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AN205003

# F²MC-8FX Family Li-ion Charger Based on MB95F223

This application note describes Li-ion Battery Charger which integrates functions like composite timer and A/D converter, for charging Li-ion battery, which is suitable for down conversion.

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# 1 Introduction

This application note describes Li-ion Battery Charger based on LPC MCU MB95F223K and MB39A134, MB95F223K is a SOP16 package MCU, which integrates functions, like composite timer and 8/10 A/D converter, on chip; the MB39A134 is a DC/DC converter IC for charging Li-ion battery, which is suitable for down conversion, and uses pulse width modulation (PWM) for controlling the charge voltage and current independently.

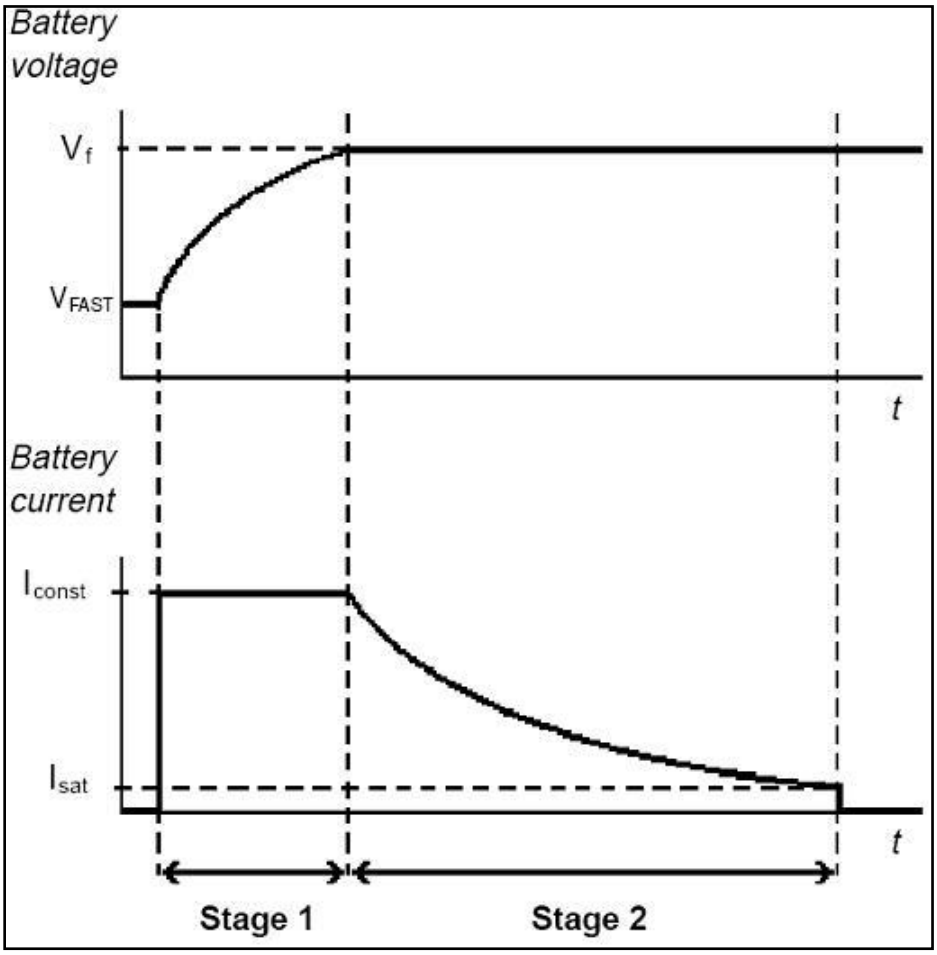
This document mainly describes the hardware and software design to implement this Li-Ion Battery Charger.

# 2 Theory of Operation

## 2.1 Battery Charging

Li-ion batteries have a very different charging procedure from NiCd or NiMH batteries. Li-ion batteries should be charged using two different methods (Figure 1), constant voltage and constant current.

