

24V Input Voltage Battery Linear Charger A< (\$, (Series

General Description

TPI€I is a complete constant-current/constant voltage linear charger for single cell lithium-ion batteries. Furthermore the TPI€I is specifically designed to work within USB power specifications.

No external sense resistor is needed and no blocking diode is required due to the internal PMOSFET architecture. 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 the charge current can be programmed externally with a single resistor. The TPI€I automatically terminates the charge cycle when the charge current drops to 1/10th the programmed value after the final float voltage is reached.

When the input supply (wall adapter or USB supply) is removed the TPI€I automatically enters a low current state dropping the battery drain current to less than 2^µA. The TPI€I can be put into shutdown mode reducing the supply current to 100^µA.

Other features include charge current monitor, undervoltage lockout, automatic recharge and a status.

Typical Application

- Cellular Telephones, PDAs
- Charging Docks and Cradles
- Bluetooth Applications

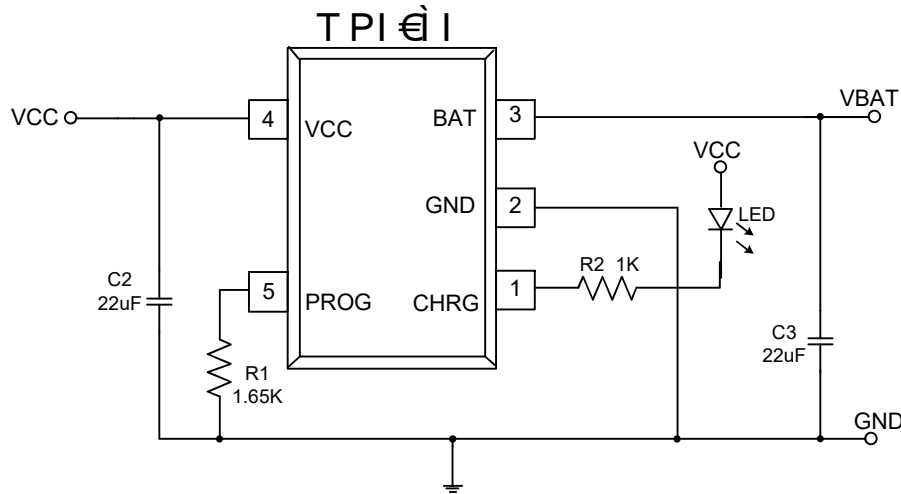
Features

- Maximum operating voltage 24V, improve system reliability
- Programmable charging current up to 600mA (SOT23-5) 1A(ESOP8)
- Protection of battery cell reverse connection
- No MOSFET sense resistor or blocking diode required
- Complete Linear Charger in Thin SOT Package for Single Cell Lithium-Ion Batteries
- Constant-Current/Constant-Voltage operation with thermal regulation to maximize Rate Without risk of overheating.
- Preset 4.2V charge voltage with ±1% accuracy
- Automatic Recharge
- Charges Single Cell Li-Ion Batteries Directly from USB Port
- C/10 charge termination
- 100^µA supply current in shutdown
- 2.9V trickle current charge threshold
- Soft-Start limits inrush current

