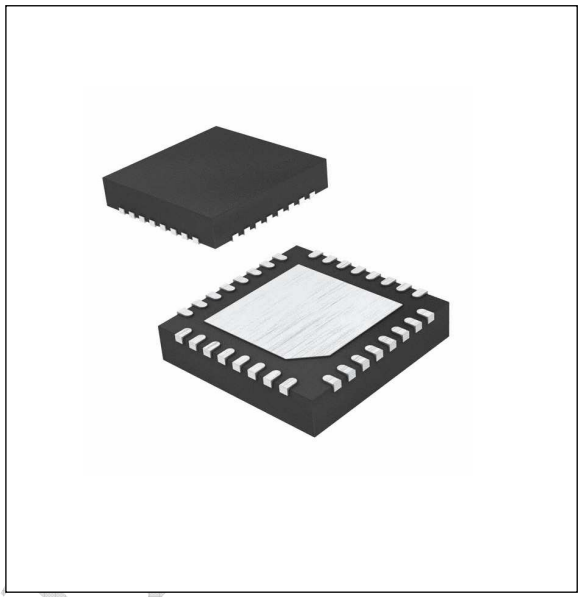
# USB Charger Controller

## Features



- High efficiency (> 85 % for 5V OTG; > 88 % for Charger)
- 2.5A maximum charging current
- 2A maximum discharging current
- Li-ion battery float voltage: 4.2V ±21mV
- 5V discharge output, VOUT, 10W Max output power
- Bi-directional switching regulator with 500kHz PWM controller, fully integrated switching Power transistors.
- NTC Monitoring of Battery Temperature
- QFN-32 Package

# 1. Description

The AP9928A is a battery charge and discharge controller for 1-cell Li-ion battery.

With a 5V USB input source (from host port or charging port) is connected to VBUS, the Li-ion battery is charged to 4.2V with an accuracy of ±0.5%. The maximum charging current for the battery is 2.5A.

When the 5V USB input source is removed, the Li-ion battery will be discharged to VOUT providing a 5V output to the load. The maximum discharging current for the battery is 2A at VOUT=5V with a max output power of 10W.

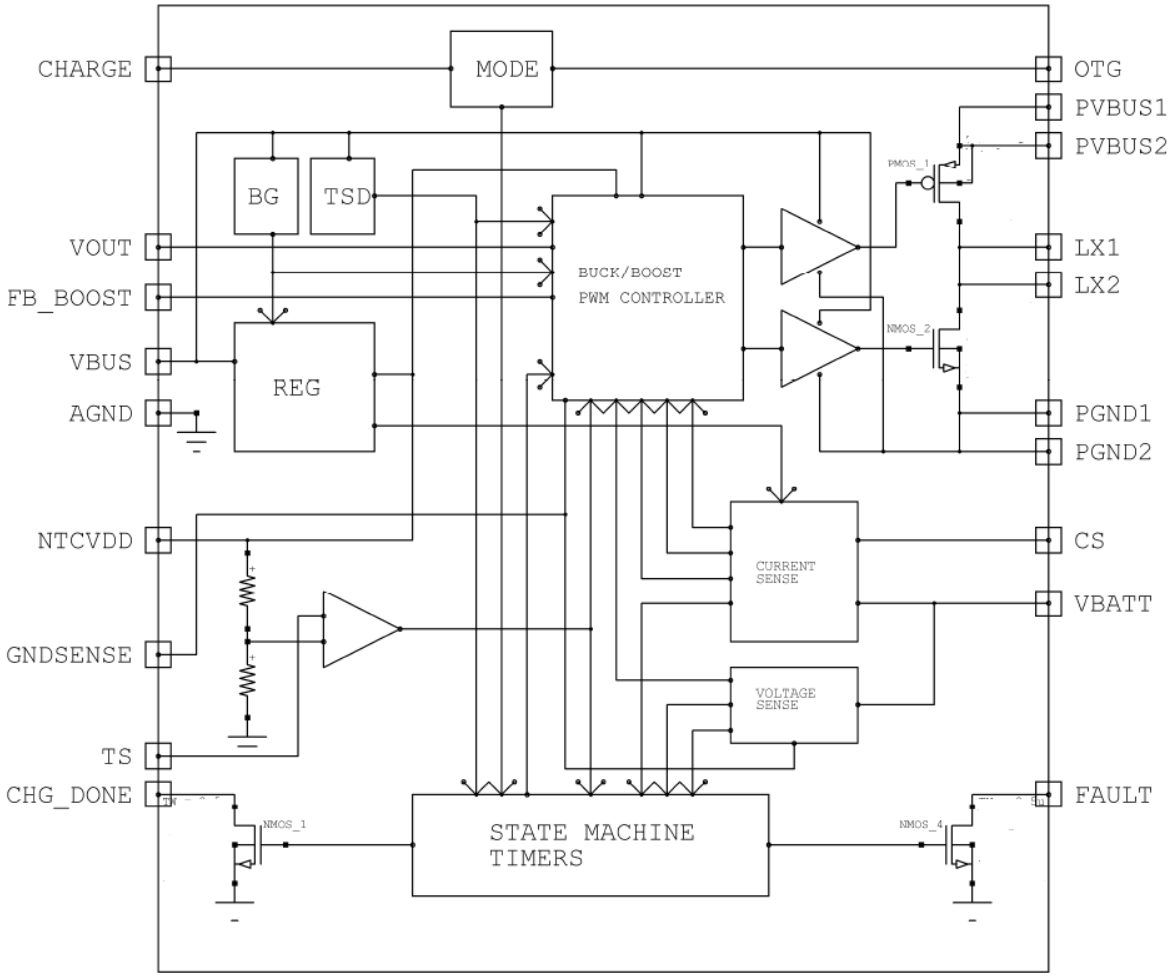
The AP9928A enters sleeping mode to save the battery power when both CHARGE and OTG are LOW.