Figure 1. Li-ion Charging Method




For example, charging single li-ion batteries needs two stages. During Stage 1 (constant current charge), the charging current is kept at a constant value ($I_{const}$) until the battery voltage reaches the final cell voltage ($V_F$). Note that the battery could suffer significant damage if this final voltage is exceeded. Then, in Stage 2 (constant voltage charge), the voltage is kept constant within this limit by slowly decreasing the current. Charging is stopped when the current drops below the manufacturer fixed threshold value ($I_{SAT}$). This current indicates that the battery is saturated.

If the battery voltage drops below a certain threshold ($V_{FAST}$), a fast charge is applied. After a certain time ($t_{FAIL}$) of fast charging, and if battery voltage remains particularly low (under $V_{FAIL}$), the charger indicates a battery failure and stops charging.

If the charging time exceeds a certain expiration value ($t_{EXP}$), charging is stopped even if the battery is not yet saturated. As the $t_{EXP}$ value is greater than the $t_{FAIL}$ value, the charger indicates that the battery is in good condition and fully charged

The battery temperature is also monitored. If the battery overheats, charging is suspended until the battery cools down.

Once the battery is saturated, its voltage is still monitored to prevent the battery from discharging completely. If the battery voltage drops below $V_{TRI}$, charging restarts until $V_F$ is reached again. Charge time is reset when trickle charging starts.

Charge Parameters used by the Evaluation Board:

Table 1.Charge Parameters

| Symbol | Meaning | Value | Unit |
|---|---|---|---|
| $V_F$ | Final Battery Voltage | 4.2 | V |
| $V_{TRI}$ | Trickle Charge Voltage | 1.0 | |
| $V_{FAST}$ | Fast Charge Voltage | 3.0 | |
| $V_{FAIL}$ | Battery Failure Voltage | 1.0 | |
| $I_{CONST}$ | Constant Charge Current | 2.0 | A |
| $I_{SAT}$ | Battery Saturation Current | 100 | mA |
| $T_{FAIL}$ | Battery Failure Time | 1 | H |
| $T_{EXP}$ | Charge Expire Time | 4 | |

## 2.2 Man-Machine Interface

As the charger periodically checks battery presence, no button is needed to start or stop charging.

A reset button is included on the evaluation board for development purposes.

A pair of LEDs (green/red) is dedicated to each slot to indicate the charge status.

Table 2. LED Color and Status

| Color | Status |
|---|---|
| Off | No battery or bad battery or No charging |
| Red only | Battery under charge |
| Red and green | Overheat or super-cooling |
| Green only | Battery full |
| Flashing red | Trickle charge |
| Flashing green | Fast charge |

# 3 Li-Ion Battery Charger features

The MB39A134+LPC Li-Ion Battery Charger have the following features:

- Input voltage:8-25V
- Charge current: 0.2A-5A
- Supports 2, 3 and 4 cell battery pack by setting the CELLS pin
- Charge voltage can be set as 4.1V/cell or 4.2V/cell by setting the ADJ3 pin
- Over voltage protection
- Overcharge protection to prevent damaging the battery
- Overcurrent protection in the event of a shorted battery
- Battery insertion detection
- Faulty battery detection
- Over temperature protection to prevent the battery from reaching too high a temperature during charge

- Supports CC/CV mode charge
- Supports Trickle charge (on Li-battery is under 3.0V)
- Supports full charge detection
- Charge voltage setting accuracy ±0.7%(on 4.2V setting)

**Li-Ion Battery Charger Specification:**

Table 3. Li-Ion Battery Charger Specification

| Parameter | MIN | TYP | MAX | Unit |
|---|---|---|---|---|
| Input voltage | 8 | 19 | 25 | V |
| Output voltage | 4.1 | 12.6 | 16.8 | V |
| Output current | 0 | 2 | 5 | A |

