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

General Description

The RT9503A is a fully integrated low cost single-cell Li-Ion battery charger IC ideal for portable applications. The RT9503A is capable of being powered up via the AC adapter and USB (Universal Serial Bus) port inputs. The RT9503A can automatically detect and select the AC adapter and the USB port as the power source for the charger. The RT9503A enters sleep mode when both supplies are removed.

The RT9503A 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 of 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 RT9503A features 18V and 7V maximum rating voltages for AC adapter and USB port inputs respectively. Other features include external programmable 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

- RT9503A
- 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.

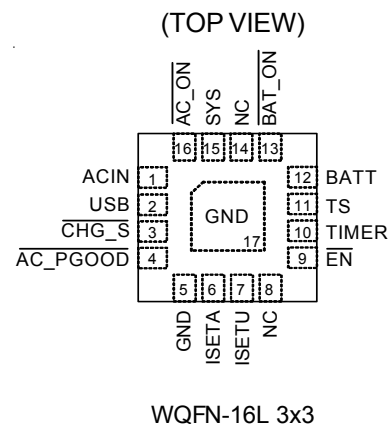
Features

- Automatic Input Supplies Selection
- 18V Maximum Rating for AC Adapter
- Integrated Selectable 100mA and 500mA USB Charge Current
- Internal Integrated Power MOSFETs
- 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 Halogen Free