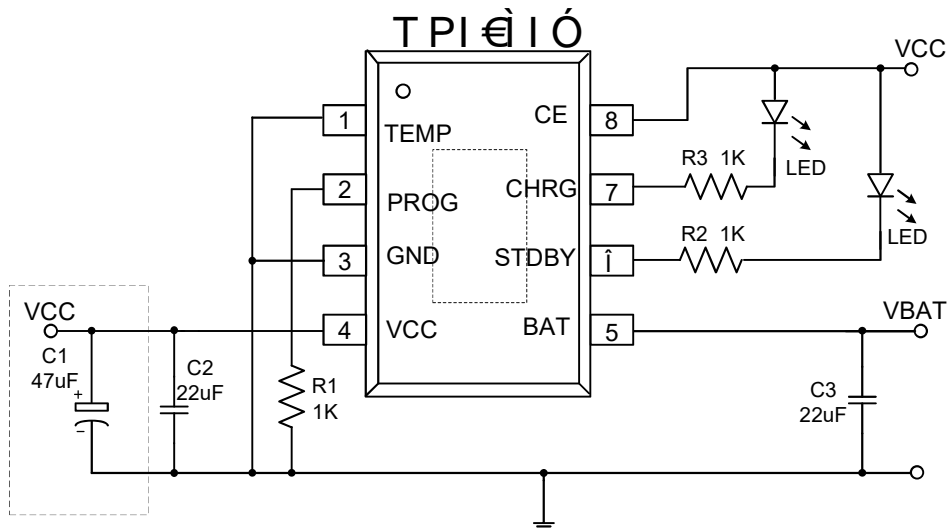
Package

- 5 - pin SOT23-5
- 8 - pin ESOP8

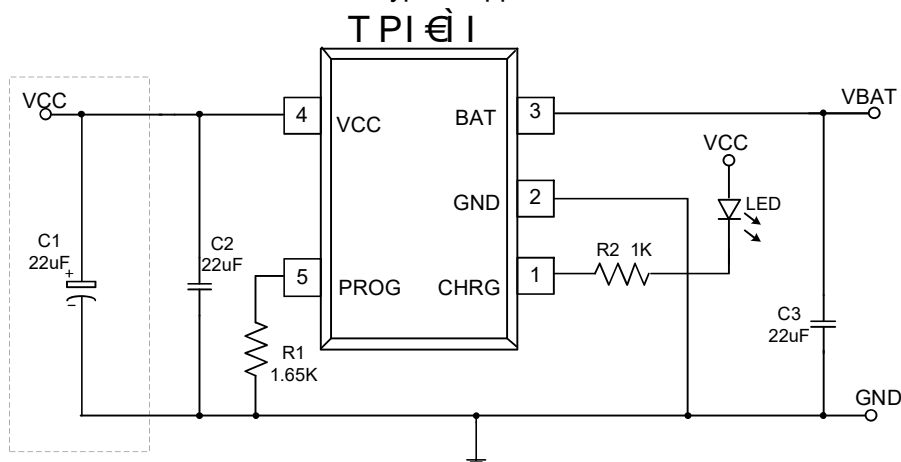
Typical Application circuit



TPI 1 OE Typical application circuit

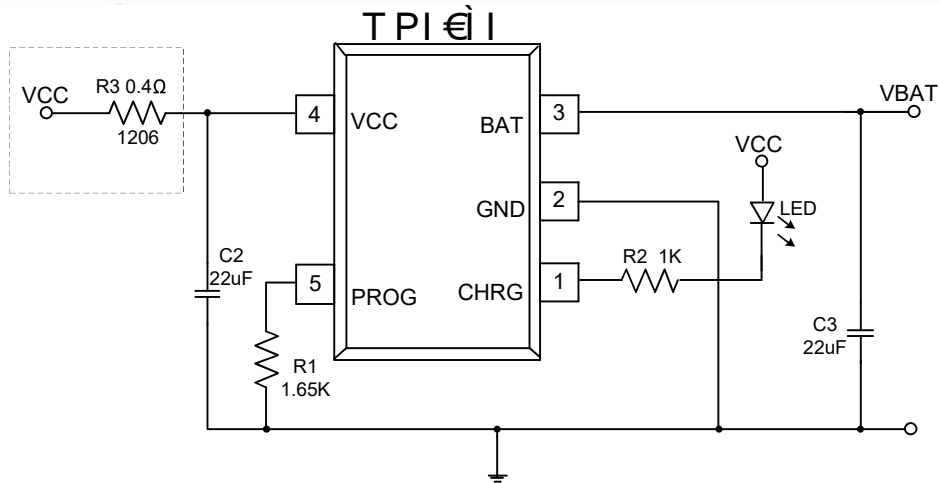


TPI 1 IO Typical application circuit



TPI 1 OE Application circuit of hot swap resistance 1

Note: An electrolytic capacitor of 22uF above the input is required if the input is required to withstand 24V power hot-plug applications.



TPI€I Application circuit of hot swap resistance 2

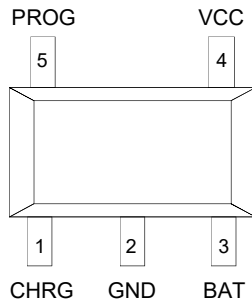
Note: As another application of the input voltage resistance to 24V hot plug, a resistor of 0.4 ohm can be connected in series at the input end, but it should be noted that the package size of the resistor is at least 1206 and above.

Selection Guide

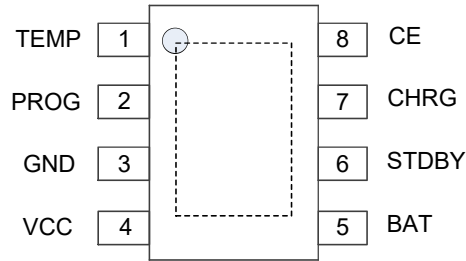
product series	product description
TTTTPI€IÓÁ	$V_{\text{FLOAT}} = 4.2\text{V}$; Package: SOT23-5
TTTTPI€IÓ	$V_{\text{FLOAT}} = 4.2\text{V}$; Package: ESOP8

NOTE: If you need other voltage and package, please contact our sales staff.