**Note:** This solution is applied to the application it does not required charge current monitor at full charge.

# 4 Li-Ion Battery Charger Hardware Design

## 4.1 Hardware Block Diagram

Figure 2. Hardware Block Diagram

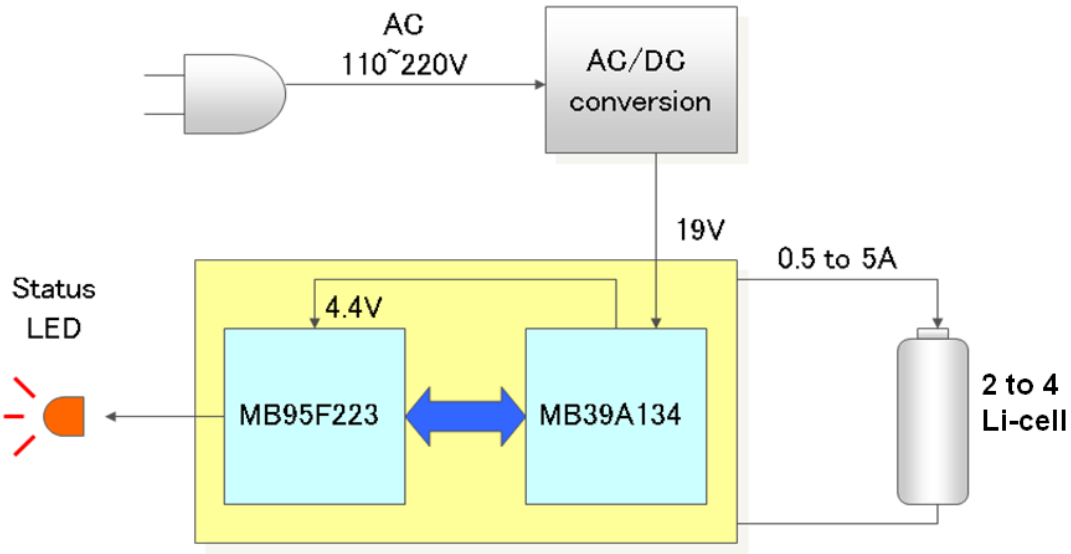
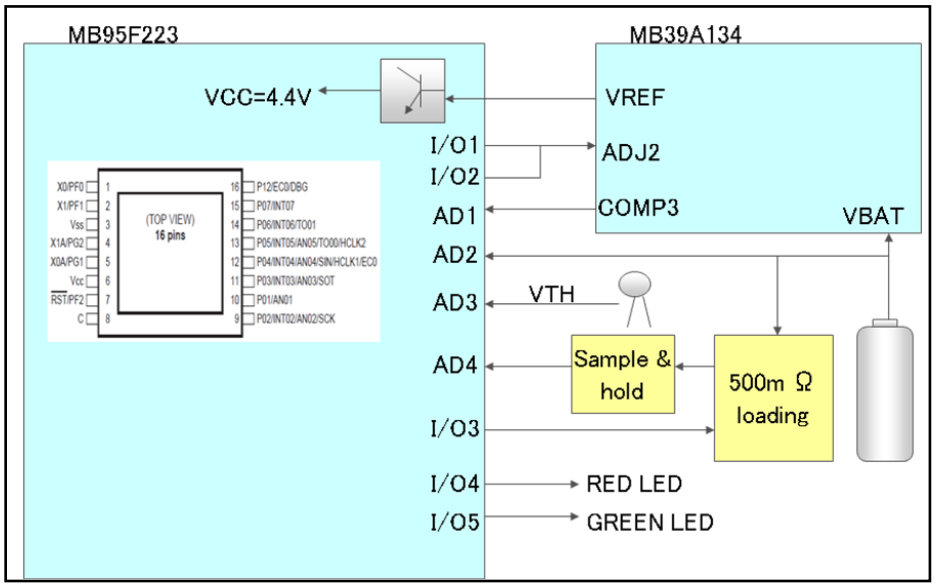