The AP9928A can initiate and complete a charging cycle itself. It charges the battery in three phases: precharge, constant current and constant voltage. In the end, the charger automatically terminates when the safety termination timer is timeout or the end of charge current level is reached. Later on, when the battery voltage falls below the recharge threshold, the charger will automatically start another charging cycle.

The AP9928A provides various safety features for battery charging and system operation, including negative thermistor monitoring, charging safety timer.

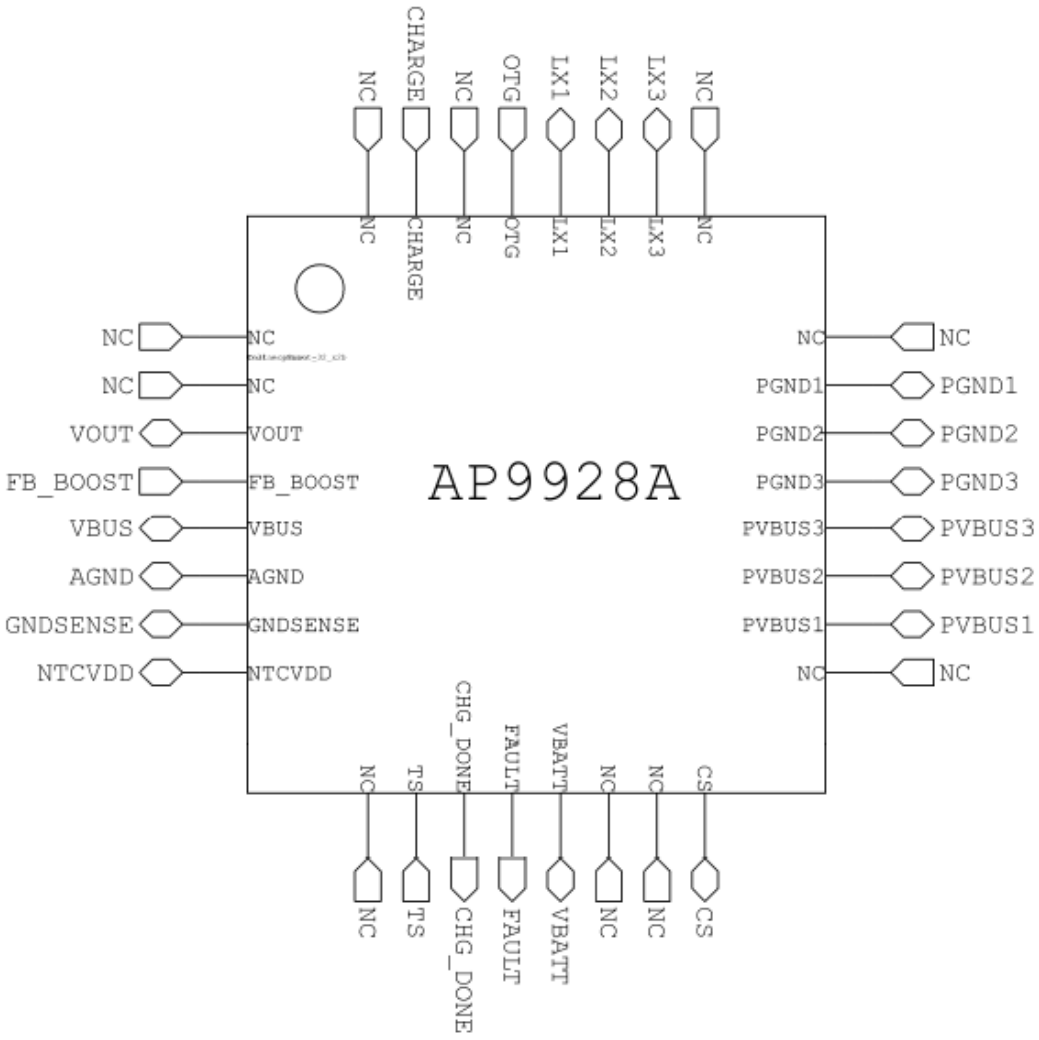
External MCU is required to drive LEDs for battery charge level, handle the user interface such as push button, USB detection, etc., and to generate the two control signals, OTG and CHARGE for the chip.

