

Fully Integrated Linear Single Cell Li-Ion Battery Charger with Power Path

General Description

The RT9503 is a fully integrated low cost single-cell Li-Ion battery charger IC ideal for portable applications. The RT9503 is capable of being powered up from AC adapter and the USB (Universal Serial Bus) port inputs. The RT9503 can automatically detect and select the AC adapter and the USB port as the power source for the charger. The RT9503 enters sleep mode when both supplies are removed.

The RT9503 optimizes the charging task by using a control algorithm including preconditioning mode, fast charge mode and constant voltage mode. The charging task is terminated as the charge current drops below the preset threshold. The USB charge current can be selected from preset ratings 100mA and 500mA, while the AC adapter charge current can be programmed up to 1A with an external resistor. The internal thermal feedback circuitry regulates the die temperature to optimize the charge rate for all ambient temperatures.

The RT9503 features 18V and 7V maximum rating voltages for AC adapter and USB port inputs respectively. The other features are external programmed safety timer, under voltage protection, over voltage protection for AC adapter supply, battery temperature monitoring, power supply status indicators and charge status indicator.

Ordering Information

RT9503 □ □

- Package Type
QW : WQFN-16L 3x3 (W-Type)
- Lead Plating System
P : Pb Free
G : Green (Halogen Free and Pb Free)

Note :

Richtek products are :

- ▶ RoHS compliant and compatible with the current requirements of IPC/JEDEC J-STD-020.
- ▶ Suitable for use in SnPb or Pb-free soldering processes.

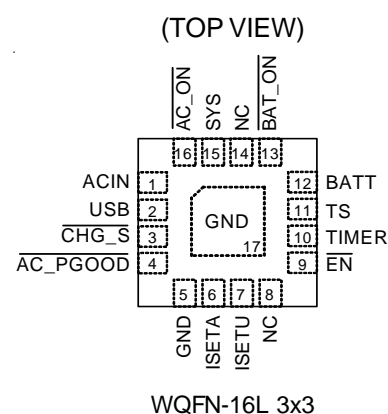
Features

- Automatic Input Supplies Selection
- 18V Maximum Rating for AC Adapter
- Integrated Selectable 100mA and 500mA USB Charge Current
- Internal Integrated Power FETs
- AC Adapter Power Good Status Indicator
- Charge Status Indicator
- External Capacitor Programmable Safety Timer
- Under Voltage Protection
- Over Voltage Protection
- Automatic Recharge Feature
- Battery Temperature Monitoring
- Small 16-Lead WQFN Package
- Thermal Feedback Optimizing Charge Rate
- Power Path Controller
- RoHS Compliant and 100% Lead (Pb)-Free

Applications

- Digital Cameras
- Cellular Phones
- PDAs and Smart Phones and MP3
- Portable Instruments

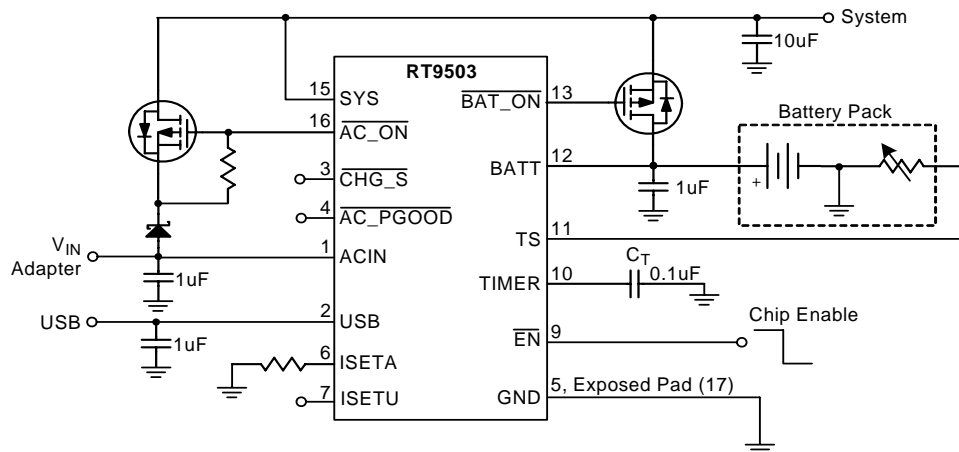
Pin Configurations



Marking Information

For marking information, contact our sales representative directly or through a Richtek distributor located in your area.