Figure 3. MCU Pin Assignment

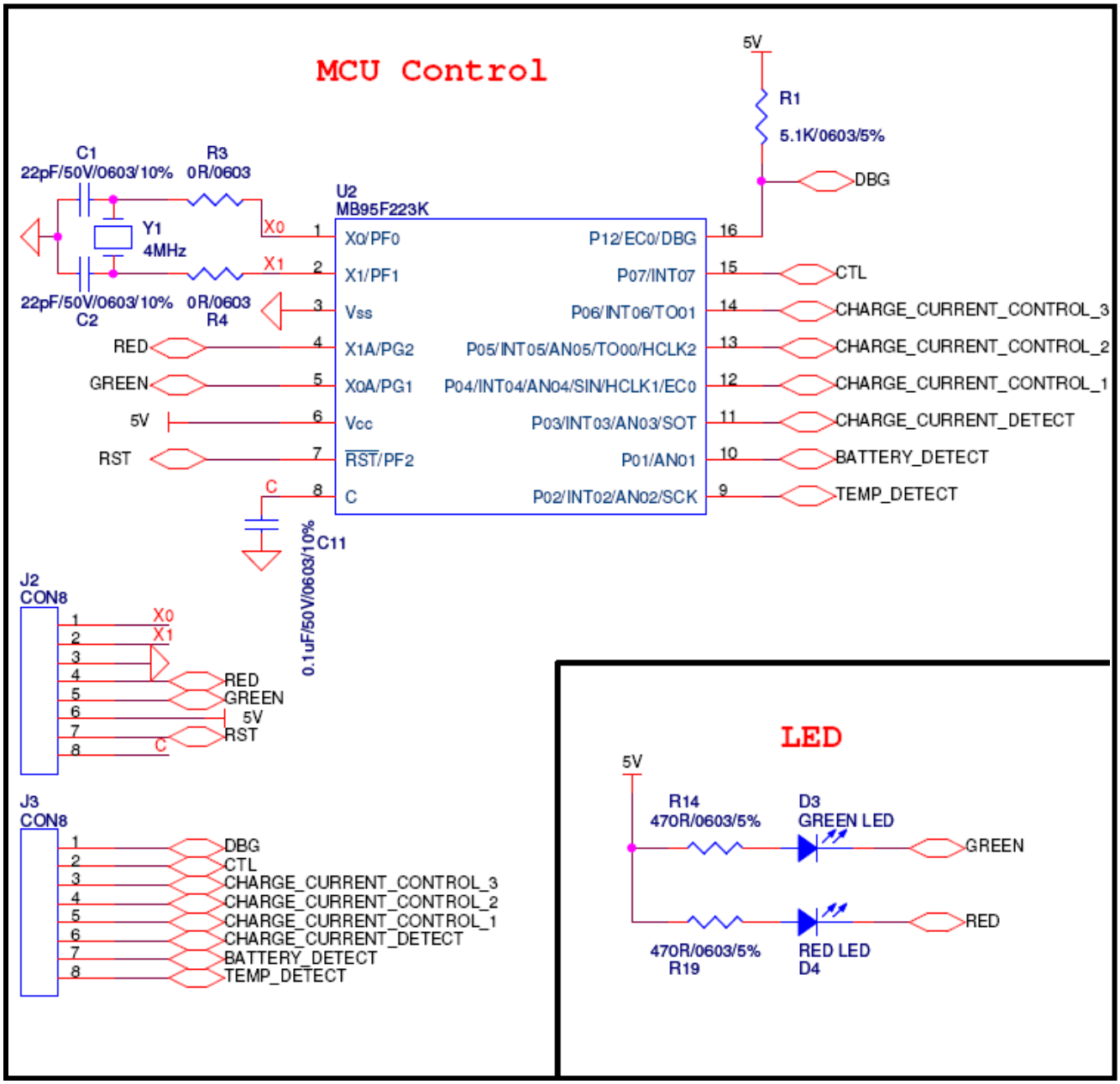


## 4.2 MCU Control Circuit

The P06, P05 and P04 are used to control charge current. A/D channel 3 is used to detect charge current. A/D channel 1 is used to detect charge voltage. A/D channel 2 is used to detect cell temperature. P07 is used to control charge mode. PG2 and PG1 are used to control 2 LEDs which indicate charge status. 4M crystal is used as main clock. DBG pin is used as debug pin.