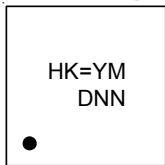
Applications

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

Pin Configurations



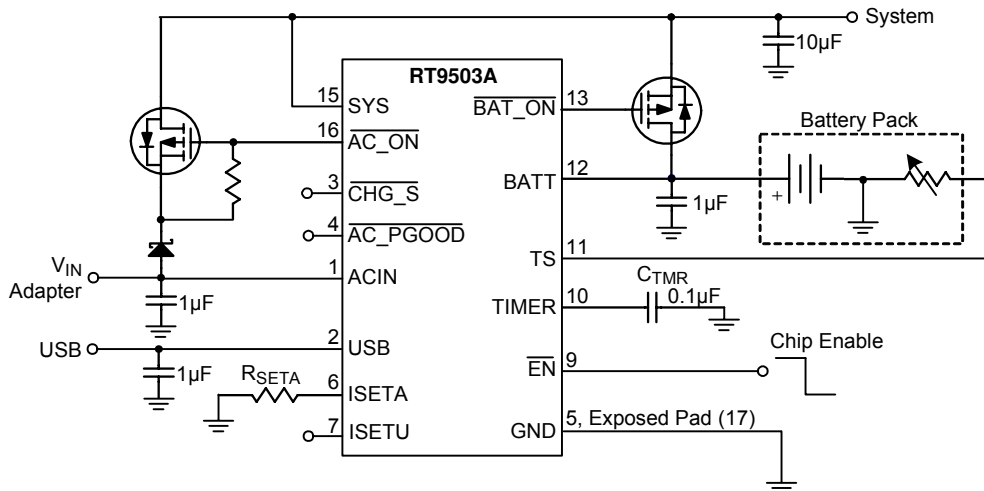
Marking Information



HK= : Product Code

YMDNN : Date Code

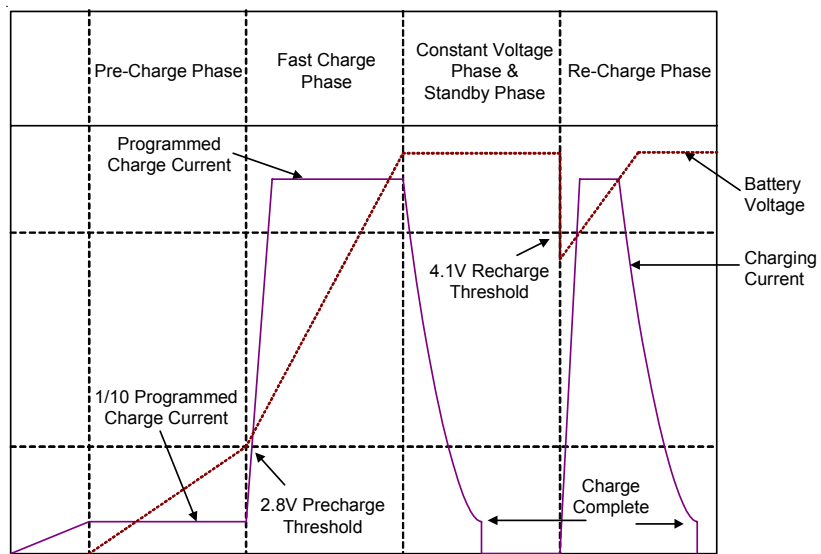
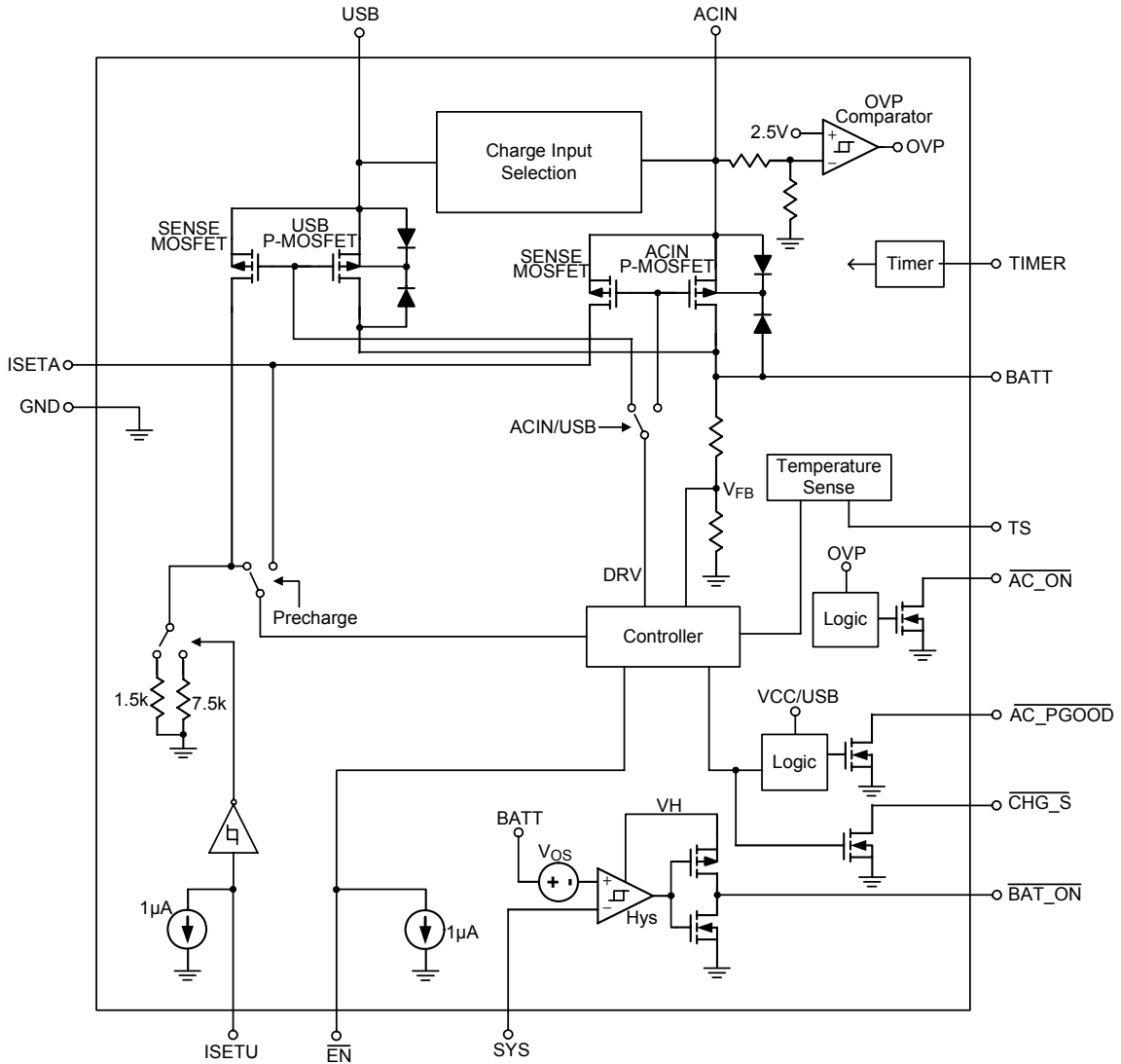
Typical Application Circuit



Functional Pin Description

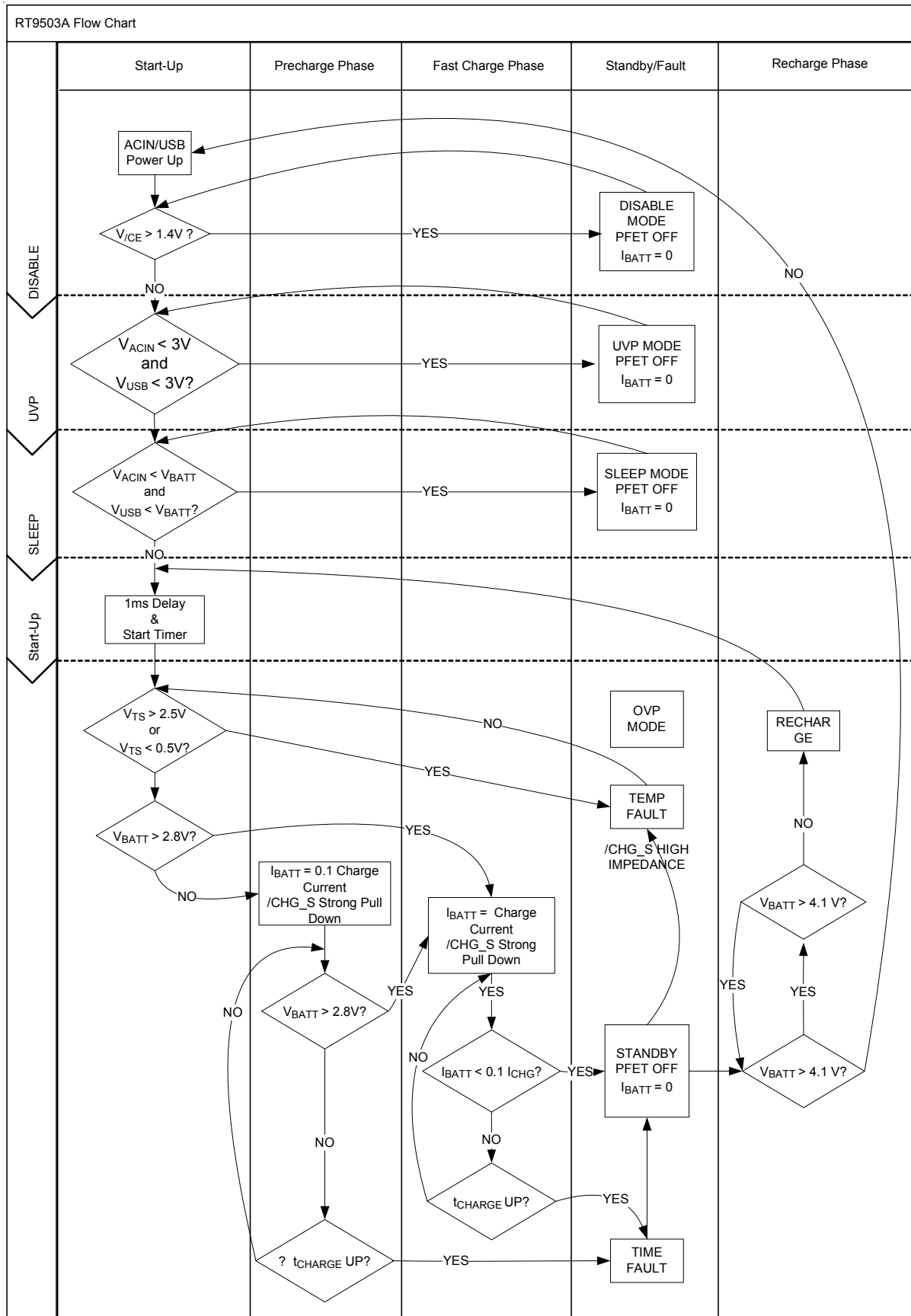
| Pin No. | Pin Name | Pin Function |
|------------------------|-------------------------------|---|
| 1 | ACIN | Wall Adaptor Charge Supply Input. |
| 2 | USB | USB Charge Supply Input. |
| 3 | $\overline{\text{CHG_S}}$ | Charge Status Indicator Output (open drain). |
| 4 | $\overline{\text{AC_PGOOD}}$ | Wall Adaptor Power Good Indicator Output (open drain). |
| 5, 17 (Exposed Pad) | GND | Ground. The exposed pad must be soldered to a large PCB and connected to GND for maximum power dissipation. |
| 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. Pull low to turn on the external P-MOSFET . |
| 15 | SYS | System Voltage Detecting Input. |
| 16 | $\overline{\text{AC_ON}}$ | P-MOSFET Switch Control Output (open drain). |