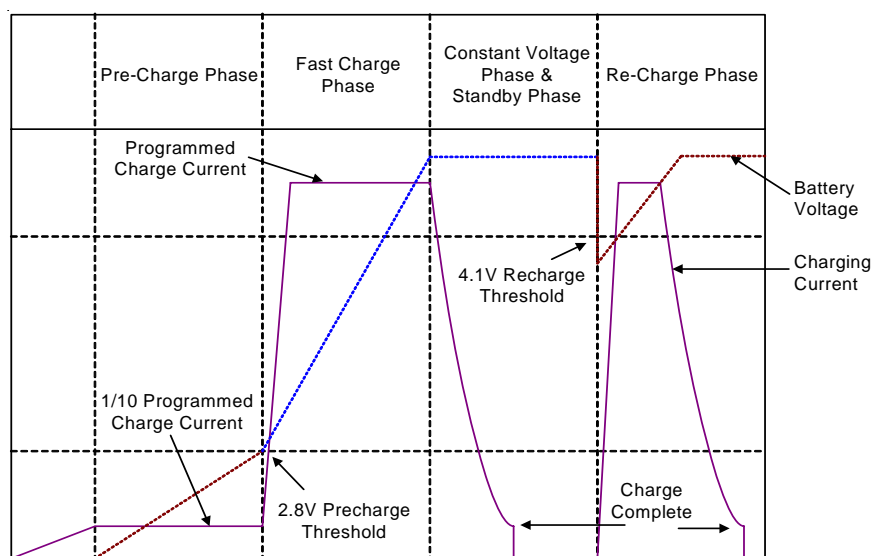
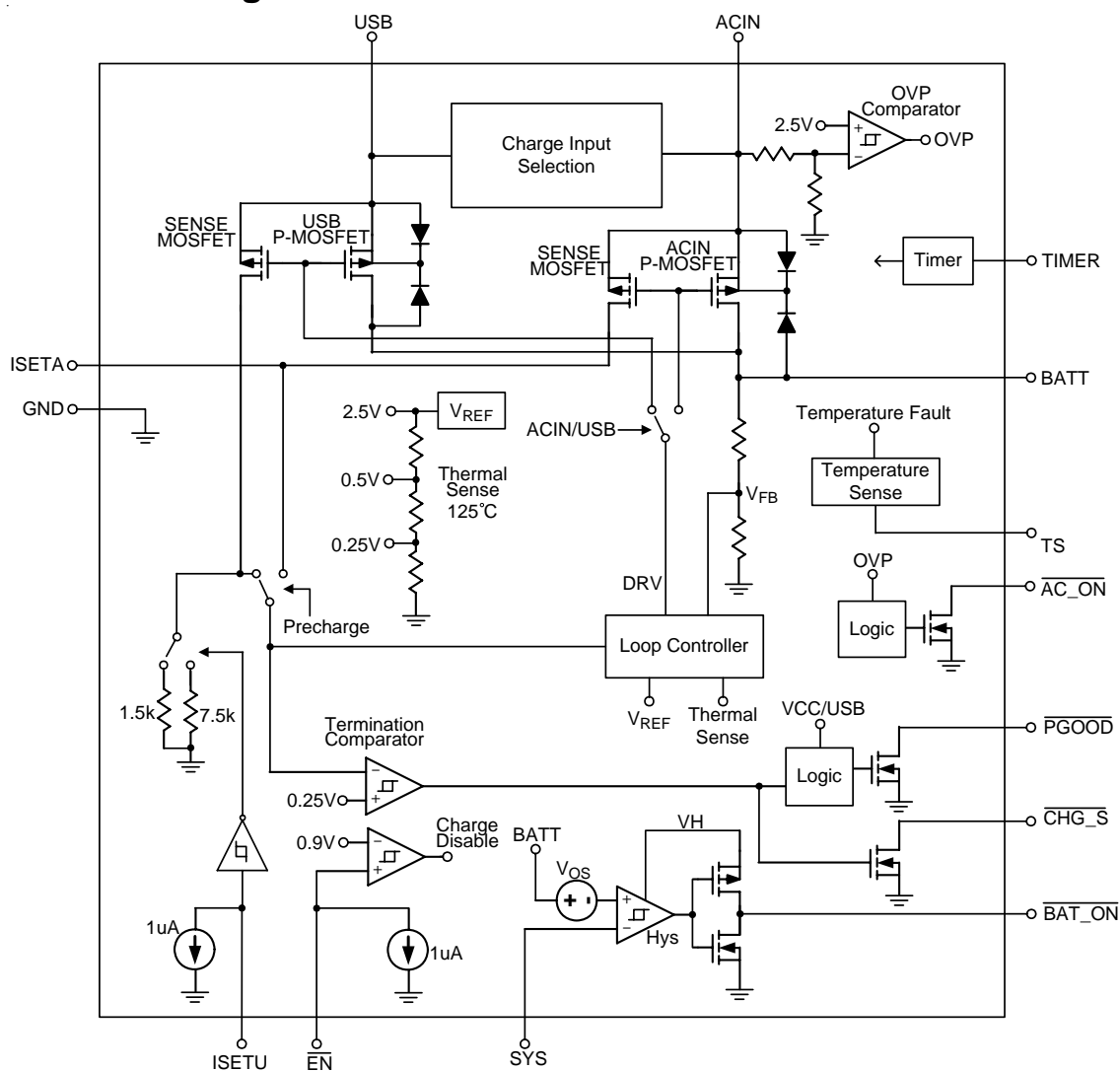
Typical Application Circuit



Functional Pin Description

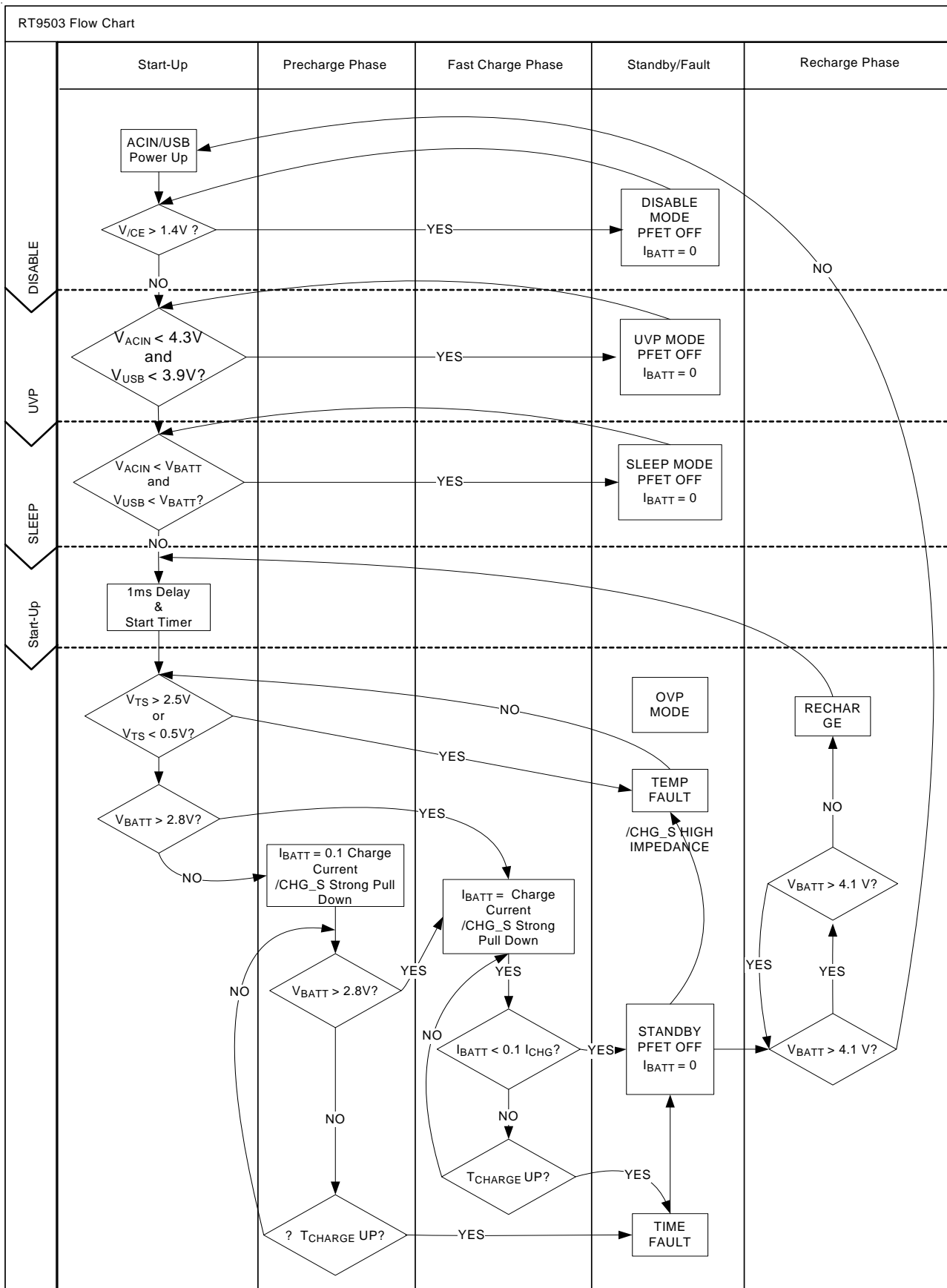
Pin No.	Pin Name	Pin Function
1	ACIN	Wall Adaptor Charge Input Supply.
2	USB	USB Charge Input Supply.
3	$\overline{\text{CHG_S}}$	Charge Status Indicator Output (open drain).
4	$\overline{\text{AC_PGOOD}}$	Wall Adaptor Power Good Indicator Output (open drain).
5	GND	Ground.
6	ISETA	Wall Adaptor Supply Charge Current Set Point.
7	ISETU	USB Supply Charge Current Set Input (active low).
8, 14	NC	No Internal Connection.
9	$\overline{\text{EN}}$	Charge Enable (Active Low).
10	TIMER	Safe Charge Timer Setting.
11	TS	Temperature Sense Input.
12	BATT	Battery Charge Current Output.
13	$\overline{\text{BAT_ON}}$	Power path controller output, low to turn on the external P-MOSFET.
15	SYS	System Voltage Detecting Pin.
16	$\overline{\text{AC_ON}}$	P-MOSFET Switch Control Output (open drain).
17 (Exposed Pad)	GND	The exposed pad must be soldered to a large PCB and connected to GND for maximum power dissipation.