Below figure shows MCU control circuit.

Figure 4. MCU Control Circuit



## 4.3 Charger Main Control Circuit

AO4425 is a P-Channel mode field effect transistor, G pin is the base of AO4425, which is controlled by PWM output of MB39A134.

The charger voltage depends on the Pin ADJ3 and CELLS setting, shown at below table. Besides, the charger voltage should be lower than system input voltage. By default, ADJ3 pin is connected to VREF. The number of cell depends on CELLS pin setting.

Table 4. ADJ3 and CELLS Setting

| ADJ3 Input Voltage | CELLS | Charge Voltage | Note |
|---|---|---|---|
| VREF pin (ADJ3 ≥ 4.6 V) | OPEN | 8.4 V | 2 Cell × 4.20 V/Cell |
| | GND | 12.6 V | 3 Cell × 4.20 V/Cell |
| | VREF | 16.8 V | 4 Cell × 4.20 V/Cell |
| GND pin (ADJ3 ≤ 0.2 V) | OPEN | 8.2 V | 2 Cell × 4.10 V/Cell |
| | GND | 12.3 V | 3 Cell × 4.10 V/Cell |
| | VREF | 16.4 V | 4 Cell × 4.10 V/Cell |
| External voltage setting (ADJ3 = 0.4 V to 4.4 V) | OPEN | 4 × ADJ3 pin voltage | 2 Cell × 2 × ADJ3 pin voltage/Cell |
| | GND | 6 × ADJ3 pin voltage | 3 Cell × 2 × ADJ3 pin voltage/Cell |
| | VREF | 8 × ADJ3 pin voltage | 4 Cell × 2 × ADJ3 pin voltage/Cell |

**Note:** Charge single cell, ADJ3 pin connected to external voltage 1.05V and CELLS pin set open.

Table 5. CELLS Setting

| Reference Name | Function | OPEN | AGND | VREF |
|---|---|---|---|---|
| CELLS | Numbers of CELL Selection | 2 CELLS | 3 CELLS | 4 CELLS |

**Note:** Charge single cell, ADJ3 pin connected to external voltage 1.05V and CELLS pin set open.

The PWM rate (open rate of AO4425) depends on charge voltage and current, charge voltage can be set by ADJ3 and CELLS pin, and charge current can be set by ADJ2, which is indirectly controlled by 3 IO ports of MCU.