Function Block Diagram



Charging I-V Curve

Table



Absolute Maximum Ratings (Note 1)

- Supply Input Voltage, ACIN ----- -0.3V to 18V
- Supply Input Voltage, USB ----- -0.3V to 7V
- CHG_S, 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 ----- 1.471W
- Package Thermal Resistance (Note 2)
 WQFN-16L 3x3, θ_{JA} ----- 68°C/W
 WQFN-16L 3x3, θ_{JC} ----- 7.5°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 | Unit |
|---------------------------------------|-------------------------|--|-------|------|-------|------|
| Supply Input | | | | | | |
| ACIN UVP Rising Threshold Voltage | V _{UV_ACIN} | | -- | 3 | -- | V |
| USB UVP Rising Threshold Voltage | V _{UV_USB} | V _{BATT} = 3V | -- | 3 | -- | V |
| ACIN/USB UVP Hysteresis | V _{UV_HYS} | V _{BATT} = 3V | -- | 100 | -- | mV |
| ACIN/USB Standby Current | I _{STBY} | V _{BATT} = 4.5V | -- | 300 | 500 | 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 | 4.138 | 4.2 | 4.262 | V |
| ACIN MOSFET Dropout | | V _{BATT} = 4V, I _{CHG_AC} = 1A | 400 | 500 | 620 | mV |
| USB MOSFET Dropout | | V _{BATT} = 4V, I _{CHG_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 | Unit |
|---|--------------|-------------------------|--|-------|-------|-------|-------------|
| 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 | | | | | | | |
| $\overline{CHG_S}$ Pull Down Voltage | | $V_{\overline{CHG_S}}$ | $I_{\overline{CHG_S}} = 5mA$ | -- | 213 | -- | mV |
| $\overline{AC_PGOOD}$ Pull Down Voltage | | $V_{\overline{PGOOD}}$ | $I_{\overline{PGOOD}} = 5mA$ | -- | 213 | -- | mV |
| \overline{PGOOD} Pull Down Voltage | | $V_{\overline{PGOOD}}$ | $I_{\overline{PGOOD}} = 5mA$ | -- | 65 | -- | mV |
| \overline{EN} Threshold Voltage | Logic-High | V_{IH} | | 1.5 | -- | -- | V |
| | Logic-Low | V_{IL} | | -- | -- | 0.4 | V |
| \overline{EN} Pin Input Current | | $I_{\overline{EN}}$ | | -- | -- | 1.5 | μA |
| 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 | μA |
| USB Charge Current & Timing | | | | | | | |
| Soft-Start Time | | t_{SS} | V_{ISETA} from 0V to 2.5V | -- | 100 | -- | μs |
| USB Charge Current | | I_{CHG_USB} | $V_{ACIN} = 2.5V, V_{USB} = 5V, V_{BATT} = 3.5V, V_{ISETU} = 5V$ | 400 | 450 | 500 | mA |
| USB Charge Current | | I_{CHG_USB} | $V_{ACIN} = 2.5V, V_{USB} = 5V, V_{BATT} = 3.5V, V_{ISETU} = 0V$ | 60 | 80 | 100 | mA |
| Timer | | | | | | | |
| TIMER Pin Source Current | | I_{TIME} | $V_{TIMER} = 2V$ | -- | 1 | -- | μA |
| Pre-charge Fault Time | | t_{PCHG_F} | $C_{TIMER} = 0.1\mu F, f_{CLK} = 7Hz$ | 1720 | 2460 | 3200 | s |
| Charge Fault Time | | t_{FCHG_F} | $C_{TIMER} = 0.1\mu F, f_{CLK} = 7Hz$ | 13790 | 19700 | 25610 | s |
| Battery Temperature Sense | | | | | | | |
| TS Pin Source Current | | I_{TS} | $V_{TS} = 1.5V$ | -- | 102 | -- | μA |
| 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 | -- | $^{\circ}C$ |
| OVP SET Voltage | | | Internal Default | -- | 6.5 | -- | V |
| Power Path Controller | | | | | | | |
| $\overline{BAT_ON}$ Pull Low | | | As SYS Falling, $V_{BATT} = 4V, SYS-BAT$ | -150 | -- | -20 | mV |

To be continued

| Parameter | Symbol | Test Conditions | Min | Typ | Max | Uni |
|------------------------------------|--------|--|-----|-----|-----|-----|
| BAT_ON Pull High | | As SYS Raising, V _{BATT} = 4V, SYS-BAT | -50 | -- | 0 | mV |
| BAT_ON Pull Low Switch Resistance | | V _{BATT} = 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 thermal conductivity four-layer test board of JEDEC 51-7 thermal measurement standard. The measurement case position of θ_{JC} is on the exposed pad of the package.