## 1.1 Device block diagram



# 2 Pin description

## 2.1 Pin out




**QFN32 package allows more pins for the high current devices on the chip.**

## 2.2 Preliminary pin list (QFN32)

| Pin No. | Name | Description |
|---|---|---|
| 1,2 | NC | |
| 3 | VOUT | Output discharge voltage, 5V, Connect a 150uF from VOUT to PGND |
| 4 | FB_BOOST | Booster feedback connection; For typical 5V application, connect a 2M ohm resistor between pin 4 and pin3; a 590k ohm resistor from pin 4 to ground. FB_BOOST is at 1.15V when feedback loop is operating |
| 5 | VBUS | 5V USB input; Connect a 10uF, max, from VBUS to PGND |
| 6 | AGND | Analog Ground |
| 7 | GNDSENSE | Battery connection point to negative terminal of the battery pack |
| 8 | NTCVDD | Internal power supply, NTC bias voltage. Connect a 1uF from this pin to analog GND |
| 9 | NC | |
| 10 | TS | Temperature sense input. Connect a negative TC (NTC) thermistor |
| 11 | CHG_DONE | Charge complete flag, open-drain output. Low active |
| 12 | FAULT | Bad battery indicator and Timeout indicator, open-drain output<br>Bad battery: Blink at 1s interval<br>Timeout: LED stays ON |
| 13 | VBATT | Battery connection point to positive terminal of the battery pack. Connect a 68uF from VBATT to Battery GND |
| 14,15 | NC | |
| 16 | CS | Sense input for USB input current limit |
| 17 | NC | |
| 18 | PVBUS1 | VBUS Pin 1 |
| 19 | PVBUS2 | VBUS Pin 2 |
| 20 | PVBUS3 | VBUS Pin 3 |
| 21 | PGND3 | Power ground3, |
| 22 | PGND2 | Power ground2, |
| 23 | PGND1 | Power ground1, |
| 24, 25 | NC | |
| 26 | LX3 | Drain of N-channel Power Switch. Connecting to output inductor. |
| 27 | LX2 | Drain of N-channel Power Switch. Connecting to output inductor. |
| 28 | LX1 | Drain of N-channel Power Switch. Connecting to output inductor |
| 29 | OTG | Boost mode enables, Active High, 5V |
| 30 | NC | No Connection |
| 31 | CHARGE | Charge mode enables, Active High, 5V |
| 32 | NC | |

# 3 Electrical specifications

## 3.1 Absolute maximum ratings

**Table 3. Absolute maximum ratings**

| Symbol | Parameter | Value | Unit |
|---|---|---|---|
| VDD | DC supply voltage | 6 | V |
| $T_{op}$ | Operating temperature | 0 to 70 | ℃ |
| $T_j$ | Junction temperature | –40 to 150 | ℃ |
| $T_{stg}$ | Storage temperature | –40 to 150 | ℃ |
| HBM | ESD Susceptibility | 2000 | V |
| MM | ESD Susceptibility | TBD | V |

## 3.2 Thermal data

**Table 4. Thermal data**

| Symbol | Parameter | Min | Typ | Max | Unit |
|---|---|---|---|---|---|
| $\theta_{jc}$ | Junction to Case Thermal resistance. Attached to Heat Sink, still air. | | 31 | | ℃/W |

## 3.3 Electrical specifications

Unless otherwise stated, the results in *Table 5* below are given for the conditions:
VDD = TBD V, and $T_A$ = 25 ℃.