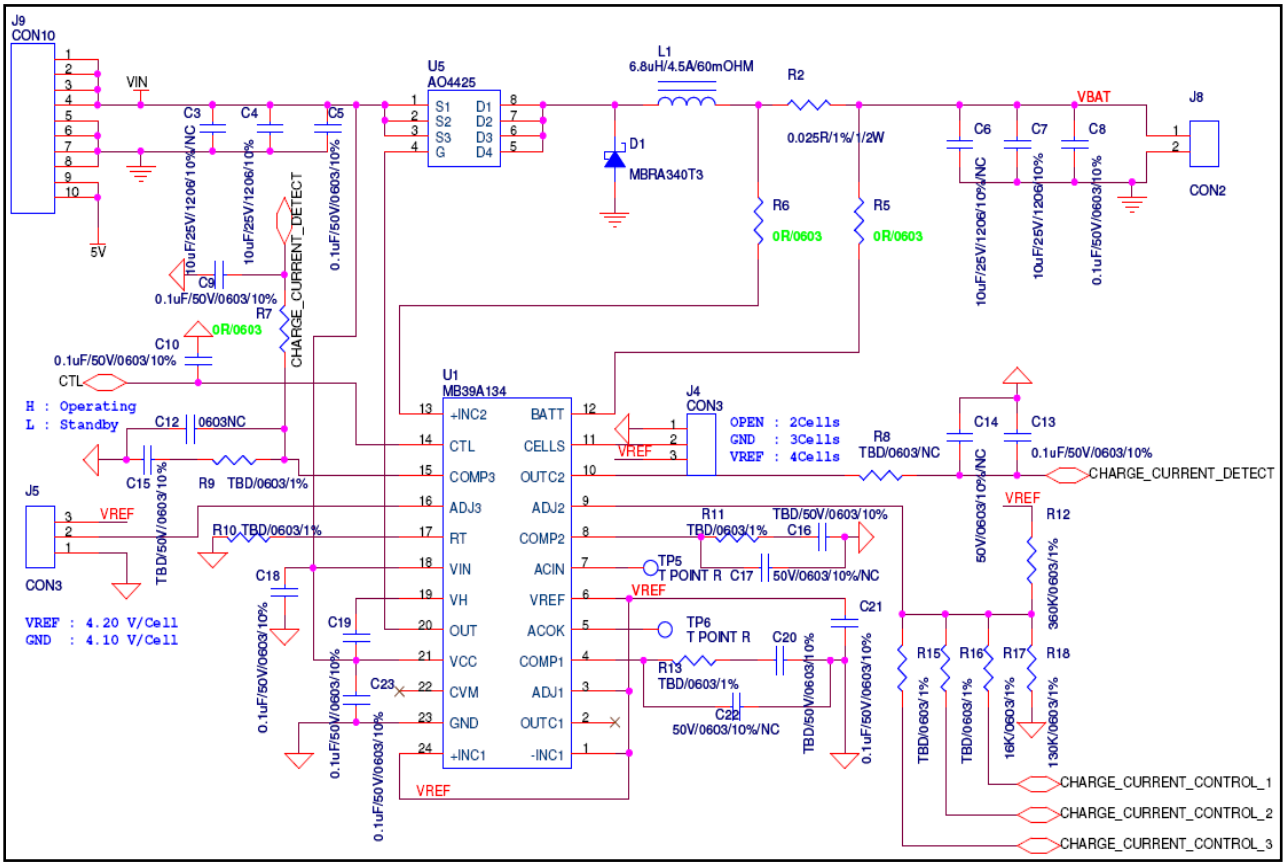
Table 6. ADJ2, Battery Charge Current Setting Voltage

| ADJ2 Input Voltage | Charge Current Control Block Output Voltage | Charge Current | | |
|---|---|---|---|---|
| | | R5 = 40 mΩ | R5 = 20 mΩ | R5 = 15 mΩ |
| VREF (ADJ2 > 4.6 V) | 1.5 V | 1.425 A | 2.85 A | 3.79 A |
| External Voltage Setting (ADJ2 = GND to 4.4 V) | VADJ2(V) | VADJ2-0.075(A) | 2 × (VADJ2-0.075) (A) | 2.66 × (VADJ2-0.075) (A) |

The charge current (R2's current) is detected by +INC2 and BATT pin of MB39A134, as it integrates an amplifier on chip and can amplify the current signal, which may be so weak that it cannot be identified by MCU internal 8/10 bit A/D converter. And the OUTC2 pin outputs the amplified current that inputs MCU A/D channel. The charge voltage (VBAT) can be directly detected by MCU internal A/D converter.

Below figure shows the main control circuit of charger, the main unit in this circuit is MB39A134.