Pin Configuration & Pin Assignment



SOT23-5

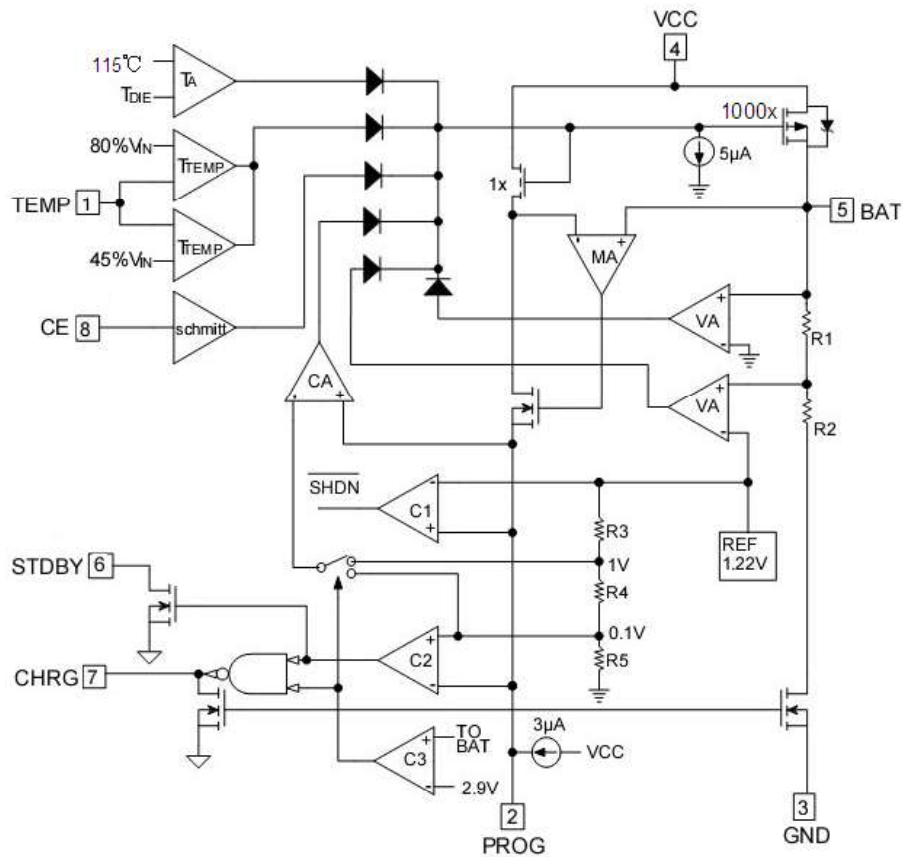


ESOP8

Pin Assignment

Pin Num. (SOT23-5)	Pin Num. (ESOP8)	Symbol	Function
1	7	CHRG	Open-Drain charge status output When the battery is being charged, the CHRG pin is pulled low by an internal switch, otherwise, CHRG pin is in high impedance state.
-	1	TEMP	Temperature sense input Connecting TEMP pin to NTC thermistor's output in Lithium ion battery pack. If TEMP pin's voltage is below 45% or above 80% of supply voltage VCC, this means that battery's temperature is too low or too high, charging is suspended. The temperature sense function can be disabled by grounding the TEMP pin.
2	3	GND	Ground
3	5	BAT	Battery connection Pin Connect the positive terminal of the battery to this pin. BAT pin provides charge current to the battery and provides regulation voltage of 4.2V.
4	4	VCC	Positive input supply voltage Provides power to the internal circuit. When VCC drops to within 70mV of the BAT pin voltage, the TPI € I enters low power sleep mode, dropping IBAT to less than 1µA.
5	2	PROG	Constant Charge Current Setting and Charge Current Monitor Pin The charge current is programmed by connecting a resistor RPROG from this pin to GND.
-	6	STDBY	Charge terminated status output STDBY is pulled low by an internal switch to indicate a battery charge terminated; this means Charge termination. Otherwise STDBY pin is in high impedance state.
-	8	CE	Chip enable input A high input will put the device in the normal operating mode. Pulling the CE pin to low level will put the TPI € I into disable mode. The CE pin can be driven by TTL or CMOS logic level.

Block Diagram



Absolute Maximum Ratings

Parameter	Rating	Unit	
Input supply voltage : V_{CC}	-0.3~24	V	
PROG、TEMP pin voltage	-0.3~6	V	
BAT pin voltage	-0.3~6.5	V	
CHRG、STDBY、CE pin voltage	-0.3~24	V	
BAT pin current	1200	mA	
PROG pin current	1200	μ A	
Junction temperature	-40~150	$^{\circ}$ C	
Operating ambient temperature : T_{opa}	-40~85	$^{\circ}$ C	
Storage temperature : T_{str}	-55~150	$^{\circ}$ C	
Soldering temperature and time	+260 (Recommended 10S)	$^{\circ}$ C	
Package thermal impedance: θ_{JA}	SOT23-5	210	$^{\circ}$ C/W
	ESOP8	63	
Maximum Power Dissipation: P_d	SOT23-5	0.6	W
	ESOP8	1.98	

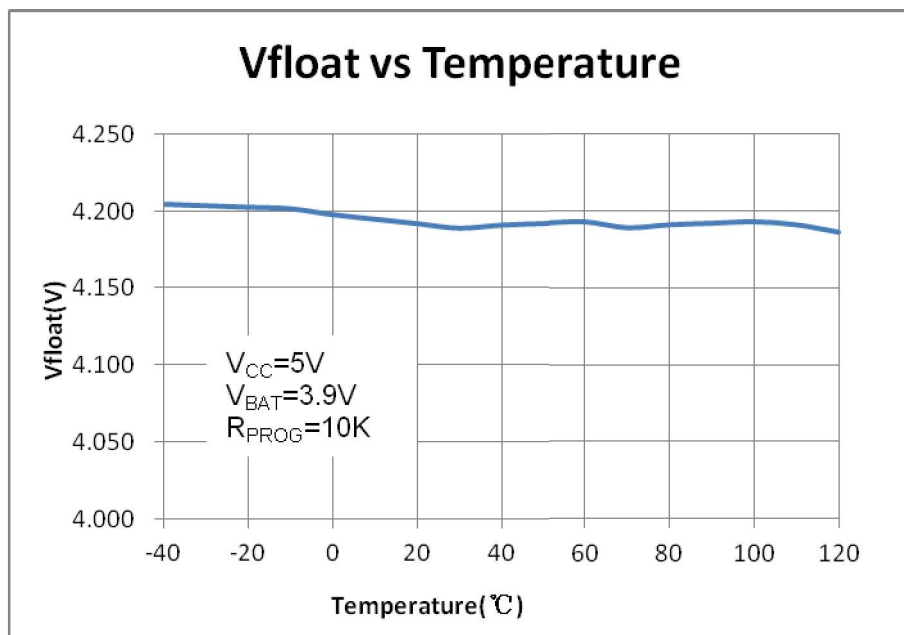
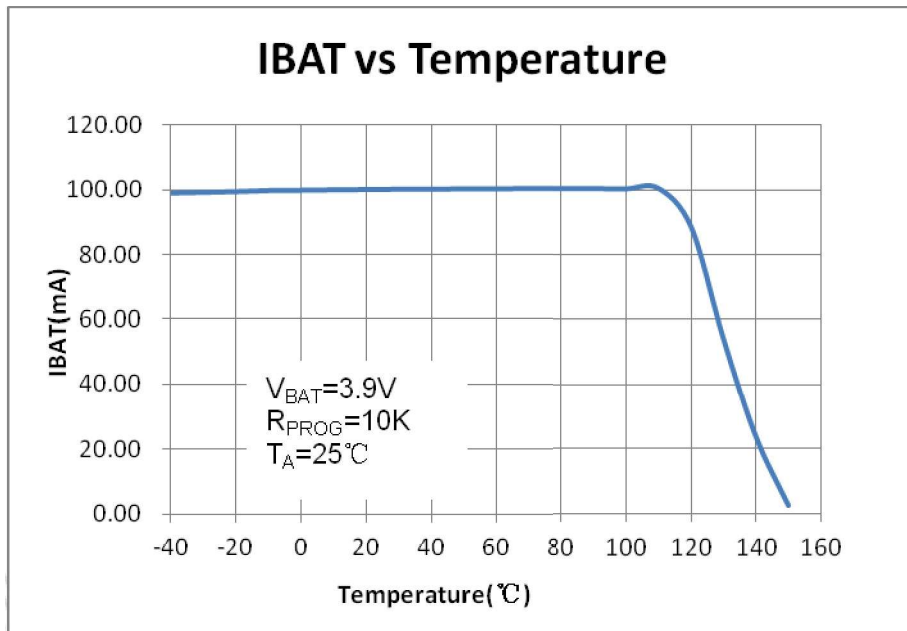
Caution: The absolute maximum ratings are rated values exceeding which the product could suffer physical damage. These values must therefore not be exceeded under any conditions.