**Table 5. Electrical specifications**

| Symbol | Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| Vdd | Internal supply voltage; NTC bias voltage | | | 2.3 | | V |
| Isleep | Sleep mode current | In sleep mode; measured from battery | | 2 | TBD | uA |
| **Battery Charger (Buck mode; when Vbus > Vuvlo; CHARGE=HIGH)** | | | | | | |
| Vbus | USB input voltage | | 4.75 | 5 | 5.25 | V |
| Vuvlo | Vbus UVLO | Vbus rising | | 4 | | V |
| Vuvlo_hys | Vbus UVLO hysteresis | | | 100 | | mV |
| AIUSB | Vbus low threshold voltage | | | 4.5 | | V |
| Ibus | Input quiescent current from Vbus | Vbus > Vuvlo, Charge enabled | | 14 | TBD | mA |
| Ibus(LIMIT) | Total input current limit from Vbus | | | 2500 | | mA |
| Vbatt | Battery floating voltage | | | 4.2 | | V |
| Vbatt% | Battery voltage accuracy | | -0.5 | | 0.5 | % |
| Vtrkl | Trickle charge threshold voltage | | | 3 | | V |
| Vtrkl_hys | Trickle charge hysteresis voltage | | | 200 | | mV |
| Itrkl | Trickle charging current | | | 400 | | mA |
| ΔVrecharge | Recharge battery threshold voltage | | | -250 | | mV |
| Istop | End of Charge current | | | 200 | | mA |
| | Safety timer charging period | Timer start when Vbatt > Vtrkl | | 480 | | Minutes |