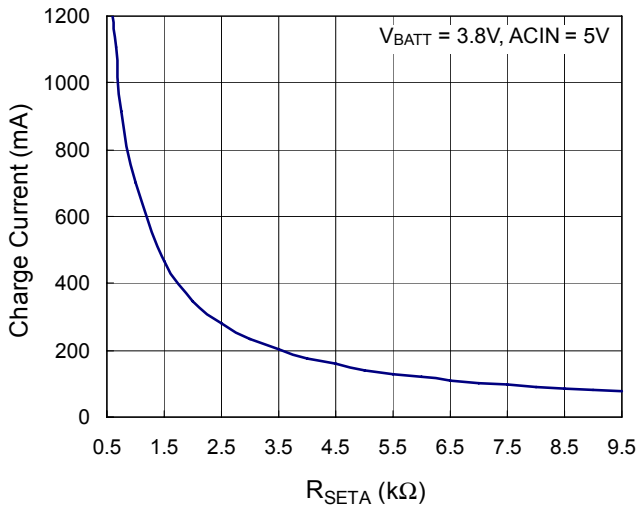
Note 3. Devices are ESD sensitive. Handling precaution is recommended.

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

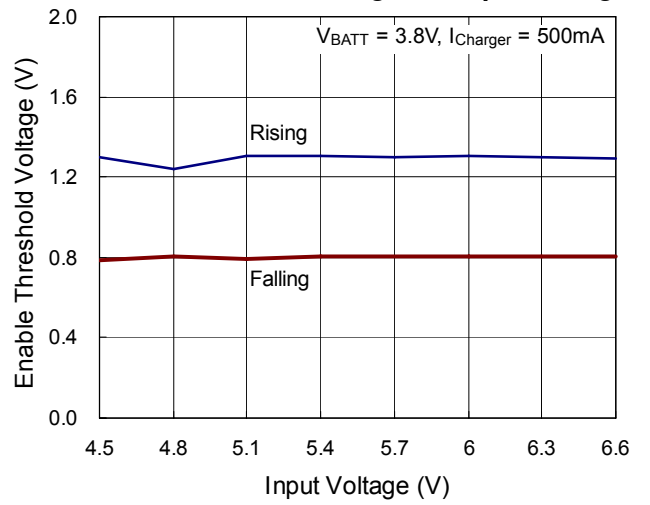
Note 5. Guaranteed by design.

Typical Operating Characteristics

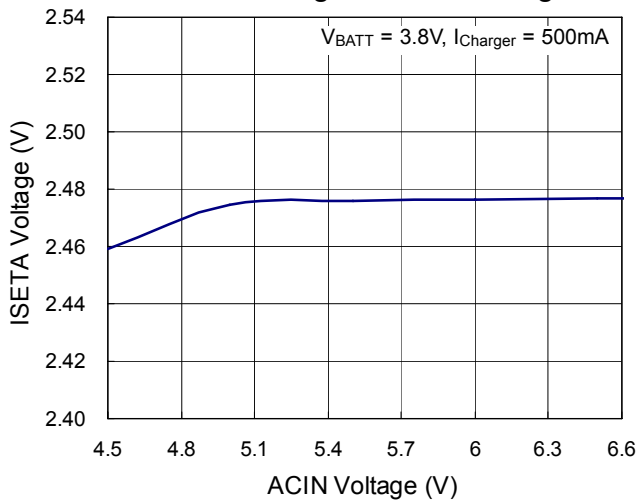
Charge Current vs. R_{SETA}



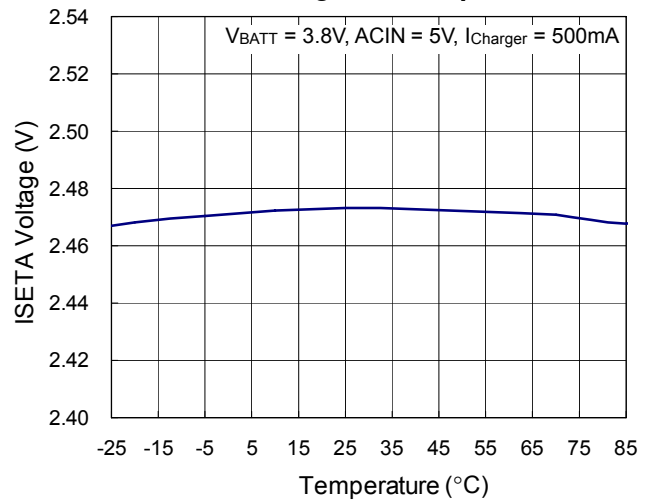
Enable Threshold Voltage vs. Input Voltage