Electrical Characteristics

Symbol	Parameter	Condition	Min	Typ.	Max	Unit
V_{CC}	Input supply voltage	•	4.7	5.0	6.5	V
I_{CC}	Input current	• Standby mode(charge end) • Shutdown mode (R_{PROG} not connected, $V_{CC} < V_{BAT}$, or $V_{CC} < V_{UV}$)	-	100	200	μA
V_{FLOAL}	Regulated output voltage	$0^{\circ}C \leq T_A \leq 85^{\circ}C$	4.158	4.20	4.242	V
I_{BAT}	BAT pin current (The condition of current mode is $V_{BAT}=3.9V$)	• $R_{PROG}=1.65K\Omega$, current mode	540	600	660	mA
		• $R_{PROG}=1K\Omega$, current mode	900	1000	1100	mA
		• Standby mode: $V_{BAT}=4.2V$	-	0.1	± 1	μA
		Shutdown mode, R_{PROG} not connected	-	± 1	± 2	μA
		Sleep mode, $V_{CC}=0V$	-	0.1	± 1	μA
I_{TRIKL}	Trickle charge current	• $V_{BAT} < V_{TRIKL}$, $R_{PROG}=1.65K\Omega$	-	60	-	mA
		• $V_{BAT} < V_{TRIKL}$, $R_{PROG}=1K\Omega$	-	100	-	
V_{TRIKL}	Trickle charge threshold voltage	$R_{PROG}=1.65K\Omega$, V_{BAT} rising	2.8	2.9	3.0	V
V_{TRHYS}	Trickle voltage hysteresis voltage	$R_{PROG}=1.65K\Omega$	-	300	-	mV
V_{UV}	V_{CC} under voltage lockout threshold	• V_{CC} from low to high	3.7	3.9	4.1	V
V_{UVHYS}	V_{CC} under voltage lockout hysteresis	•	-	150	-	mV
V_{ASD}	$V_{CC}-V_{BAT}$ lockout threshold voltage	V_{CC} from low to high	-	150	-	mV
		V_{CC} from high to low	-	70	-	
I_{TERM}	termination current threshold	• $R_{PROG}=1.65K\Omega$	-	60	-	mA
		• $R_{PROG}=1K\Omega$	-	100	-	
V_{PROG}	PROG pin voltage	• $R_{PROG}=1.65K\Omega$, current mode	0.9	1.0	1.1	V
V_{CHRG}	CHRG Pin output low voltage	$I_{CHRG}=5mA$	-	0.3	0.6	V
V_{STDBY}	STDBY Pin output low voltage	$I_{STDBY}=5mA$	-	0.3	0.6	V
V_{TEMP-H}	The voltage at TEMP increase		-	80	83	$\%V_{CC}$
V_{TEMP-L}	The voltage at TEMP decrease		42	45	-	$\%V_{CC}$
$t_{RECHARGE}$	Recharge comparator filter time	V_{BAT} from low to high	0.8	1.7	4	mS
t_{TERM}	Termination comparator filter time	I_{BAT} below $I_{CHG}/10$	0.8	1.7	4	mS

Note: The • denotes specifications which apply over the full operating temperature rang, otherwise specifications are at $T_A=25^{\circ}C$, $V_{CC}=5V$, unless otherwise specified.

Typical performance characteristics



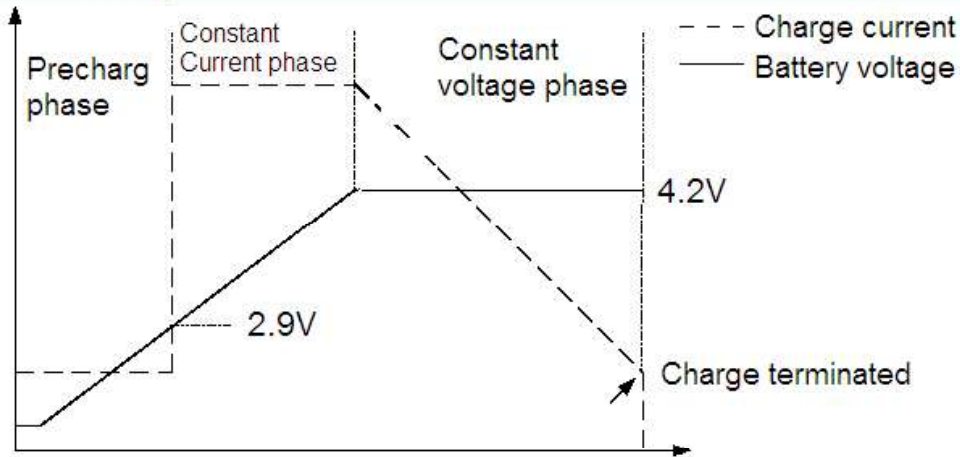
Description of the Principle

The $\mu\text{PI} \epsilon\text{I}$ is a complete constant-current/constant-voltage linear charger for single cell lithium-ion batteries. Constant-current/constant-voltage to charge battery by internal MOSFET. It can deliver up to 600mA of charge current. No blocking diode or external current sense resistor is required. The $\mu\text{PI} \epsilon\text{I}$ include one Open-Drain charge status Pin: Charge status indicator CHRG.