| | Safety timer termination period | Timer start when Vbatt reaches final value | | 300 | | Minutes |
| Tdbp | Dead battery termination time | Vbatt < Vtrkl | | 30 | 45 | Minutes |
| | | | | | | |

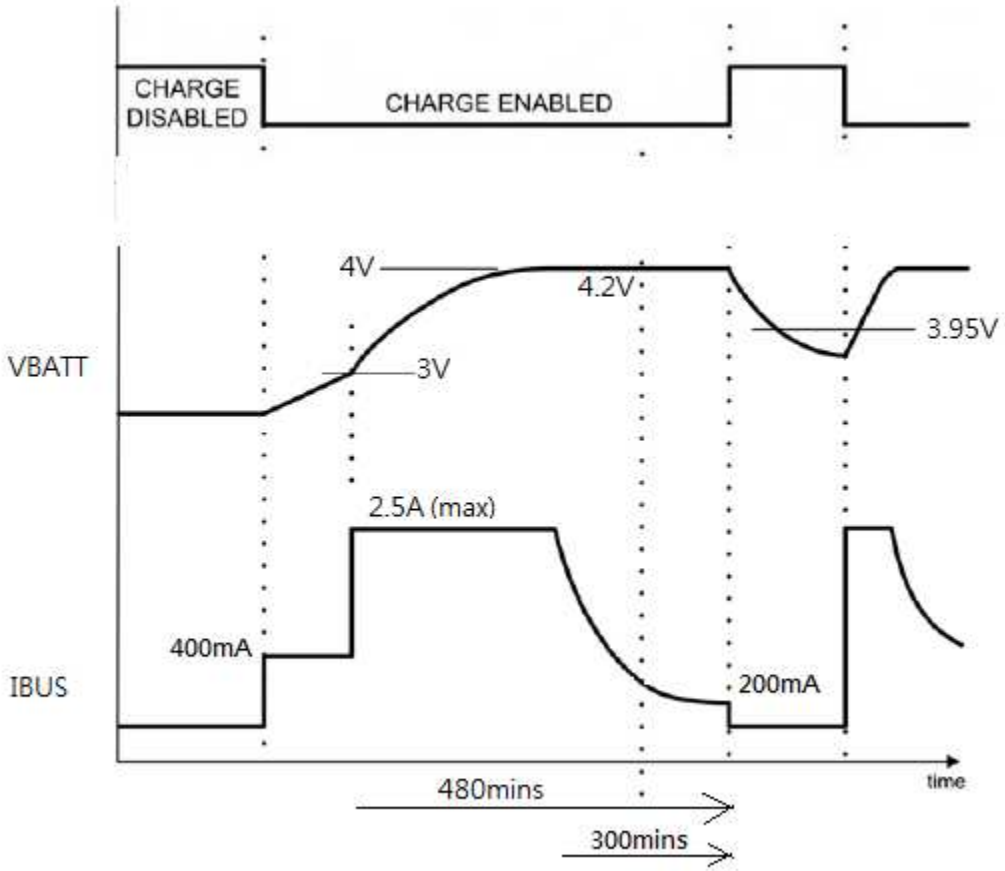
| | | | | | | |
|---|---|---|---|---|---|---|
| **Boost Mode, VOUT (Vbatt > Vbatt_low ; OTG=HIGH)** | | | | | | |
| Vbatt_otg | Battery operating voltage for boost mode | | 3.2 | | 4.2 | V |
| Vbatt_low | Battery over discharge threshold voltage | | | 2.8 | | V |
| V_otg | Output voltage, VOUT, range | | | 5 | | V |
| V_otg% | Output voltage accuracy | | -5 | | 5 | % |
| I_otg | Output current | V_otg=5V | 2 | | | A |
| I_otgp | Peak inductor current limit | | | 5 | | A |
| I_otgq | Total quiescent current from Vbatt | No load at Vbus | | 14 | TBD | mA |
| Vfb_boost | Feedback voltage | | | 1.15 | | V |
| **PWM Controller** | | | | | | |
| f | PWM operating frequency | | | 500 | | kHz |
| Rdsonn | Internal bottom switching MOSFET on resistance | Measured from LX to PGND | | 0.2 | | ohm |
| **Status indicator** | | | | | | |
| Vled_lo | Open drain pull-down voltage | Sink current =5mA | | | 0.4 | V |
| **NTC** | | | | | | |
| Vhot | Hot temperature fault threshold | | | 35 | | %Vdd |
| Vhot_hys | Hot temperature fault threshold hysteresis | | | 5 | | %Vdd |