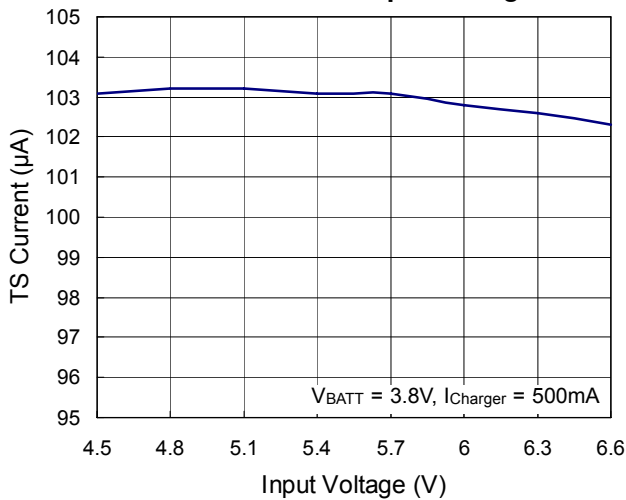
ISETA Voltage vs. ACIN Voltage



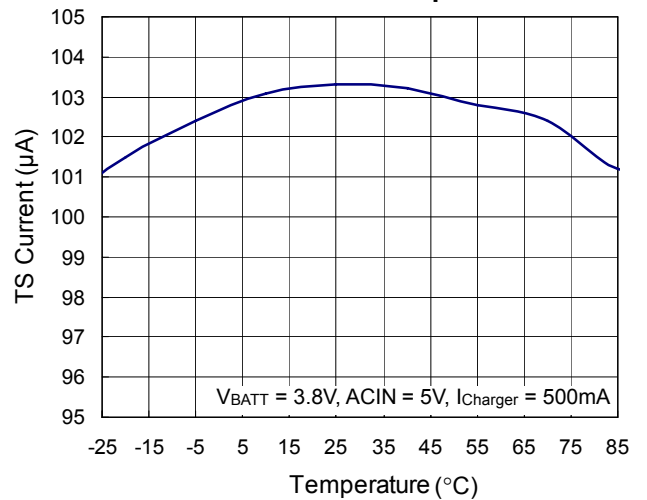
ISETA Voltage vs. Temperature



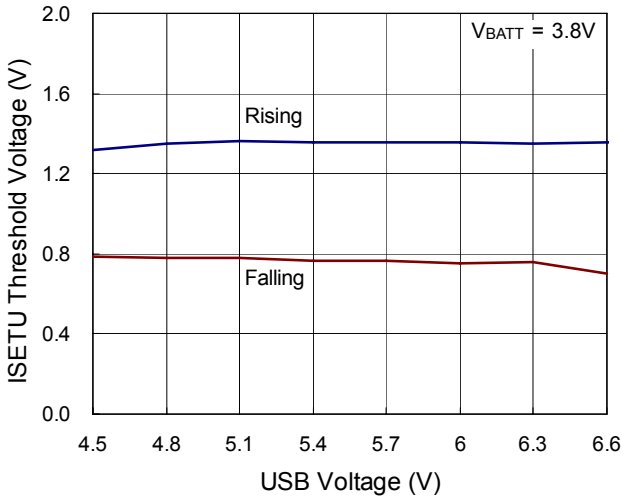
TS Current vs. Input Voltage



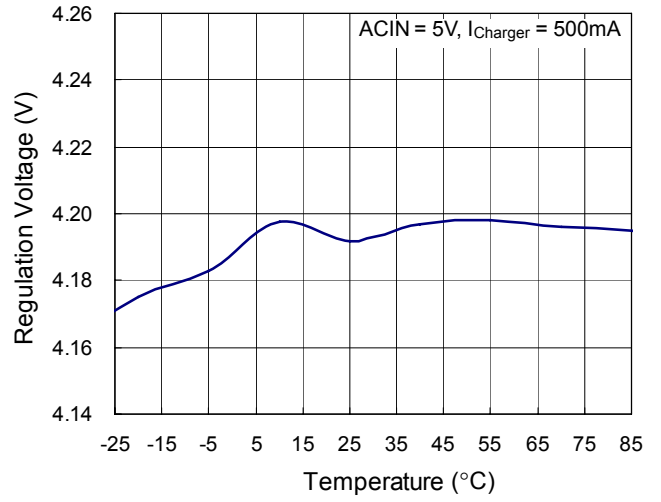
TS Current vs. Temperature



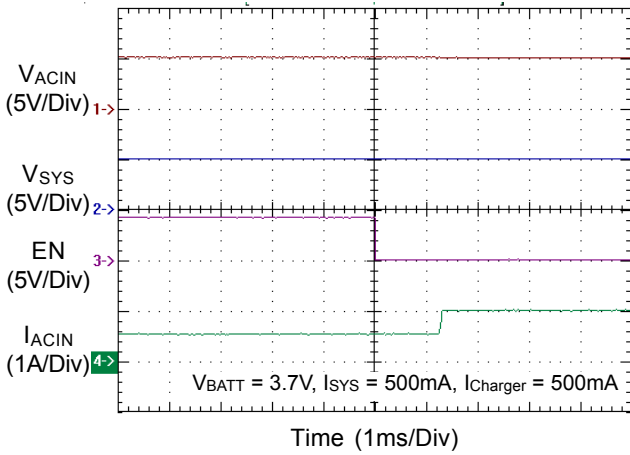
ISETU Threshold Voltage vs. USB Voltage



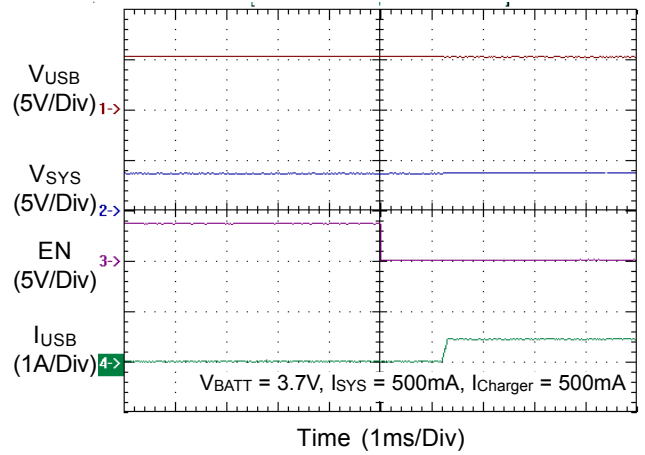
Regulation Voltage vs. Temperature



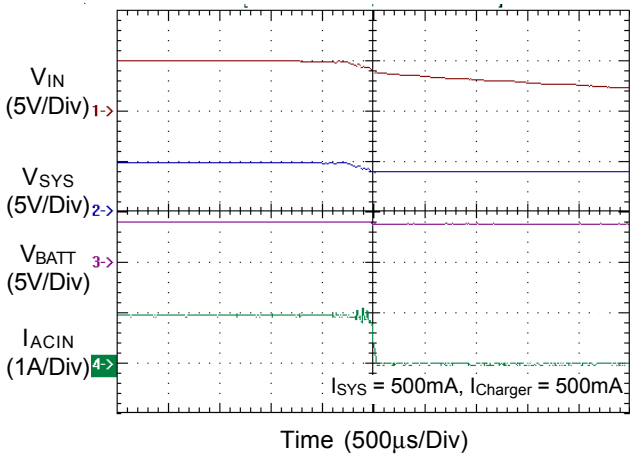
ACIN Power On



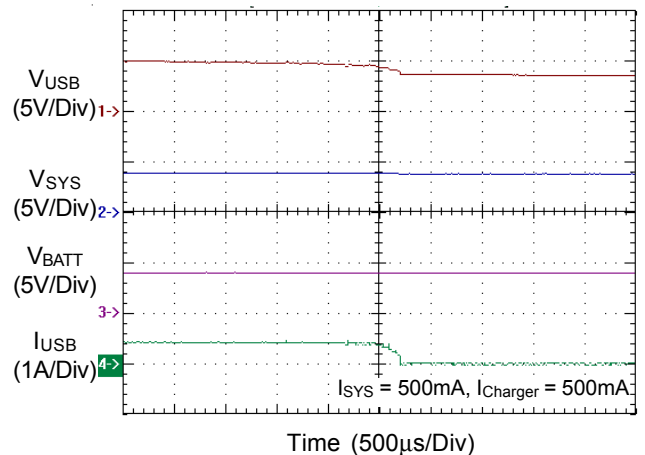
USB Power On



ACIN Power Off



USB Power Off



Application Information

The RT9503A is a fully integrated low cost single-cell Li-Ion battery charger for portable applications. The RT9503A can be adopted for two input power source including AC and USB inputs. 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 (3V), the RT9503A 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 below 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 RT9503A. Once the ACIN voltage is higher than the OVP, the RT9503A 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 removed and USB input voltage is higher than UVP voltage level (3V), the RT9503A will operate in the USB Mode. In the USB Mode, ACIN P-MOSFET is turned off while 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 RT9503A 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.

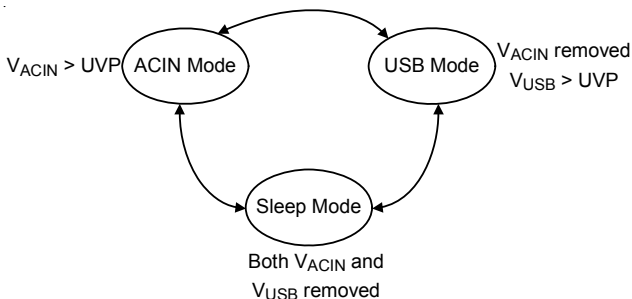


Figure 1. Input Power Source Operation Mode

Power-Path Management

The RT9503A powers the system and independently charging the battery while the input source is AC. This feature 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 Source is AC

In this case, the system load is powered directly from the AC adapter through the transistor Q1. For RT9503A, Q1 and Q2 act as a switch as long as the RT9503A is ready. Once the AC voltage is ready (<OVP), the battery charge by the RT9503A internal MOSFET and Q1 starts regulating the output voltage supply system (Q2 is turn off). Once the AC voltage is higher than the operation voltage (>OVP), the RT9503A stop charging battery, Q1 turns off and Q2 starts to supply power for system.