Function Block Diagram



Charging I-V Curve

RT9503 Flow Chart



Absolute Maximum Ratings (Note 1)

• Supply Input Voltage, ACIN	-----	-0.3V to 18V
• Supply Input Voltage, USB	-----	-0.3V to 7V
• CHG_SB, AC_PGOOD, AC_ON	-----	-0.3V to 18V
• Other Pins	-----	-0.3V to 5.5V
• Power Dissipation, P _D @ T _A = 25°C		
WQFN-16L 3x3	-----	1.667W
• Package Thermal Resistance (Note 2)		
WQFN-16L 3x3, θ_{JA}	-----	60°C/W
WQFN-16L 3x3, θ_{JC}	-----	8.2°C/W
• Lead Temperature (Soldering, 10 sec.)	-----	260°C
• Junction Temperature	-----	150°C
• Storage Temperature Range	-----	-65°C to 150°C
• ESD Susceptibility (Note 3)		
HBM (Human Body Mode)	-----	2kV
MM (Machine Mode)	-----	200V

Recommended Operating Conditions (Note 4)

• Supply Input Voltage Range, ACIN	-----	4.5V to 12V
• Supply Input Voltage Range, USB	-----	4.1V to 6V
• Junction Temperature Range	-----	-20°C to 125°C
• Ambient Temperature Range	-----	-20°C to 85°C

Electrical Characteristics

(ACIN = USB = 5V, T_A = 25°C, unless otherwise specification)

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
Supply Input						
ACIN UVP Rising Threshold Voltage	V _{UV_ACIN}		4.1	4.3	4.5	V
USB UVP Rising Threshold Voltage	V _{UV_USB}	V _{BATT} = 3V	3.7	3.9	4.1	V
ACIN/USB UVP Hysteresis	V _{UV_HYS}	V _{BATT} = 3V	40	100	140	mV
ACIN/USB Standby Current	I _{STBY}	V _{BATT} = 4.5V	--	300	500	μA
ACIN/USB Shutdown Current	I _{SHDN}	V _{EN} = High	--	50	100	μA
BATT Sleep Leakage Current	I _{SLEEP}	V _{ACIN} = 4V, V _{USB} = 4V, V _{BATT} = 4.5V	--	5	15	μA
Voltage Regulation						
BATT Regulation Voltage	V _{REG}	I _{BATT} = 60mA	4.158	4.2	4.242	V
ACIN MOSFET Dropout		V _{BATT} = 4V, I _{CHG} = 1A	400	500	620	mV
ACIN MOSFET Dropout		V _{BATT} = 4V, I _{USB} = High	500	650	800	mV
Current Regulation						
ISETA Set Voltage (Fast Charge Phase)	V _{ISETA_FCHG}	V _{BATT} = 3.5V	2.43	2.48	2.53	V
Full Charge Setting Range	I _{CHG_AC}		100	--	1000	mA
AC Charge Current Accuracy	I _{CHG_AC}	V _{BATT} = 3.8V, R _{ISSET} = 1.5kΩ	--	500	--	mA

To be continued

Parameter		Symbol	Test Conditions	Min	Typ	Max	Units
Precharge							
BATT Pre-charge Threshold		V _{PRECH}		2.7	2.8	2.9	V
BATT Pre-charge Threshold Hysteresis		ΔV _{PRECH}		60	100	140	mV
Pre-Charge Current		I _{PCHG}	V _{BATT} = 2V	8	10	12	%
Recharge Threshold							
BATT Re-charge Falling Threshold Hysteresis		ΔV _{RECH_L}		50	95	140	mV
Charge Termination Detection							
Termination Current Ratio (Note5)		I _{TERM}	V _{BATT} = 4.2V	--	10	--	%
Logic Input/Output							
CHG_S Pull Down Voltage		V _{CHG_S}	I _{CHG_S} = 5mA	--	213	--	mV
AC_PGGOOD Pull Down Voltage		V _{PGOOD}	I _{PGOOD} = 5mA	--	213	--	mV
PGOOD Pull Down Voltage		V _{PGOOD}	TBD; I _{PGOOD} = 5mA	--	65	--	mV
EN Threshold	Logic-High Voltage	V _{IH}		1.5	--	--	V
	Logic-Low Voltage	V _{IL}		--	--	0.4	V
EN Pin Input Current		I _{EN}		--	--	1.5	uA
ISETU Threshold	High Voltage	V _{ISETU_HIGH}		1.5	--		V
	Low Voltage	V _{ISETU_LOW}		--	--	0.4	V
ISETU Pin Input Current		I _{ISETU}		--	--	1.5	uA
USB Charge Current & Timing							
Soft-Start Time		T _{SS}	V _{ISETA} from 0V to 2.5V	--	100	--	us
USB Charge Current		I _{CHG_USB}	V _{ACIN} = 3.5V, V _{USB} = 5V, V _{BATT} = 3.5V, I _{SETU} = 5V	400	450	500	mA
USB Charge Current		I _{CHG_USB}	V _{ACIN} = 3.5V, V _{USB} = 5V, V _{BATT} = 3.5V, I _{SETU} = 0V	60	80	100	mA
Timer							
TIME Pin Source Current		I _{TIME}	V _{TIMER} = 2V	--	1	--	uA
Pre-charge Fault Time		T _{PCHG_F}	C _{TIMER} = 0.1uF, f _{CLK} = 7Hz	1720	2460	3200	s
Charge Fault Time		T _{FCHG_F}	C _{TIMER} = 0.1uF, f _{CLK} = 7Hz	13790	19700	25610	s
Battery Temperature Sense							
TS Pin Source Current		I _{TS}	V _{TS} = 1.5V	96	102	108	uA
TS Pin Threshold	High Voltage	V _{TS_HIGH}		0.485	0.5	0.515	V
	Low Voltage	V _{TS_LOW}		2.45	2.5	2.55	V
Protection							
Thermal Regulation				--	125	--	°C
OVP SET Voltage			Internal Default	--	6.5	--	V
Power Path Controller							
BAT_ON Pull Low			As SYS Falling, V _{BATT} = 4V, SYS-BAT	-150	--	-20	mV

To be continued

Parameter	Symbol	Test Conditions	Min	Typ	Max	Units
BAT_ON Pull High		As SYS Raising, V _{BATT} = 4V, SYS-BAT	-50	--	0	mV
BAT_ON Pull Low Switch Resistance		V _{BAT} = 4V	--	10	--	Ω
BAT_ON Pull High Switch Resistance		V _{ACIN} = 5V	--	30	--	Ω

Note 1. Stresses listed as the above “Absolute Maximum Ratings” may cause permanent damage to the device. These are for stress ratings. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may remain possibility to affect device reliability.