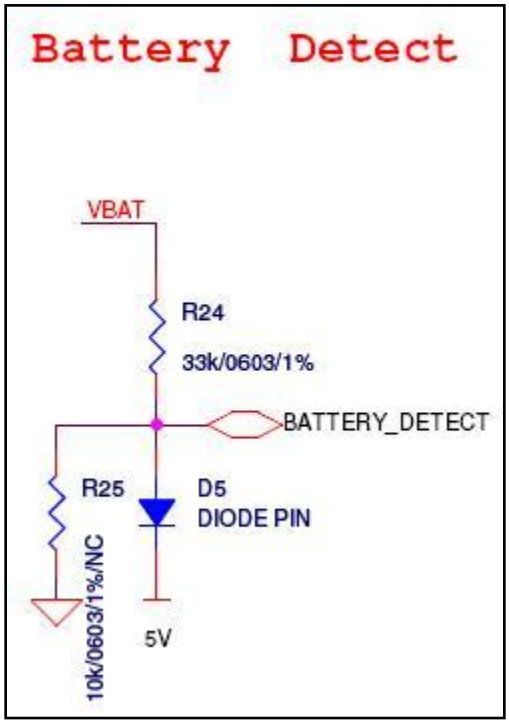
Figure 5. Charger Main Control Circuit



## 4.4 Battery Voltage Detect Circuit

Below figure shows the battery voltage detection circuit. The battery voltage signal is directed to one A/D converter analogy input pin of MCU.

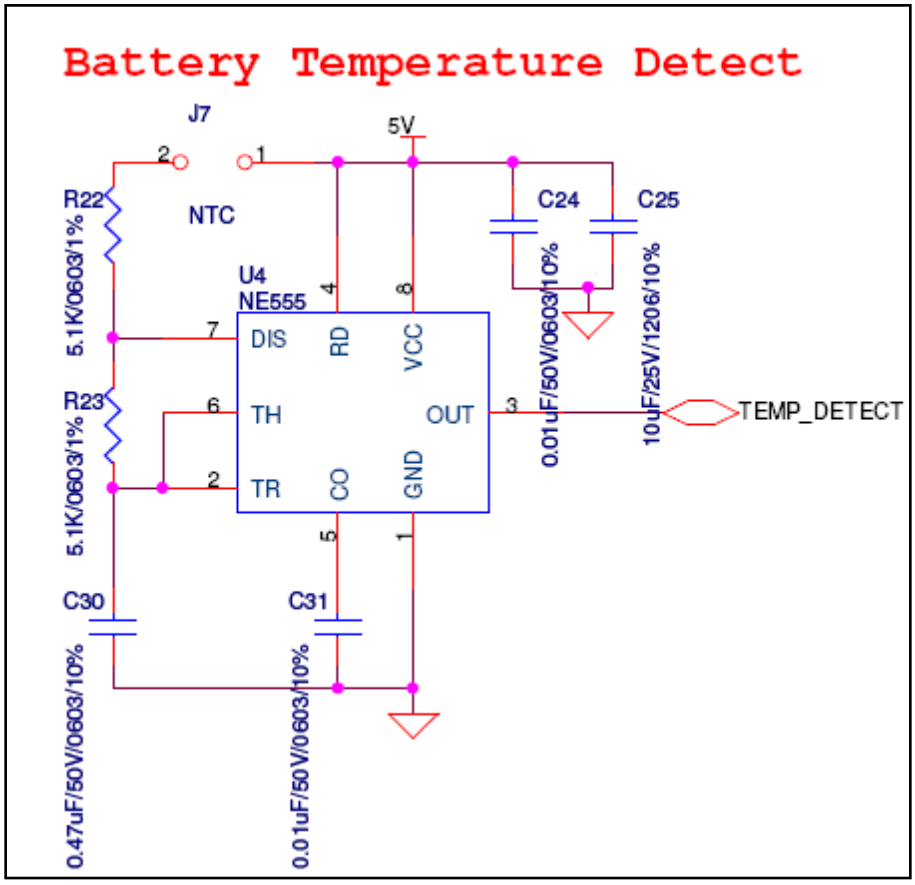
Figure 6. Battery Voltage Detect Circuit



## 4.5 Battery Temperature Detect Circuit

Below figure shows the battery temperature detection circuit. The battery temperature signal is directed to one A/D converter analogy input pin of MCU.