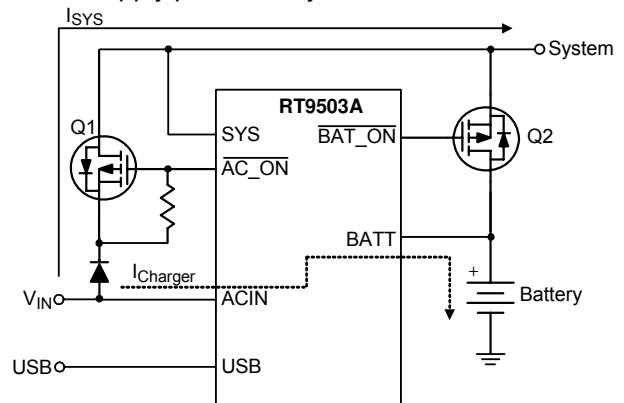


Figure 2. ACIN Input

Case 2 : Input Source is USB

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

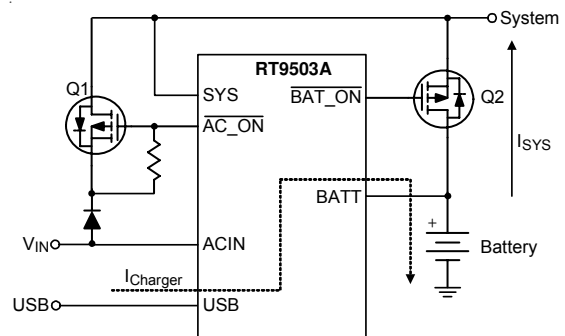


Figure 3. USB Input

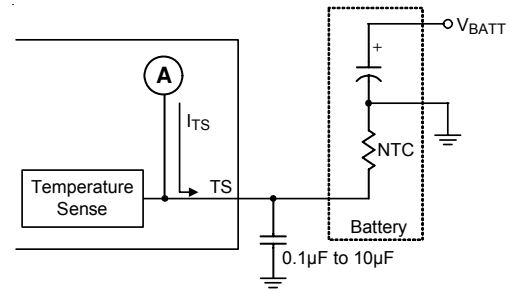
ACIN Over-Voltage Protection

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 resistor. The protection threshold is set to 6.5V, but ACIN input voltage over 18V still leads the RT9503A 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 RT9503A continuously monitors battery temperature by measuring the voltage between the TS and GND pins. The RT9503A has an internal current source to provide the bias for the most common 10kΩ negative-temperature coefficient thermal resistor (NTC) (see Figure 4). The RT9503A compares the voltage on the TS pin against the internal V_{TS_HIGH} and V_{TS_LOW} thresholds to determine if charging is allowed. When the temperature outside the V_{TS_HIGH} and V_{TS_LOW} thresholds is detected, the device will immediately stop charging. The RT9503A stops charging and keeps monitoring the battery temperature when the temperature-sense voltage is back to the threshold between V_{TS_HIGH} and V_{TS_LOW} , the charger will be resumed. Charge is resumed when the temperature returns to the normal range. However, the user may modify thresholds via the negative-temperature coefficient thermal resistor or by adding two external resistors. (see Figure 5.)

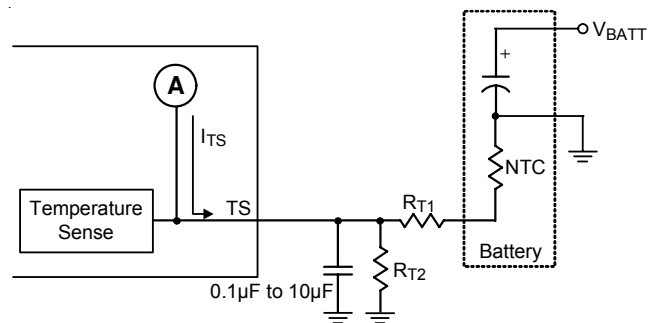
The capacitor should be placed close to TS (Pin 11) and connected to the ground plane. The capacitance value (0.1μF to 10μF) should be selected according to the quality of PCB layout. It is recommended to use 10μF if the layout is poor for noise prevention.



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

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 ISETA pin is used to determine the ACIN charge rate from 100mA to 1A. The charge current can be calculated as following equation.

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

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

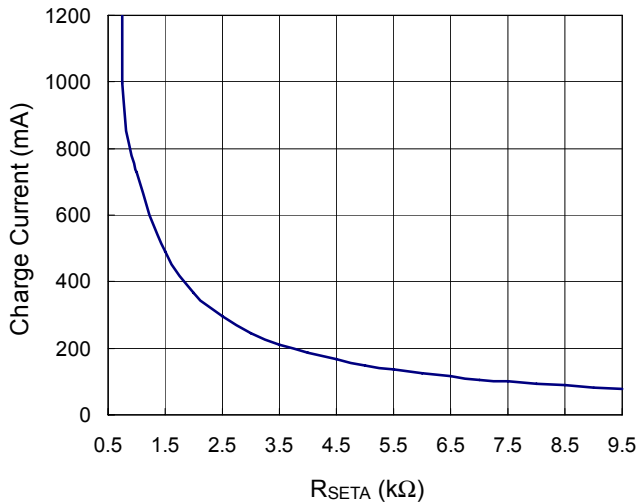


Figure 6. AC Mode Charge Current Setting

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 VPRECH threshold, the RT9503A applies a pre-charge mode to the battery. This feature revives deeply discharged cells and protects battery life. The RT9503A internally determines the pre-charge rate as 10% of the fast-charge current.

Battery Voltage Regulation

The RT9503A monitors the battery voltage through the BATT pin. Once the battery voltage level closes in on the VREG threshold, the RT9503A voltage enters constant phase and the charging current begins to taper down. When battery voltage is over the VREG threshold, the RT9503A will stop charging but continue to monitor the battery voltage. However, when the battery voltage decreases 100mV below VREG, it will be recharged to preserve the battery voltage.

Charge Status Outputs

The open-drain CHG_S and 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 | | CHG_S | 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 the charge rate, the RT9503A 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 RT9503A throttles back on the charge current in order to maintain a junction temperature around the thermal regulation threshold (125°C). The RT9503A monitors the junction temperature, Tj, of the die and disconnects the battery from the input if Tj 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 from exceeding typical design conditions.

External Timer

As a safety mechanism, the RT9503A provides 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 TIMER pin (CTMR), if the TIMER pin is short to GND, the charge safety timer is disabled.

As CTMR = 0.1μF, tPCHG_F is ~2460 secs and tFCHG_F is 8 x tPCHG_F. tPCHG_F = CTMR x 2460/0.1μ

When timer faults, re-plug-in power or pull high and then pull low EN to release the fault condition.

Selecting the Input and Output Capacitors

In most applications, the most important is the high frequency decoupling capacitor on the input of the RT9503A.

A 1μF 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 10µF ceramic capacitor to the input. The RT9503A requires a small output capacitor for loop stability. A 1µF ceramic capacitor placed between the BATT pin and GND is typically sufficient.

Thermal Considerations

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

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

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

For recommended operating condition specifications of RT9503A, the maximum junction temperature is 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 68°C/W on a standard JEDEC 51-7 four-layer thermal test board. The maximum power dissipation at $T_A = 25^\circ\text{C}$ can be calculated by the following formula :

$$P_{D(MAX)} = (125^\circ\text{C} - 25^\circ\text{C}) / (68^\circ\text{C/W}) = 1.471\text{W for WQFN-16L 3x3 package}$$

The maximum power dissipation depends on the operating ambient temperature for fixed $T_{J(MAX)}$ and thermal resistance, θ_{JA} . For RT9503A package, the derating curve in Figure 7 allows the designer to see the effect of rising ambient temperature on the maximum power dissipation.