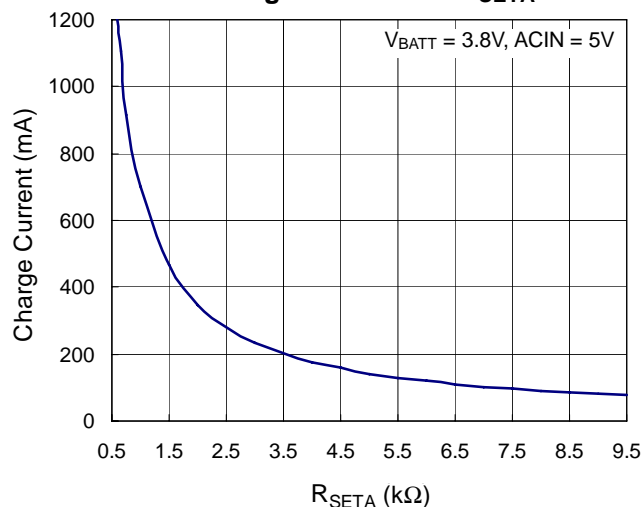
Note 2. θ_{JA} is measured in the natural convection at $T_A = 25^\circ\text{C}$ on a high effective four layers thermal conductivity test board of JEDEC 51-7 thermal measurement standard. The case point of θ_{JC} is on the expose pad for the package.

Note 3. Devices are ESD sensitive. Handling precaution is recommended.

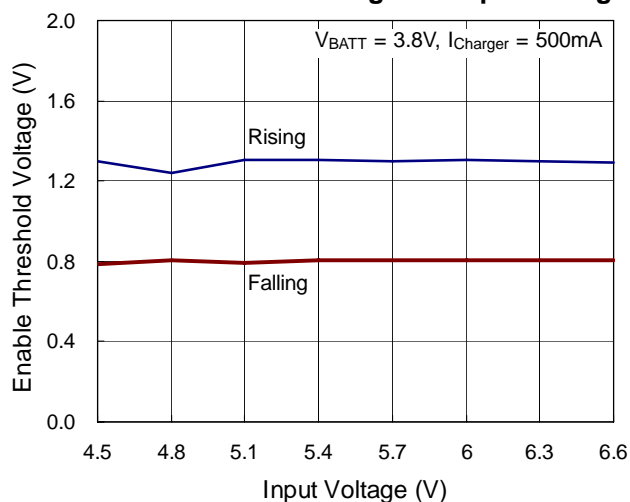
Note 4. The device is not guaranteed to function outside its operating conditions.

Note 5. Guaranteed by design.

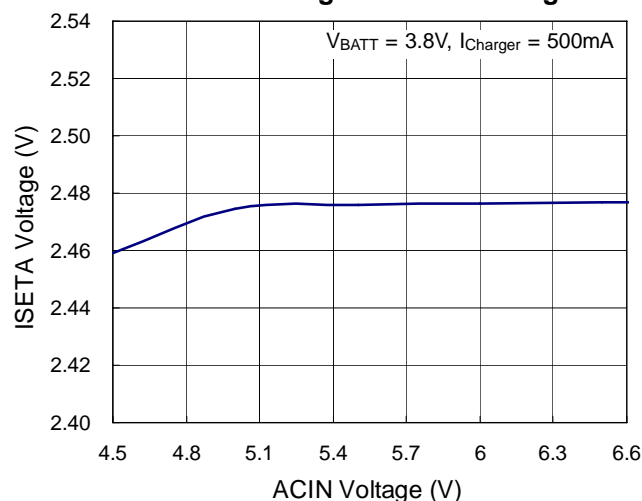
Typical Operating Characteristics

Charge Current vs. R_{SETA} 

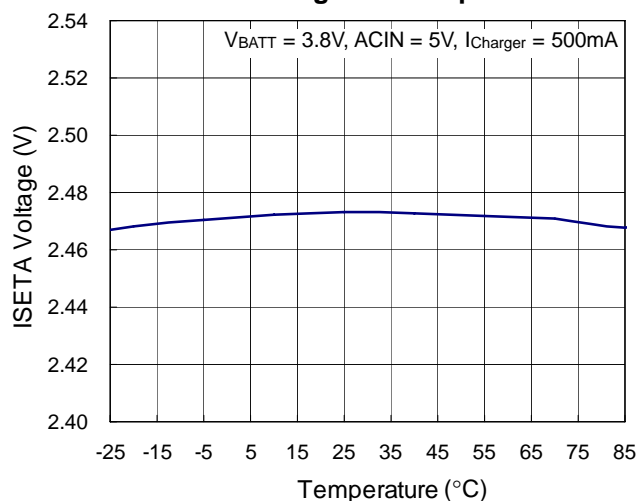
Enable Threshold Voltage vs. Input Voltage