The internal thermal regulation circuit reduces the programmed charge current if the die temperature attempts to rise above a preset value of approximately 115°C. This feature protects the $\mu\text{PI} \epsilon\text{I}$ 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 $\mu\text{PI} \epsilon\text{I}$ 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 V_{CC} pin rises above the UVLO level, a current set resistor is connected from the PROG pin to ground. 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 precharge 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 2.9 V. In constant current mode, the charge current is set by R_{PROG} . When the battery approaches the regulation voltage 4.2V, the charge current begins to decrease as the $\mu\text{PI} \epsilon\text{I}$ 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. 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. 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 2 μA . This greatly reduces the current drain on the battery and increases the standby time.

The charging profile is shown in the following figure:



Charging current setting

The charging current is set using a resistor connected to the PROG pin and the ground. The calculation formula of setting resistor and charging current is as follows:

$$R_{\text{PROG}} = 1000 / I_{\text{BAT}}$$

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_{TEMP} (typically 1.7ms), Charging is terminated. The charge current is latched off and the TPI € I enters standby mode, where the input supply current drops to 100µA (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 1.7mS filter time (t_{TEMP}) 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 TPI € I 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 TPI € I constantly monitors the BAT pin voltage in standby mode. If this voltage drops below the 4.1V recharge threshold (V_{RECHRG}), another charge cycle begins and current is once again supplied to the battery.

Charge status indicator

TPI € I has two open-drain status indicator output CHRG and STDBY. CHRG is pull-down when the TPI € I 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

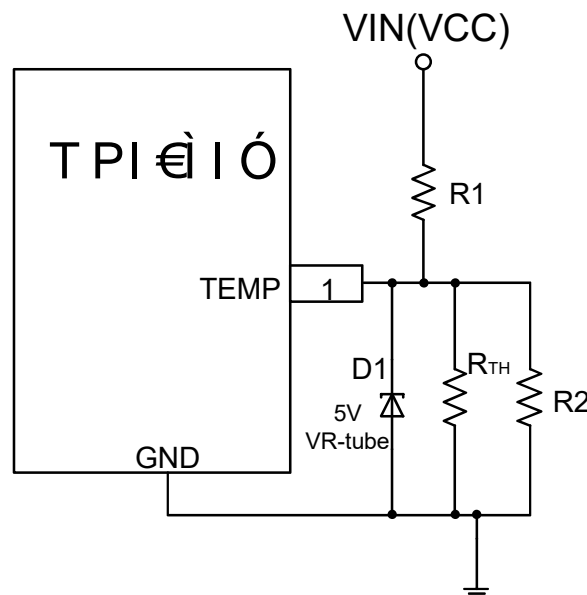
green LED all don't light. The battery temperature sense function is disabled by connecting TEMP pin to GND. If battery is not connected to charger, CHRГ pin outputs a PWM level to indicate no battery. If BAT pin connects a 10 μ F capacitor, the frequency of CHRГ flicker about 1-4S, If not use status indicator should set status indicator output connected to GND.

charger's status	Red led CHRГ	Green led STDBY
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 10 μ F capacitor, No battery mode (TEMP=GND)	Green LED bright, Red LED flicker F=1-4 S (At this time, reverse-battery, the light does not shine, this phenomenon is normal. Such a case, after the battery is properly connected to the indicator light back to light and flicker.)	

Thermal limiting

An internal thermal feedback loop reduces the programmed charge current if the die temperature attempts to rise above a preset value of approximately 115 $^{\circ}$ C . The feature protects the TPI ϵ I 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 TPI ϵ I . The charge current can be set according to typical (not worst-case) ambient temperature with the assurance that the charger will automatically reduce the current in worst-case conditions.

Selecting R1 and R2



The values of R1 and R2 in the application circuit can be determined according to the assumed temperature monitor range and thermistor's values. The Follows is an example: Assume temperature monitor range is $T_L \sim T_H$, ($T_L < T_H$); the thermistor in battery has negative temperature coefficient (NTC, R_{TL} is thermistor's resistance at

TL, RTH is the resistance at TH, so $R_{TL} > R_{TH}$, then at temperature TL, the voltage at TEMP pin is:

$$V_{TEMPH} = \frac{R2 // R_{TH}}{R1 + R2 // R_{TH}} \times V_{IN}$$

At temperature TH, the voltage at TEMP pin is:

$$V_{TEMPL} = \frac{R2 // R_{TL}}{R1 + R2 // R_{TL}} \times V_{IN}$$

We know $V_{TEMPL} = V_{HIGH} = K2 \times V_{CC}$ ($K2=0.8$); $V_{TEMPH} = V_{LOW} = K1 \times V_{CC}$ ($K1=0.45$) Then we can have:

$$R1 = \frac{R_{TL} \times R_{TH} (K2 - K1)}{(R_{TL} - R_{TH}) K1 \times K2} \quad R2 = \frac{R_{TL} \times R_{TH} (K2 - K1)}{R_{TL} (K1 - K1 \times K2) - R_{TH} (K2 - K1 \times K2)}$$

For example, NCP03YS110, operating Temperature is -40°C to 125°C . If using environment temperature is -25°C to 125°C , then R_{TL} is the value of the resistance of NCP03YS110 at -25°C , about 66.148Ω ; R_{TH} is the value of the resistance of NCP03YS110 at 125°C , about 1.077Ω .