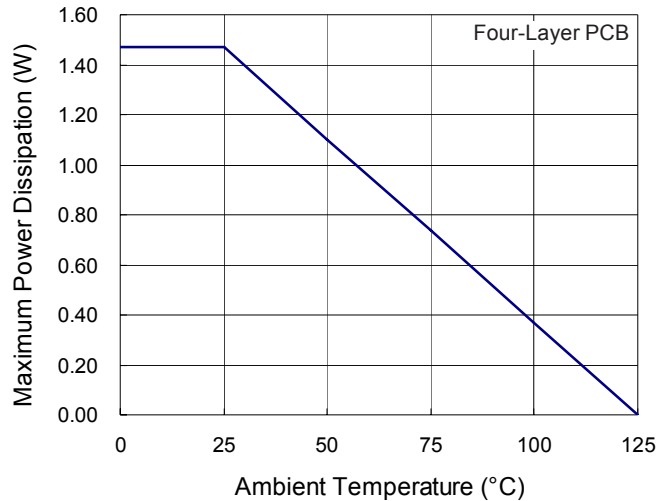


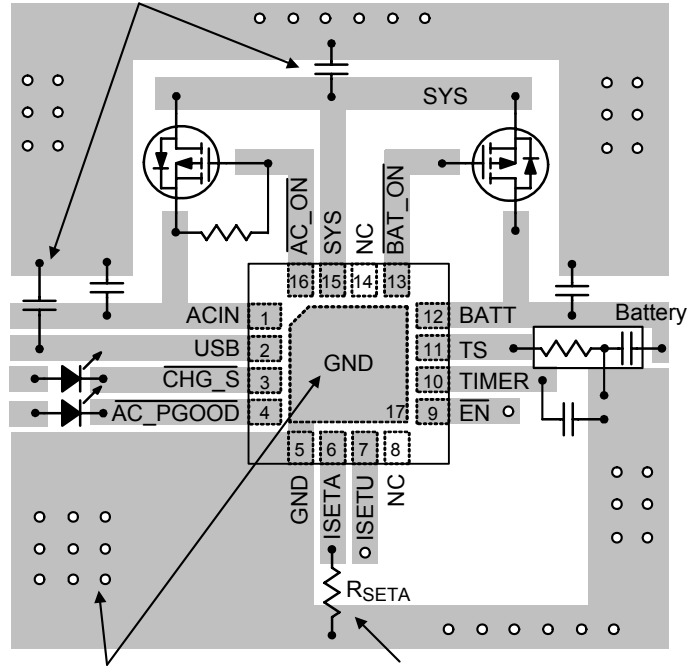
Figure 7. Derating Curves for RT9503A Package

Layout Consideration

The RT9503A 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 the RT9503A.

- ▶ 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.
- ▶ Connection of the R_{SETA} should be isolated from other noisy traces. A 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.

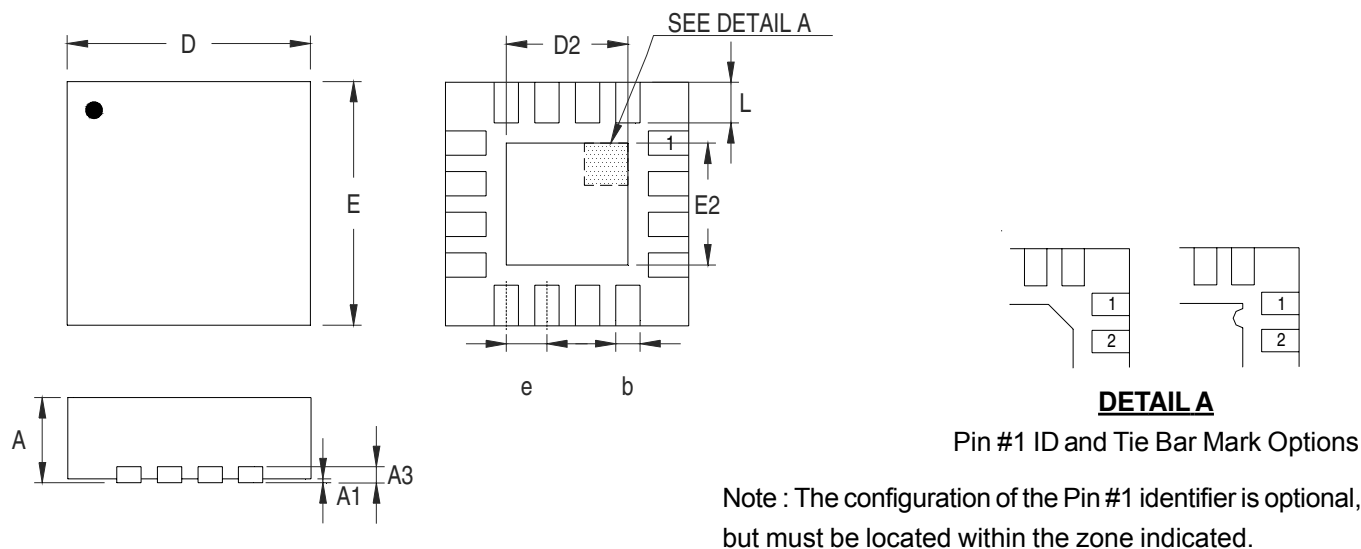


The GND should be connected to a strong ground plane for heat sinking and noise protection.

Connection of RSETA should be isolated from other noisy traces.

Figure 8. PCB Layout Guide

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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