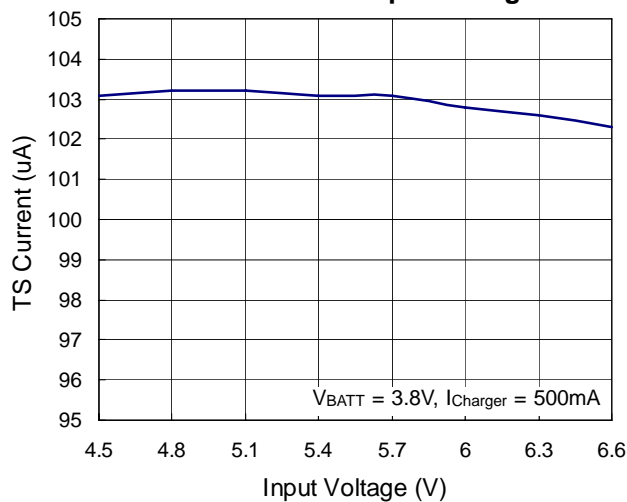
ISETA Voltage vs. ACIN Voltage



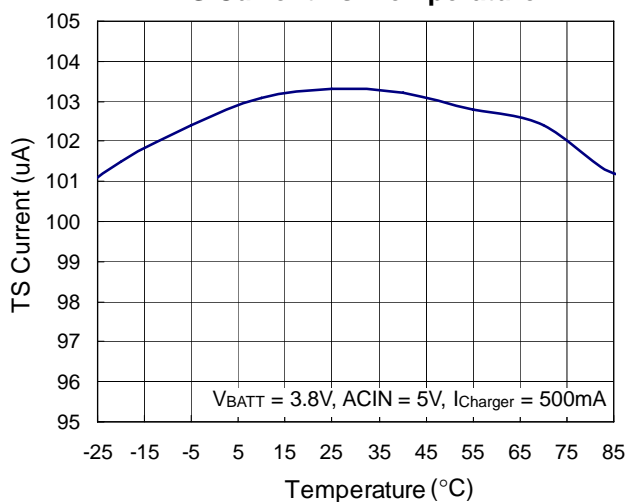
ISETA Voltage vs. Temperature



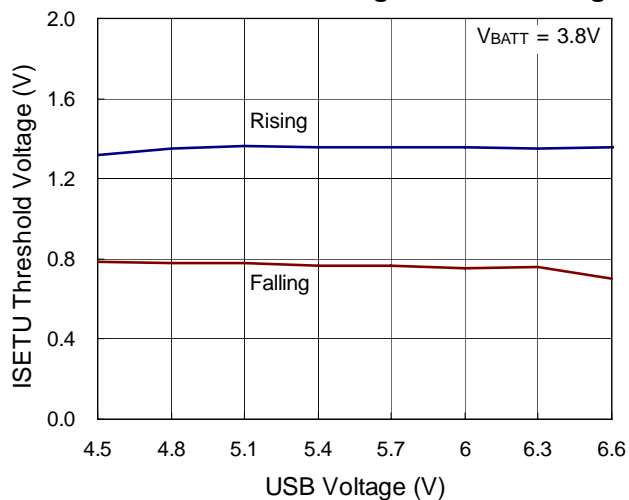
TS Current vs. Input Voltage



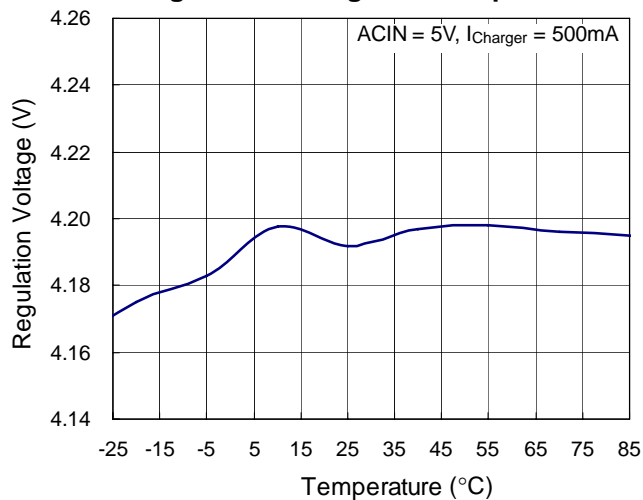
TS Current vs. Temperature



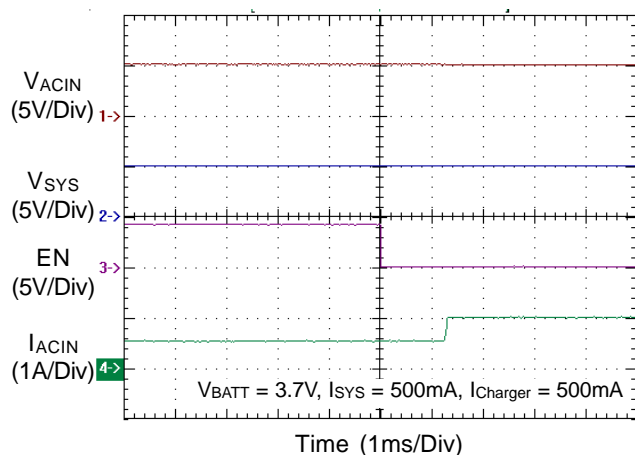
ISETU Threshold Voltage vs. USB Voltage



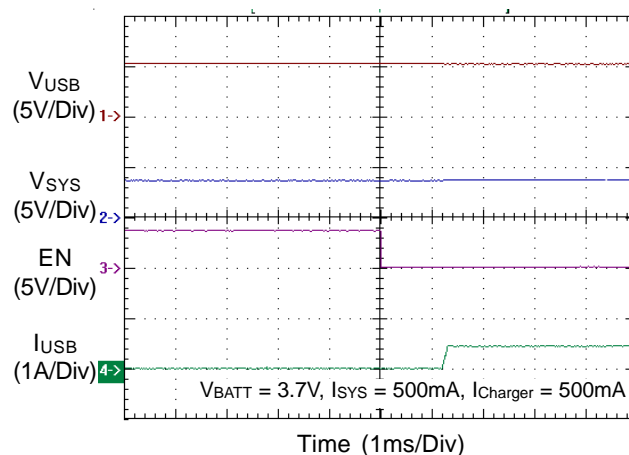
Regulation Voltage vs. Temperature



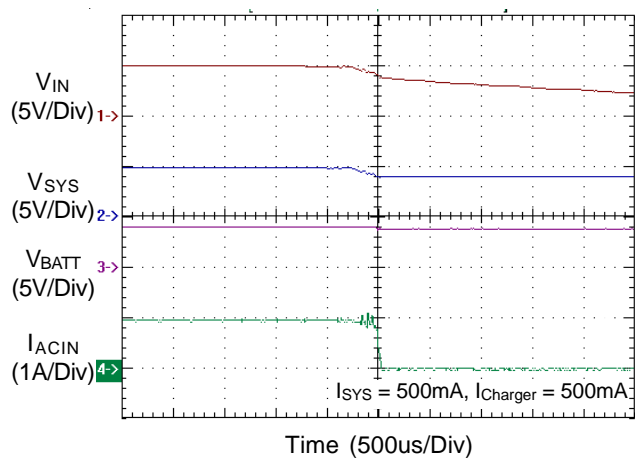
ACIN Power On



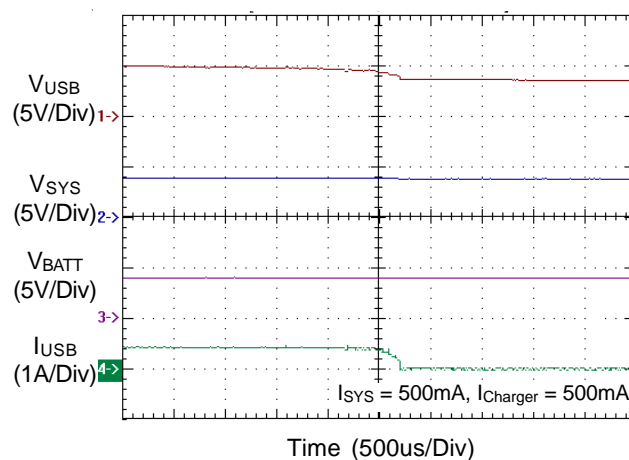
USB Power On



ACIN Power Off



USB Power Off



Application Information

The RT9503 is a fully integrated low cost single-cell Li-Ion battery charger for portable applications. The RT9503 can be adopted for two input power source, AC USB Input. It will automatically select the input source and operate in different mode as below.