# 4 Functional Description

The AP9928A is a battery charge and discharge controller for 1-cell Li-ion battery.

***Battery Charging***

Once the VBUS > 4V and the Charge pin is HIGH, AP9928A becomes a buck converter and start to charge the battery with a preset charging profile.

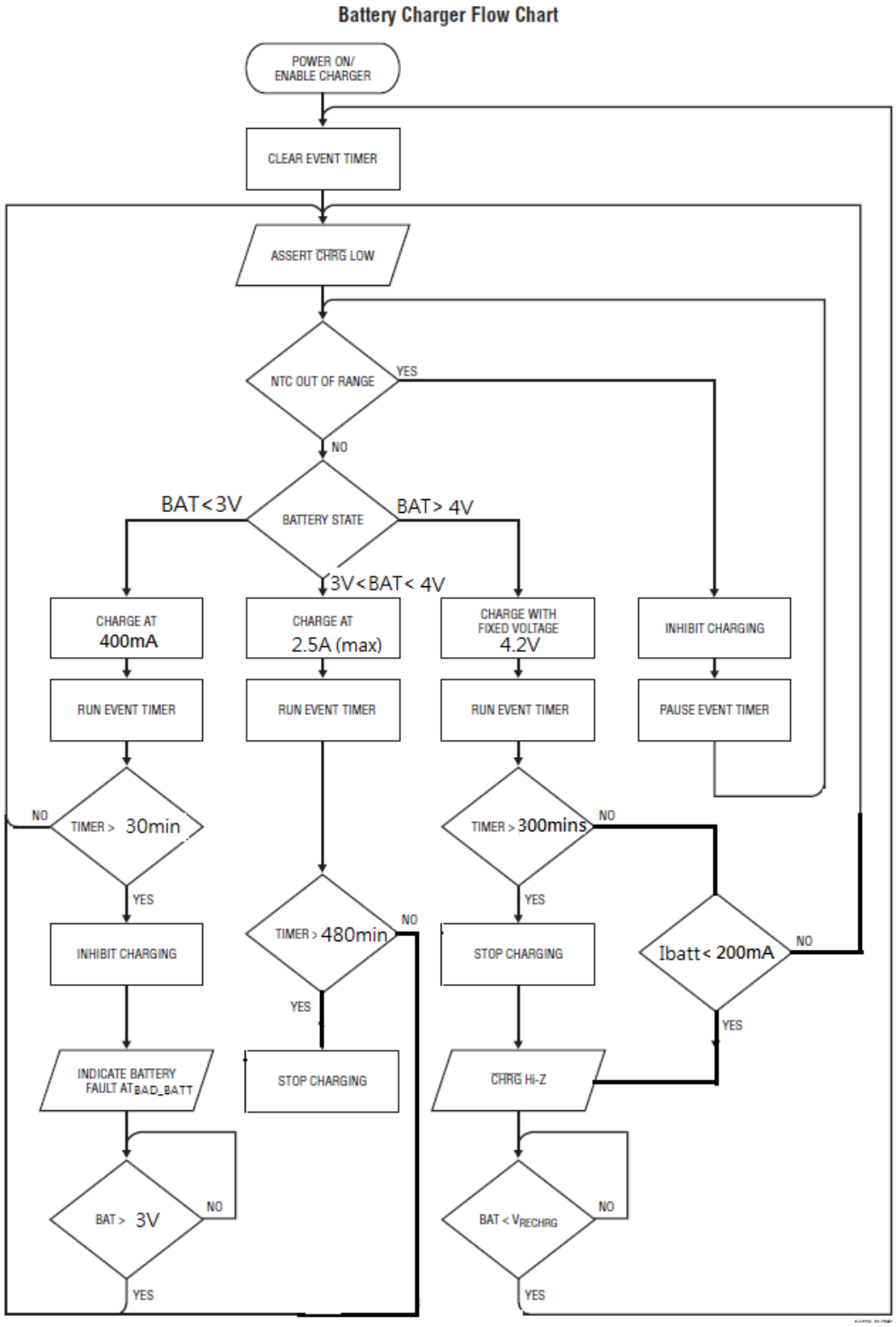



AP9928A charges the battery by the bidirectional switching regulator acts as a step-down converter in three phases, precharge, constant current and constant voltage.

When a battery charging cycle begins, the charger determines if the battery is deeply discharged. If the battery voltage is below, Vtrkl, the charger will set a charging current of ~400mA, and a 30 minutes timer will start. If the battery voltage is still remained below Vtrkl after timeout, the charging terminates. If the battery voltage hits, Vtrkl, the charger begins full power constant current mode. The charging current is continously monitored by the external current sensing resistor, 50m ohm, connected between pins CS and VBATT.

During full power charging stage, the VBUS terminal voltage is monitored. If the VBUS voltage drops below 4.5V, the charging current will reduce to avoid overloading of the input sources.

When the battery voltage reaches 4V, the charger begins constant voltage mode. The charging current will reduce and the battery voltage is regulated by the charger. When the battery voltage reaches its final value, the voltage will be regulated and the charging current will reduce. When either safety termination timer timeout or the end of charge current level is reached, the charging stops.




***Battery Charging Flow Chart***

***Boost Mode***

For USB On-The-Go applications, the bidirectional switching regulator acts as a step-up converter to deliver power from VBatt to VBUS. As a step-up converter, the bidirectional switching regulator produces 5V on VOUT and is capable of delivering at least 2000mA at VOUT=5V. USB On-The-Go will be enabled

when OTG pin is HIGH and battery voltage is above vbatt_low.

The output voltage at boost mode is defined by the ratio of resistors R20 and R19, according to the following equation:

Vout = $V_{fb\_boost}$ (1+ R20/R21))

Target value for $V_{fb\_boost}$ is 1.15V. However, this reference voltage will vary from chip to chip and should have a distribution of around +/-5%.