Likewise, for positive temperature coefficient thermistor in battery, we have $R_{TH} > R_{TL}$ and we can calculate:

$$R1 = \frac{R_{TL} \times R_{TH} (K2 - K1)}{(R_{TH} - R_{TL}) K1 \times K2} \quad R2 = \frac{R_{TL} \times R_{TH} (K2 - K1)}{R_{TH} (K1 - K1 \times K2) - R_{TL} (K2 - K1 \times K2)}$$

We can conclude that temperature monitor range is independent of power supply voltage VCC and it only depends on R1, R2, R_{TL} and R_{TH} : The values of R_{TH} and R_{TL} can be found in related battery handbook or deduced from testing data. In actual application, if only one terminal temperature is concerned (normally protecting overheating), there is no need to use R2 but R1. It becomes very simple to calculate R1 in this case.

It should be noted that when applying TEMP pin, a 5V stabilizer tube should be added to GND in TEMP to prevent damage of this pin when VCC is of high voltage. TEMP can be directly connected to GND without battery temperature detection.

Under Voltage lockout (UVLO)

An internal under voltage lockout circuit monitors the input voltage and keeps the charger in shutdown mode until VCC rises above the under voltage lockout threshold. If the UVLO comparator is tripped, the charger will not come out of shutdown mode until VCC rises 100mV above the battery voltage.

Auto restart

Once charge is terminated, TPI immediately use a 1.7ms filter time ($t_{RECHARGE}$) on the termination comparator to constant monitor the voltage on BAT pin. If this voltage drops below the 4.1V recharge threshold (about between 80% and 90% of V_{CC}), another charge cycle begins. This ensured the battery maintained (or approach) to a charge full status and avoid the requirement of restarting the periodic charging cycle. In the recharge cycle, CHRG pin enters a pulled down status.

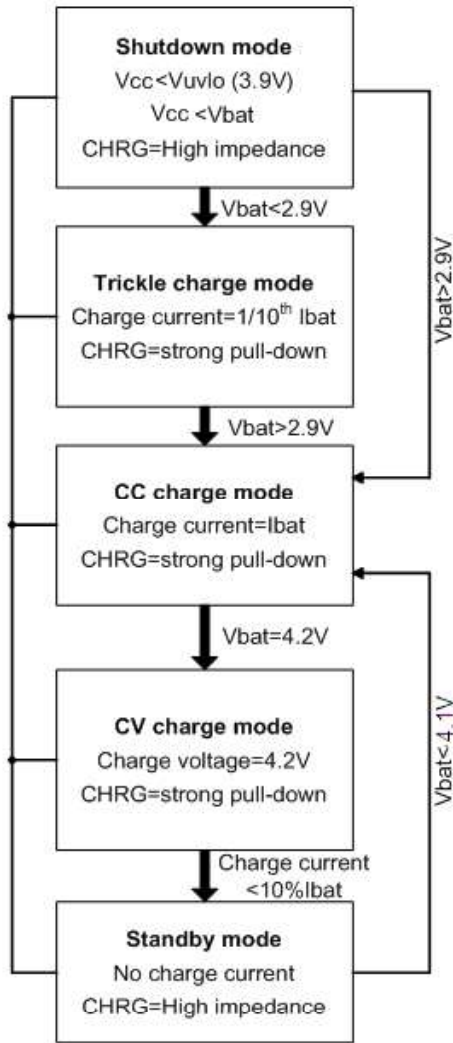


Fig.1 State diagram of a typical charge cycle

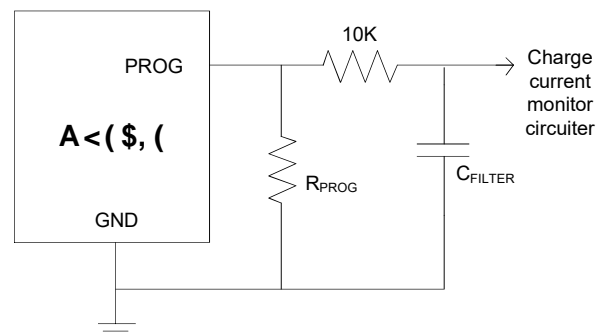


Fig.2 Isolating with capacitive load on PROG Pin

Stability Considerations

In constant-current mode, the PROG pin is in the feedback loop, not the battery. The constant-current mode stability is affected by the impedance at the PROG pin. When the PROG pin has no additional capacitance it reduces the maximum allowable resistance of the set resistor. The pole frequency on the PROG pin should be maintained at C_{prog} , the following equation should be used to calculate the maximum resistance value for R_{PROG} :

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

As user, may think charge current is important, not instantaneous current. For example, to run a low current mode switch power which parallel connected with battery, the average current from BAT pin usually importance to instantaneous current. In this case, In order to measure average charge current or isolate capacitive load from I_{PROG} pin, a simple RC filter can be used on PROG pin as shown in Figure 2. In order to ensure the stability add a 10KΩ resistor between PROG pin and filter capacitor.