AC Mode : When the AC input voltage (ACIN) is higher than the UVP voltage level (4.3V), the RT9503 will enter AC Mode. In the AC Mode, ACIN P-MOSFET is turned on and USB P-MOSFET is turned off. When ACIN voltage is between the UVP and OVP threshold levels, the switch Q1 will be turned on and Q2 will be turned off. So, the system load is powered directly from the adapter through the transistor Q1, and the battery is charged by the RT9503. Once the ACIN voltage is higher than the OVP or is lower than the UVP threshold, the RT9503 stops charging, and then Q1 will be turned off and Q2 will be turned on to supply the system by battery.

USB Mode : When AC input voltage (ACIN) is lower than UVP voltage level and USB input voltage is higher than UVP voltage level (3.9V), the RT9503 will operate in the USB Mode. In the USB Mode, ACIN P-MOSFET and Q1 are turned off and USB P-MOSFET and Q2 are turned on. The system load is powered directly from the USB/Battery through the switch Q2. Note that in this mode, the battery will be discharged once the system current is higher than the battery charge current.

Sleep Mode : The RT9503 will enter Sleep Mode when both AC and USB input voltage are removed. This feature provides low leakage current from the battery during the absence of input supply.

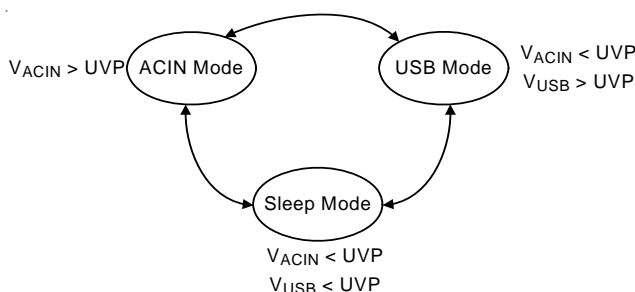


Figure 1. Input Power Source Operation Mode

Power-Path Management

The RT9503 powers the system and independently charging the battery while the input is AC. This features reduces the charge time, allows for proper charge termination, and allows the system to run with an absent or defective battery pack.

Case 1 : Input is AC

In this case, the system load is powered directly from the AC adapter through the transistor Q1. For RT9503, Q1 and Q2 act as a switch as long as the RT9503 is ready. Once the AC voltage is ready ($>UVP$ and $<OVP$), the battery charge by RT9503 internal MOSFET and Q1 starts regulating the output voltage supply system (Q2 is turn off). Once the AC voltage over operation voltage ($<UVP$ or $>OVP$), the RT9503 stop charge battery, Q1 turns off and Q2 starts supply power for system.

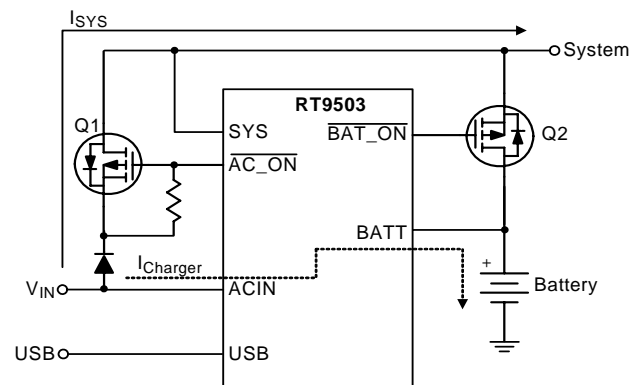


Figure 2. ACIN Input

Case 2 : Input is USB

In this case, the system load is powered directly from the battery through the switch Q2 (Q1 is turn off). Note in this case, the system current over battery charge current will lead to battery discharge.

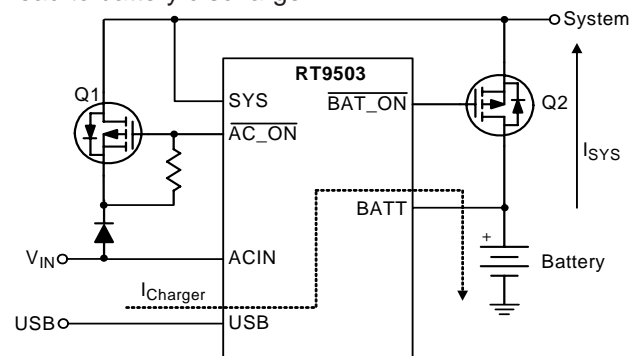


Figure 3. USB Input

ACIN Over-Voltage Protection

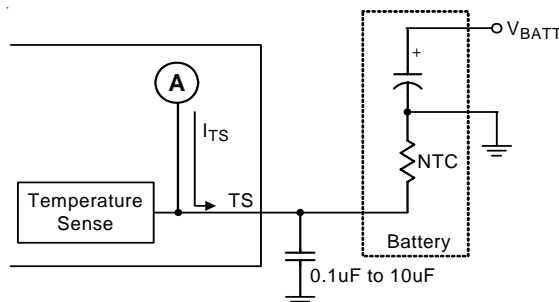
The ACIN input voltage is monitored by an internal OVP comparator. The comparator has an accurate reference of 2.5V from the band-gap reference. The OVP threshold is set by the internal resistive. The protection threshold is set to 6.5V, but ACIN input voltage over 18V still leads the RT9503 to damage. When the input voltage exceeds the threshold, the comparator outputs a logic signal to turn off the power P-MOSFET to prevent the high input voltage from damaging the electronics in the handheld system. When the input over Voltage condition is removed (ACIN < 6V), the comparator re-enables the output by running through the soft-start.

Battery Temperature Monitoring

The RT9503 continuously monitors battery temperature by measuring the voltage between the TS and GND pins.

The RT9503 has an internal current source to provide the bias for the most common 10kΩ negative-temperature coefficient thermal resistor (NTC) (see Figure 4). The RT9503 compares the voltage on the TS pin against the internal VTS_HIGH and VTS_LOW thresholds to determine if charging is allowed. When the temperature outside the VTS_HIGH and VTS_LOW thresholds is detected, the device will immediately stop the charge. The RT9503 stops charge and keep monitoring the battery temperature when the temperature sense input voltage is back to the threshold between VTS_HIGH and VTS_LOW, the charger will be resumed. Charge is resumed when the temperature returns to the normal range. However the user may modify thresholds by the negative-temperature coefficient thermal resistor or adding two external resistors. (see Figure 5.)

