$$
$$I_{BAT}=867mA$$

This shows if T_A is reduced, the CC can be increased.

The charging current CC can be increased if power dissipation on the IC is reduced. One such method is to place a small resistor in series with Vcc, as shown below:



The small resistor R_{CC} will then be able to help the power dissipation when the charging current is large such as 1A in CC mode, and negligible when the charging current is small, such as 20mA in the final stage of CV operation.

For example, if the battery voltage is 3.6V and the desired CC is 1A, with θ_{JA}=125℃/W and T_A=35℃, the maximum voltage differential between V_{CC} and V_{BAT} is then:

$$V_{CC}-V_{RCC}-V_{BAT} = (120-T_A)/(I_{BAT}*\theta_{JA})$$
$$V_{CC} - V_{RCC}-V_{BAT} = (120-35)/(1A*70^{\circ}\mathrm{C}/W)$$
$$V_{CC}-V_{RCC}-V_{BAT} = 1.21V$$

Where V_{RCC} is the voltage drop on R_{CC}.

Assuming V_{CC}=5V, we then have:

$$V_{RCC} = V_{CC} - V_{BAT} - 1.21V$$
$$V_{RCC} = 5V - 3.6V - 1.21V = 0.19V$$
$$R_{CC} = V_{RCC}/I_{BAT} = 0.19V/1A = 0.19\Omega$$

In other words, if a resistor R_{CC} of 0.19Ω is used and the battery is again assumed to be 3.6V with V_{CC}=5V, the charging current can be increased to 1A under the same conditions.

Heat Dissipation

Heat dissipation is always very important in Linear Chargers. It is important to place as large amount of cupper area on the PCB as possible.

Bypass Capacitors

By pass capacitor is important to provide a good working environment. It is recommended that the bypass capacitor is placed as close to SK4156 as possible. The bypass capacitor for the battery is also recommended, especially when battery is used to power speakers or some power tools.

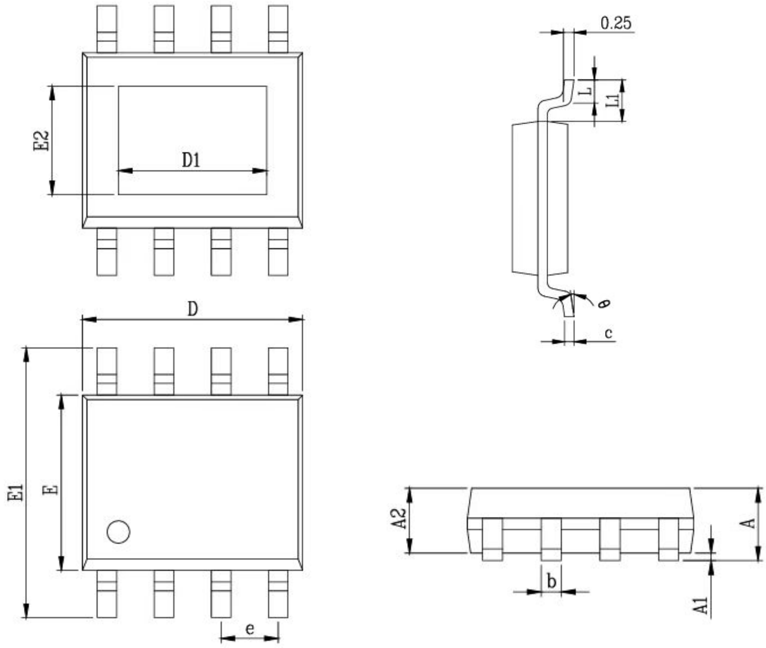
Soft Start

The SK4156 has built-in Soft-Start circuitry of around 20µS. This will prevent large inrush current on both Vin and V_{BAT}.

MPPT (Optional)

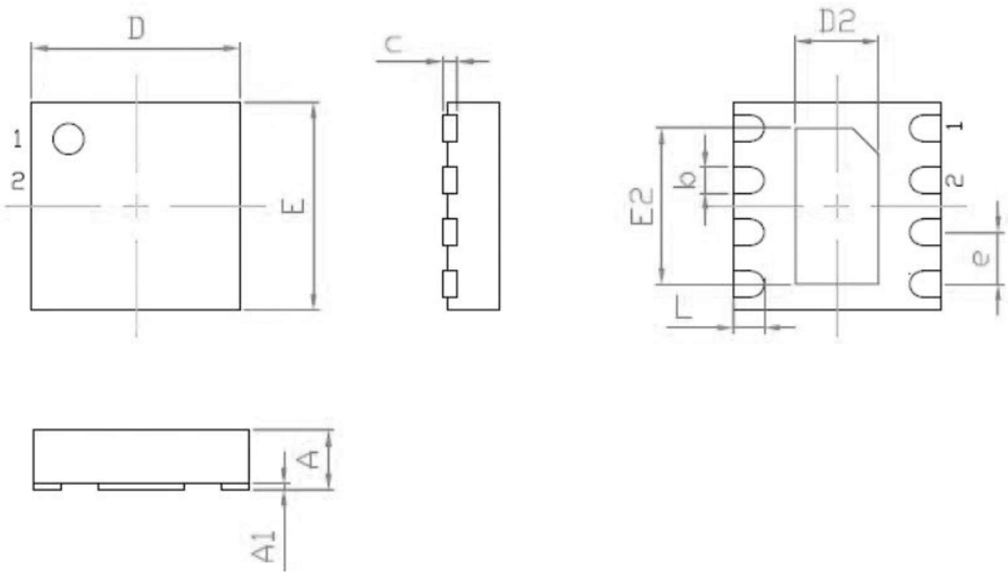
Maximum Power Point Tracking (MPPT) is a built-in feature in SK4156. This can be useful if the power source is limited under some special conditions, such as in solar panel applications, when the Sun blocks a portion of the solar panel and the amount of output is reduced. The SK4156 constantly monitors the input voltage to detect any reduction in power from the power source. When the input voltage is reduced to around 4.5V, SK4156 will gradually reduce the charging current to maintain the input voltage level. This will allow charging to continue as optimal value, not sending SK4156 into the protection mode when the input voltage becomes too low. This feature can also be useful when one adapter is used to charge several devices.

Package Dimensions: PSOP8



Symbol	Dimensions in Millimeters		
	Min	Nom	Max
A	1.35	1.55	1.75
A1	0.05	0.10	0.15
A2	1.30	1.40	1.50
b	0.39	0.42	0.45
c	0.21	0.24	0.26
D	4.70	4.90	5.10
D1	3.05	3.15	3.25
E	3.70	3.90	4.10
E1	5.80	6.00	6.20
E2	2.16	2.26	2.36
e	1.24	1.27	1.30
L	0.50	0.65	0.80
L1	0.99	1.05	1.10
θ	0°	4°	8°

Package Dimensions: DFN2x2-8



Symbol	Dimensions in Millimeters		
	Min	Nom	Max
A	0.45	0.50	0.55
A1	-	0.025	0.05
b	0.20	0.25	0.30
c	0.152BSC		
D	1.90	2.00	2.10
D2	0.80	0.90	1.00
e	0.50BSC		
E	1.90	2.00	2.10
E2	1.40	1.50	1.60
L	0.20	0.30	0.40