Power dissipation

The conditions that cause the TPI € 4 to reduce charge current through thermal feedback can be approximated by considering the power dissipated in the IC. Nearly all of this power dissipation is generated by the internal MOSFET-this is calculated to be approximately:

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

The approximate ambient temperature at which the thermal feedback begins to protect the IC is:

$$T_A = 115^\circ\text{C} - P_D \theta_{JA}; \quad T_A = 115^\circ\text{C} - (V_{CC} - V_{BAT}) \times I_{BAT} \times \theta_{JA}$$

In a fixed ambient temperature, the charge current is calculated to be approximately :

$$I_{BAT} = \frac{115^\circ\text{C} - T_A}{(V_{CC} - V_{BAT}) \cdot \theta_{JA}}$$

Just as Description of the Principle part talks about so, the current on PROG pin will reduce in proportion to the reduced charge current through thermal feedback. In TPI € I design applications don't need to considerate the worst case of thermal condition, this point is importance, because if the junction temperature up to 115°C ,IC will auto reduce the power dissipation.

Thermal considerations

Because of the small size of the thin SOT23-5 package, it is important to use a good thermal PC board layout to maximize the available charge current. The thermal path for the heat generated by the IC is from the die to the copper lead frame, through the package leads, (especially the ground lead) to the PC board copper. The PC board copper is the heat sink. The footprint copper pads should be as wide as possible and expand out to larger copper areas to spread and dissipate the heat to the surrounding ambient. Other heat sources on the board, not related to the charger, must also be considered when designing a PC board layout because they will affect overall temperature rise and the maximum charge current.

VCC bypass capacitor

Many types of capacitors can be used for input bypassing, however, caution must be exercised when using multilayer ceramic capacitors. Because of the self-resonant and high Q characteristics of some types of ceramic capacitors, high voltage transients can be generated under some start-up conditions, such as connecting the charger input to a live power source. Adding a 1.5Ω resistor in series with a ceramic capacitor will minimize start-up voltage transients.

Charging Current Soft Start

TPI € I includes a soft start circuit which used to maximize to reduce the surge current in the begging of charge cycle. When restart a new charge cycle, the charging current ramps up from 0 to the full charging current

within 20 μ s. In the start process it can maximize to reduce the action which caused by surge current load.

USB and Wall Adapter Power

TPI€I allows charging from a USB port, a wall adapter can also be used to charge Li-Ion/Li-polymer batteries. Figure 5 shows an example of how to combine wall adapter and USB power inputs. AP-channel MOSFET, M1, is used to prevent back conducting into the USB port when a wall adapter is present and Schottky diode, D1, is used to prevent USB power loss through the 1K Ω pull-down resistor.

Generally, AC adaptor is able to provide bigger much current than the value of specific current limiting which is 500mA for USB port. So can rise charge current to 600mA with using a N-MOSFET (MN1) and an additional set resistor value as high as 10K Ω .

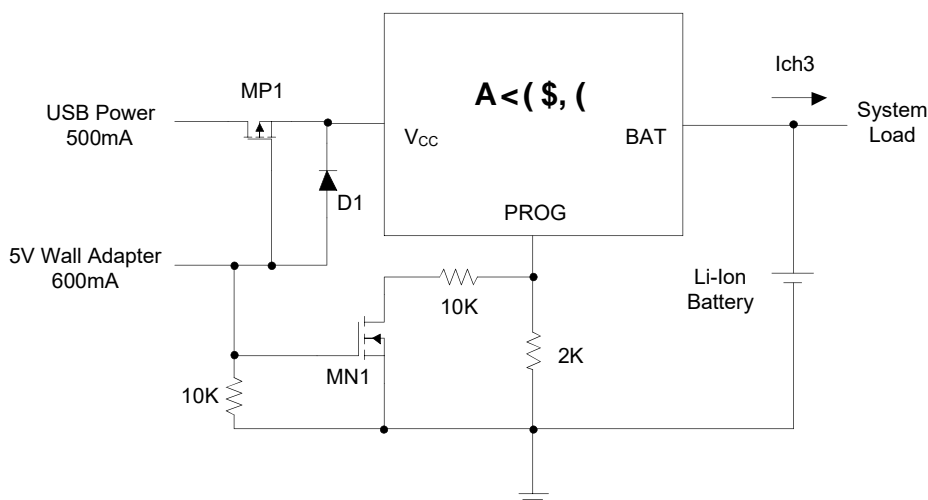


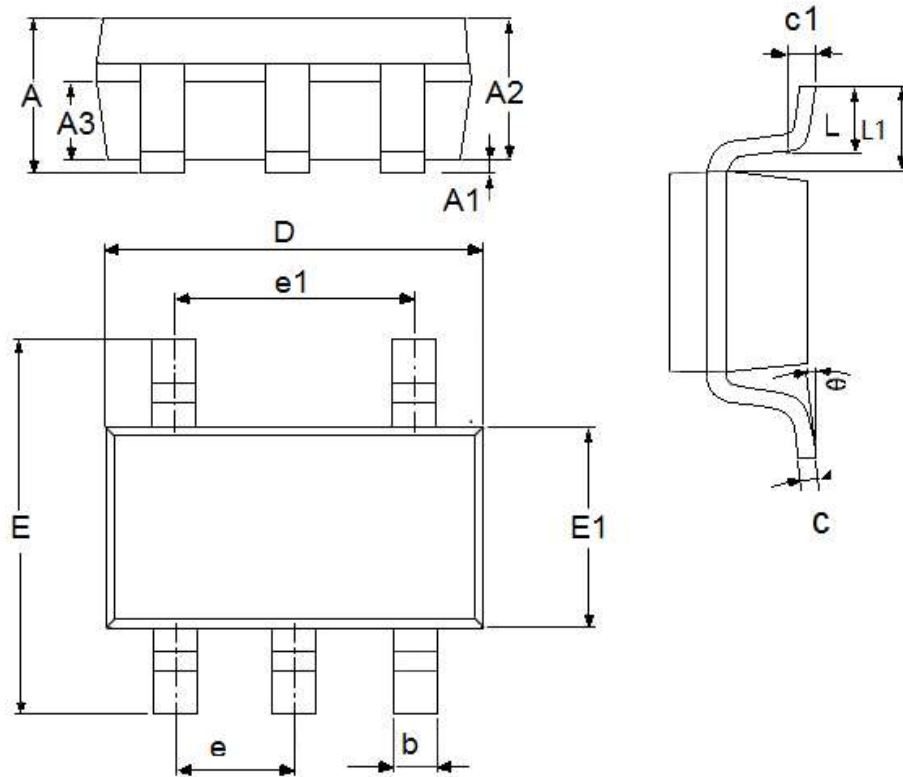
Fig.5: Combining Wall Adapter and USB Power