***Protection – NTC Thermistor***

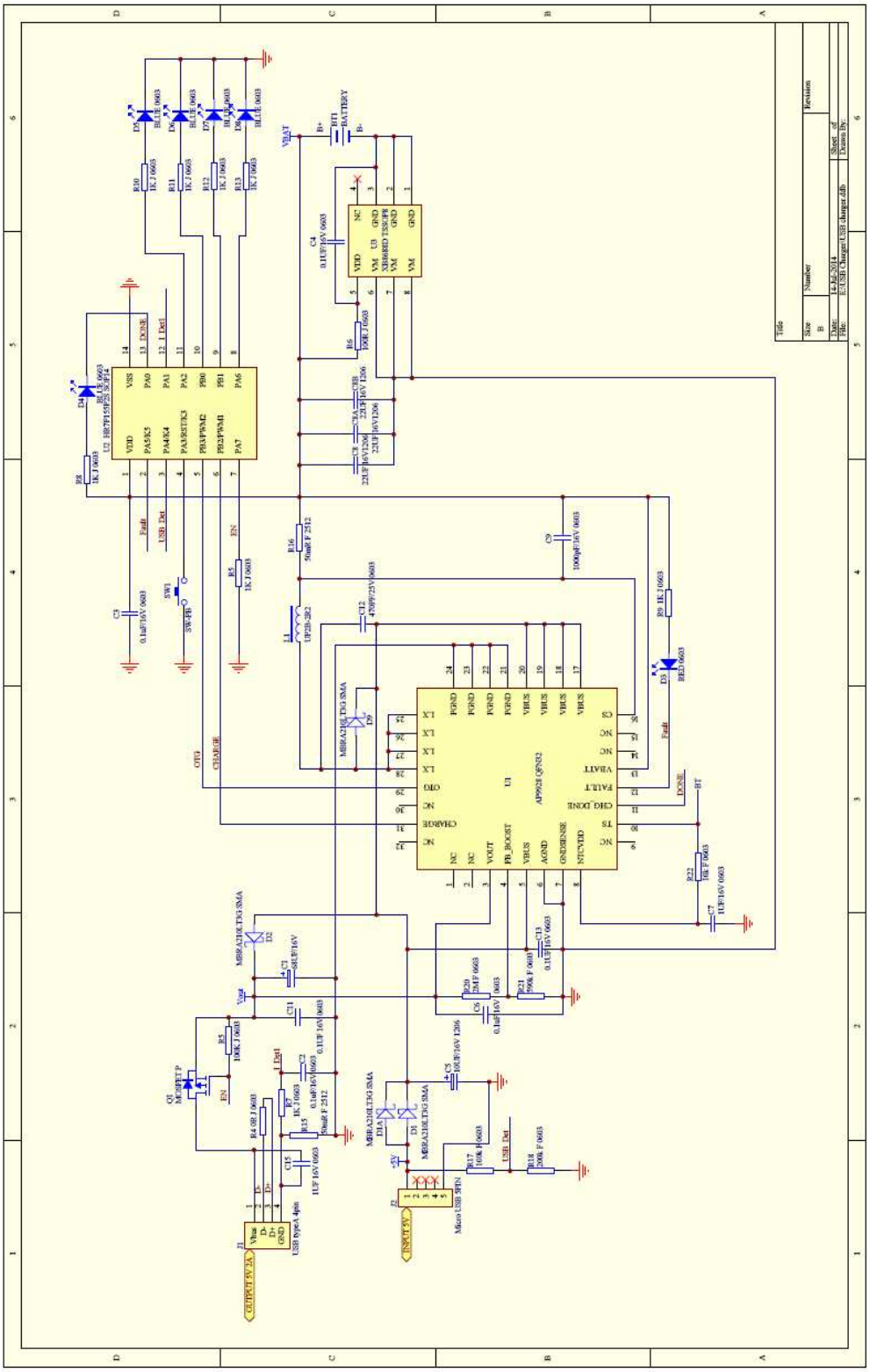
The battery temperature is measured by the negative temperature coefficient (NTC) thermistor placed close to the battery. To use this feature, connect the NTC thermistor, $R_{NTC}$, between the TS pin and ground and a bias resistor, $R_{NOM}$, from VDD to TS. $R_{NOM}$ should be a 1% 200ppm resistor with a value equal to the value of the chosen NTC thermistor at 25℃, R25.

As the temperature rises, the resistance of the NTC thermistor drops. The AP9928A will pause charging when the resistance of the NTC thermistor drops to 0.54 times the value of R25. The hot comparator has a hysteresis to prevent oscillation about the trip point.

***Critical Components Selection***

L1: Inductor, 2.2uH: UP2B-2R2, Coiltronics
D1: Schottky diode: MBRA210LT3G, On Semiconductor. 2pcs connected in parallel.
C8: Capacitor, 68uF (22uF x 3)
C7: Capacitor, 1uF
C5: Capacitor, 10uF
C1: Capacitor, 150uF
R16: Resistor, 50mΩ (60mΩ for 4.2A battery current limit)
R21: Resistor, 590kΩ
R20: Resistor, 2000kΩ
LED

# 5 Application circuit



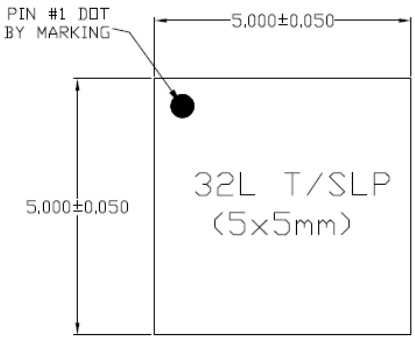
The system comprises the AP9928A controller chip, a Lithium battery protector and an MCU.