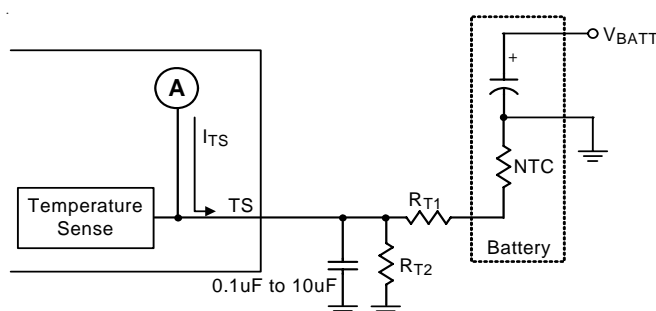
The capacitor should be placed close to TS (Pin 9) and connected to the ground plane. The capacitance value (0.1uF to 10uF) should be selected according to the quality of PCB layout. It is recommended to use 10uF if the layout is poor if prevent noise.



$$V_{TS} = I_{TS} \times R_{NTC}$$

Turn off when $V_{TS} \geq 2.5V$ or $V_{TS} \leq 0.5V$

Figure 4. Temperature Sensing Configuration



$$V_{TS} = I_{TS} \frac{R_{T2} \times (R_{T1} + R_{NTC})}{R_{T1} + R_{T2} + R_{NTC}}$$

Turn off when $V_{TS} \geq 2.5V$ or $V_{TS} \leq 0.5V$

Figure 5. Temperature Sensing Circuit

Fast-Charge Current Setting

Case 1: ACIN Mode

The RT9503 offers ISETA pin to determine the ACIN charge rate from 100mA to 1.2A. The charge current can be calculated as following equation.

$$I_{\text{charge_ac}} = K_{\text{SET}} \frac{V_{\text{SET}}}{R_{\text{SETA}}}$$

The parameter $K_{\text{SET}} = 300$; $V_{\text{SET}} = 2.5V$. R_{SETA} is the resistor connected between the ISETA and GND.

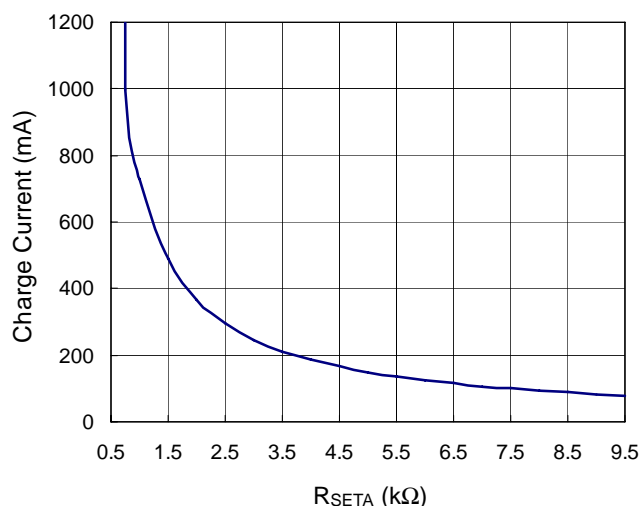


Figure 6. AC Mode Charge Current Setting

Case 2 : USB Mode

When charging from a USB port, the ISETU pin can be used to determine the charge current of 100mA or 500mA.

A low-level signal of ISETU pin sets the charge current at 100mA and a high level signal sets the charge current at 500mA.

Pre- Charge Current Setting

During a charge cycle if the battery voltage is below the V_{PRECH} threshold, the RT9503 applies a pre-charge mode to the battery. This feature revives deeply discharged cells and protects battery life. The RT9503 internal determines the pre-charge rate as 10% of the fast-charge current.

Battery Voltage Regulation

The RT9503 monitors the battery voltage through the BATT pin. Once the battery voltage level closes to the V_{REG} threshold, the RT9503 voltage enters constant phase and the charging current begins to taper down. When battery voltage is over the V_{REG} threshold, the RT9503 will stop charge and keep to monitor the battery voltage. However, when the battery voltage decreases 100mV below the V_{REG} , it will be recharged to keep the battery voltage.

Charge Status Outputs

The open-drain $\overline{CHG_S}$ and $\overline{AC_PGOOD}$ outputs indicate various charger operations as shown in the following table. These status pins can be used to drive LEDs or communicate to the host processor. Note that ON

indicates the open-drain transistor is turned on and LED bright.

Charge State		$\overline{CHG_S}$	$\overline{AC_PGOOD}$
ACIN	Charge	ON	ON
	Charge Done	OFF	ON
USB	Charge	ON	OFF
	Charge Done	OFF	OFF

Temperature Regulation and Thermal Protection

In order to maximize charge rate, the RT9503 features a junction temperature regulation loop. If the power dissipation of the IC results in a junction temperature greater than the thermal regulation threshold (125°C), the RT9503 throttles back on the charge current in order to maintain a junction temperature around the thermal regulation threshold (125°C). The RT9503 monitors the junction temperature, T_J , of the die and disconnects the battery from the input if T_J exceeds 125°C. This operation continues until junction temperature falls below thermal regulation threshold (125°C) by the hysteresis level. This feature prevents the maximum power dissipation not exceeded typical design conditions.

External Timer

As a safety mechanism the RT9503 has a user-programmable timer that monitors the pre-charge and fast charge time. This timer (charge safety timer) is started at the beginning of the pre-charge and fast charge period. The safety charge timeout value is set by the value of an external capacitor connected to the TMR pin (C_{TMR}), if pin TMR is short to GND, the charge safety timer is disabled.

As $C_{TMR} = 0.1\mu F$, T_{PRECH} is ~2460 secs and T_{FAULT} is 8 x T_{PRECH} . $T_{PRECH} = C_{TMR} \times 2460/0.1\mu$

As timer fault, re-plug-in power or pull high and re-pull low EN can release the fault condition.

As a safety mechanism, the RT9503 has a user-programmable timer that monitors the pre-charge and fast charge time. This timer(charge safe timer) is started at the beginning of the pre-charge and fast-charge period. The safety charge timeout value is set by an external capacitor (CT) connected between TIMER pin and GND. The timeout fault condition can be released by resetting

the input power or the EN pin. If the TIMER is shorted to GND, the charge safety timer will be disabled.

Selecting the Input and Output Capacitors

In most applications, the most important is the high frequency decoupling capacitor on the input of the RT9503.

A 1uF ceramic capacitor, placed in close proximity to input pin and GND pin is recommended. In some applications depending on the power supply characteristics and cable length, it may be necessary to add an additional 10uF ceramic capacitor to the input. The RT9503 requires a small output capacitor for loop stability. A 1uF ceramic capacitor placed between the BATT pin and GND is typically sufficient.