Board Layout Considerations

- R_{PROG} at PROG pin should be as close to TPI€I as possible, also the parasitic capacitance at PROG pin should be kept as small as possible.
- The capacitance at VCC pin and BAT pin should be as close to TPI€I as possible.
- It is very important to use a good thermal PC board layout to maximize charging current. The thermal path for the heat generated by the IC is from the die to the copper lead frame through the package lead (especially the ground lead) to the PC board copper, the PC board copper is the heat sink. The footprint copper pads should be as wide as possible and expand out to larger copper areas to spread and dissipate the heat to the surrounding ambient. Feed through vias to inner or backside copper layers are also useful in improving the overall thermal performance of the charger. Other heat sources on the board, not related to the charger, must also be considered when designing a PC board layout because they will affect overall temperature rise and the maximum charge current.

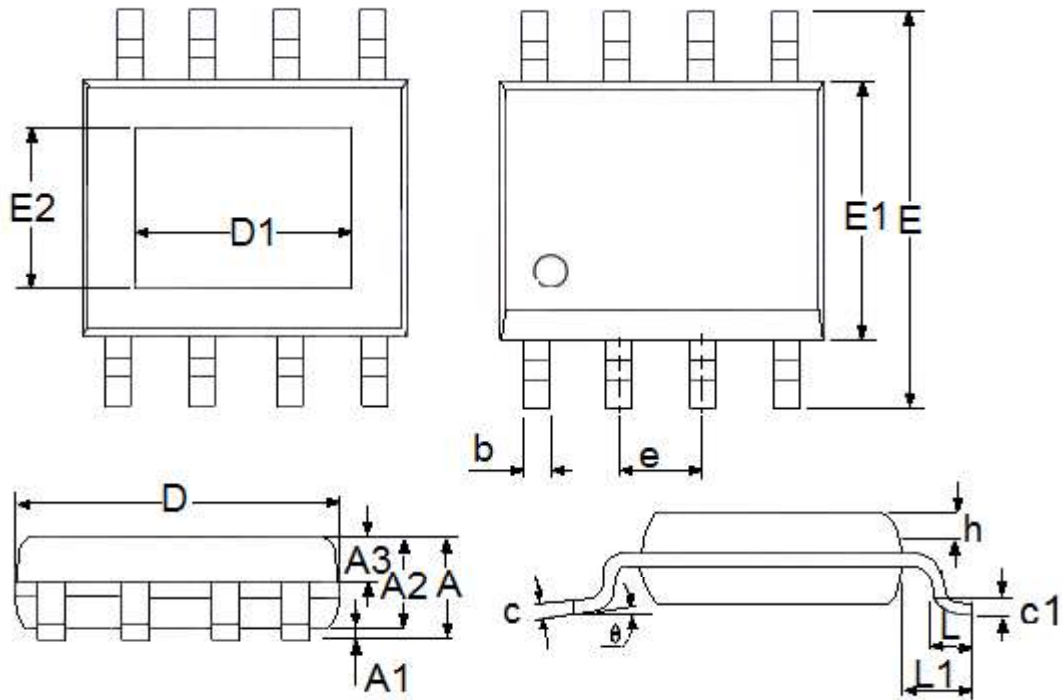
Package Information

- Package Type: SOT23-5



DIM	Millimeters		Inches	
	Min	Max	Min	Max
A	1.05	1.45	0.0413	0.0571
A1	0	0.15	0.0000	0.0059
A2	0.9	1.3	0.0354	0.0512
A3	0.6	0.7	0.0236	0.0276
b	0.25	0.5	0.0098	0.0197
c	0.1	0.23	0.0039	0.0091
D	2.82	3.05	0.1110	0.1201
e1	1.9(TYP)		0.0748(TYP)	
E	2.6	3.05	0.1024	0.1201
E1	1.5	1.75	0.0512	0.0689
e	0.95(TYP)		0.0374(TYP)	
L	0.3	0.6	0.0118	0.0236
L1	0.59(TYP)		0.0232(TYP)	
θ	0	8°	0.0000	8°
c1	0.2(TYP)		0.0079(TYP)	

● Package Type: ESOP8



DIM	Millimeters		Inches	
	Min	Max	Min	Max
A	1.3	1.75	0.0512	0.0689
A1	0	0.2	0.0000	0.0079
A2	1.25	1.65	0.0492	0.0650
A3	0.5	0.7	0.0197	0.0276
b	0.33	0.51	0.0130	0.0201
c	0.17	0.25	0.0067	0.0098
D	4.7	5.1	0.1850	0.2008
E	5.8	6.2	0.2283	0.2441
E1	3.8	4	0.1496	0.1575
e	1.27(TYP)		0.05(TYP)	
h	0.25	0.5	0.0098	0.0197
L	0.4	1.27	0.0157	0.0500
L1	1.04(TYP)		0.0409(TYP)	
θ	0	8°	0.0000	8°
c1	0.25(TYP)		0.0098(TYP)	
D1	3.1(TYP)		0.122(TYP)	
E2	2.21(TYP)		0.087(TYP)	