## 5.1 BOM

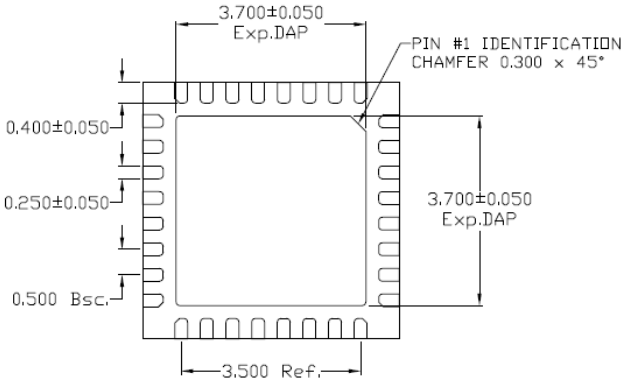
AP9928A QFN32

| Comment | Description | Designator | Footprint | LibRef | Quantity |
|---|---|---|---|---|---|
| 150μF Electrolytic cap | | C1 | | | 1 |
| 0.1uF/16V 0603 | | C3, C4, | 0603C | | 2 |
| 10UF/16V 1206 | | C5 | 1206C-T | | 1 |
| NC | | C6 | 0603C | | 1 |
| 1UF/16V 0603 | | C7 | 0603C | | 1 |
| 22UF/16V 1206 | | C8 | 1206C-T | | 3 |
| 1000pF/16V 0603 | | C9 | 0603C | | 1 |
| 470pF/25V 0603 | | C12 | 0603C | | 1 |
| MBRAF440T3 SMA or MBRA210LT3G | | D1, D9 | SMA | | 2 |
| 0R J 2010 | | D2 | SMA | | 1 |
| RED 0603 | | D3 | LED0603 | | 1 |
| BLUE 0603 | | D4, D5, D6, D7, D8 | LED0603 | | 5 |
| USB typeA 4pin | | J1, J3 | USB-A | | 2 |
| Micro USB 5PIN | | J2 | MICRO USB-B | | 1 |
| UP2B-2R2 | | L1 | UP2B | | 1 |
| 50mR F 2512 | | R5, R15, R16 | 2512R | | 3 |
| 100R J 0603 | | R6 | 0603R | | 1 |
| 1K J 0603 | | R7, R8, R9, R10, R11, R12, R13, R14, R25 | 0603R | | 9 |
| 100k F 0603 | | R17 | 0603R | | 1 |
| 200k F 0603 | | R18 | 0603R | | 1 |
| 75K F 0603 | | R19, R28 | 0603R | | 2 |
| 2M F 0603 | | R20 | 0603R | | 1 |
| 590k F 0603 | | R21 | 0603R | | 1 |
| 10k F 0603 | | R22 | 0603R | | 1 |
| 0R J 0603 | | R4, R24 | 0603R | | 3 |
| SW-PB(6*6*3mm) | | SW1 | KEY6*6-S | | 1 |
| AP9928A QFN32 | | U1 | QFN32 5*5 | | 1 |
| HR7P155P2S SOP14 | | U2 | SOP14 | | 1 |
| XB8688B | | U3 | TSSOP8 | | 1 |
| Power Bank V0.1 20140327 | | PCB | | | 1 |

# 6 Package Information



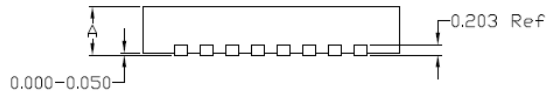

TOP VIEW




BOTTOM VIEW

NOTE:
1) TSLP AND SLP SHARE THE SAME EXPOSE OUTLINE BUT WITH DIFFERENT THICKNESS:

| | | TSLP | SLP |
|---|---|---|---|
| A | MAX. | 0.800 | 0.900 |
| | NOM. | 0.750 | 0.850 |
| | MIN. | 0.700 | 0.800 |




SIDE VIEW

# 7 Revision History

| Revision No. | Revision Date | Description |
|---|---|---|
| 0.1 | 12/06/14 | Initial release |
| 0.2 | 24/7/14 | Updated package information |
| 0.3 | 8/12/15 | Updated pin assignment table for QFN32 |

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