Thermal Considerations

For continuous operation, do not exceed absolute maximum operation junction temperature. The maximum power dissipation depends on the thermal resistance of IC package, PCB layout, the rate of surroundings airflow and temperature difference between junction to ambient. The maximum power dissipation can be calculated by following formula :

$$P_{D(MAX)} = (T_{J(MAX)} - T_A) / \theta_{JA}$$

Where $T_{J(MAX)}$ is the maximum operation junction temperature 125°C, T_A is the ambient temperature and the θ_{JA} is the junction to ambient thermal resistance.

For recommended operating conditions specification, where $T_{J(MAX)}$ is the maximum junction temperature of the die (125°C) and T_A is the ambient temperature. The junction to ambient thermal resistance θ_{JA} is layout dependent. For WQFN-16L 3x3 packages, the thermal resistance θ_{JA} is 60°C/W on the standard JEDEC 51-7 four layers thermal test board. The maximum power dissipation at $T_A = 25^\circ\text{C}$ can be calculated by following formula :

$$P_{D(MAX)} = (125^\circ\text{C} - 25^\circ\text{C}) / (60^\circ\text{C/W}) = 1.667\text{W for WQFN-16L 3x3 packages}$$

The maximum power dissipation depends on operating ambient temperature for fixed $T_{J(MAX)}$ and thermal resistance θ_{JA} . For WQFN-16L 3x3 package, the Figure 7 of derating curves allows the designer to see the effect of rising ambient temperature on the maximum power allowed.

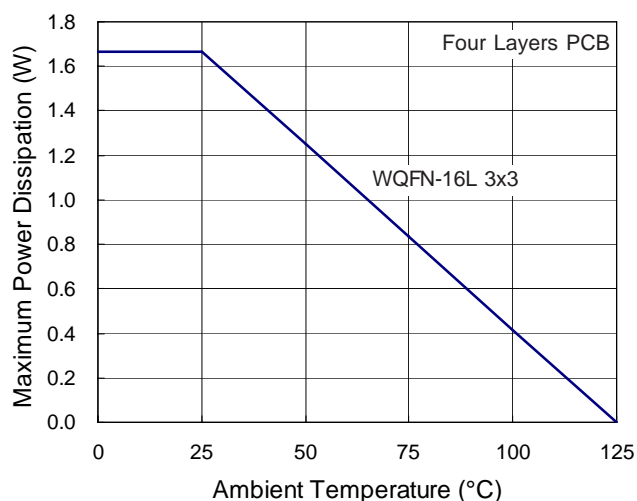


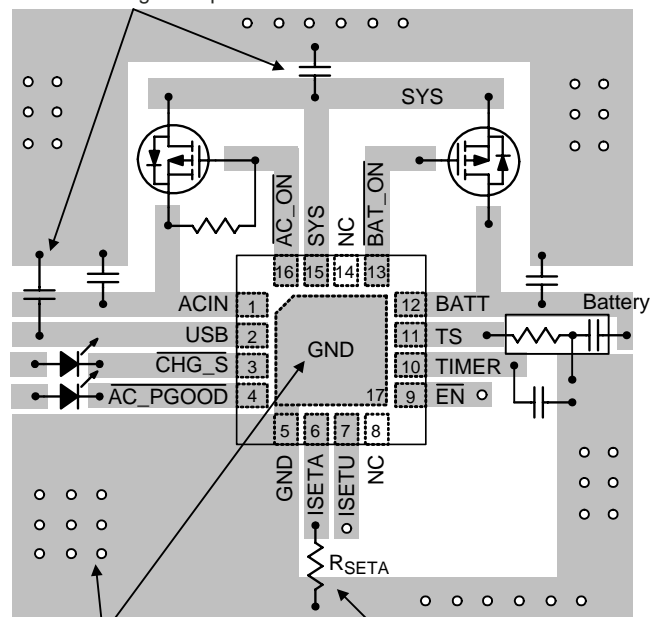
Figure 7. Derating Curves for RT9503 Package

Layout Consideration

The RT9503 is a fully integrated low cost single-cell Li-Ion battery charger ideal for portable applications. Careful PCB layout is necessary. The following guidelines should be strictly followed to achieve best performance of RT9503.

- ▶ Input capacitor should be placed close to the IC and connected to the ground plane. The trace of the input in the PCB should be placed far away from the sensitive devices or shielded by the ground.
- ▶ The GND should be connected to a strong ground plane for heat sinking and noise protection.
- ▶ The connection of the R_{SETA} should be isolated from other noisy traces. The short wire is recommended to prevent EMI and noise coupling.
- ▶ Output capacitor should be placed close to the IC and connected to ground plane to reduce noise coupling.

The capacitors should be placed close to the IC and connected to ground plane.

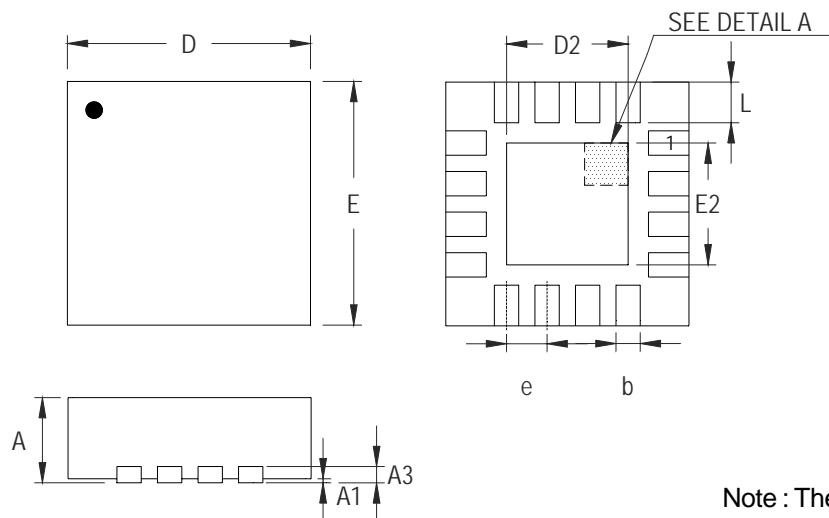


The GND should be connected to a strong ground plane for heat sinking and noise protection.

The connection of R_{SETA} should be isolated from other noisy traces.

Figure 8

Outline Dimension



DETAIL A

Pin #1 ID and Tie Bar Mark Options

Note : The configuration of the Pin #1 identifier is optional, but must be located within the zone indicated.

Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min	Max	Min	Max
A	0.700	0.800	0.028	0.031
A1	0.000	0.050	0.000	0.002
A3	0.175	0.250	0.007	0.010
b	0.180	0.300	0.007	0.012
D	2.950	3.050	0.116	0.120
D2	1.300	1.750	0.051	0.069
E	2.950	3.050	0.116	0.120
E2	1.300	1.750	0.051	0.069
e	0.500		0.020	
L	0.350	0.450	0.014	0.018

W-Type 16L QFN 3x3 Package

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