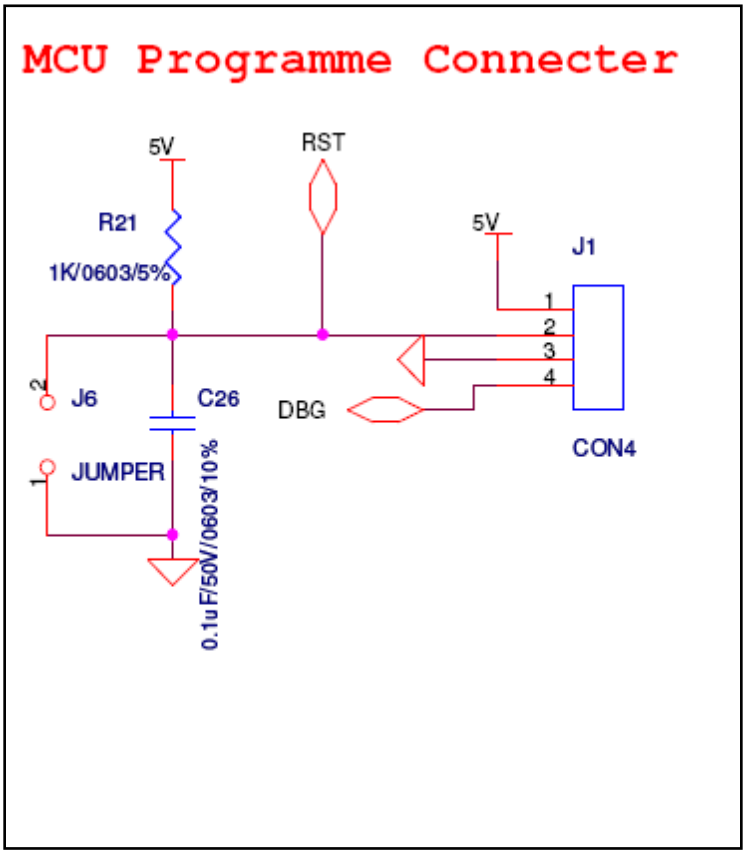
Figure 7. Battery Temperature Detects Circuit



## 4.6 MCU Programme Circuit

Below figure shows the MCU programmer circuit. J1 is connected to BGM Adaptor and JUPMER is the reset key.

Figure 8. MCU Programme Connecter Circuit



## 4.7 Terminal Information

Table 7. Terminal J1-J9 Information

| Reference name | Description |
|---|---|
| J1 | MCU program download and On-chip debug terminal |
| J2 | 1 to 8 pin terminal of MCU |
| J3 | 9 to 16 pin terminal of MCU |
| J4 | Numbers of cell selection terminal |
| J5 | Charge voltage selection terminal |
| J6 | Manual reset terminal |
| J7 | NTC terminal |
| J8 | Power output terminal |
| J9 | Power input terminal and +5V output terminal |

Table 8. Terminal ADJ3 Connect

| Reference Name | Function | OPEN | AGND | VREF |
|---|---|---|---|---|
| ADJ3 | Numbers of CELL Selection | 2 CELLS | 3 CELLS | 4 CELLS |

**Note:** Charge single cell, ADJ3 pin connected to external voltage 1.05V and CELLS pin set open.

Table 9. Terminal ADJ2 Connect

| Reference Name | Function | AGND | VREF |
|---|---|---|---|
| ADJ2 | Charge voltage Selection | 4.1V/cell | 4.2V/cell |

# 5 Li-Ion Battery Charger Software

## 5.1 Software Description

Firstly MCU initializes the on-chip peripherals and initializes the system parameters when the battery has been detected. If the single battery voltage is above 1V, then enter the trickle charge and charge current is 0.1C. When the trickle charge time is over 1hour, it shows the battery is fault.

When it is detected that the single battery voltage is above 3V, the system will enter fast charge and start with 1C charge current. In the fast charge status, the MCU compares detected temperature and voltage, if COMP4 voltage of MB39A134 is under 1.6V, the cell will be considered charge fully, and enters the battery full status and charge current is under 0.1C.

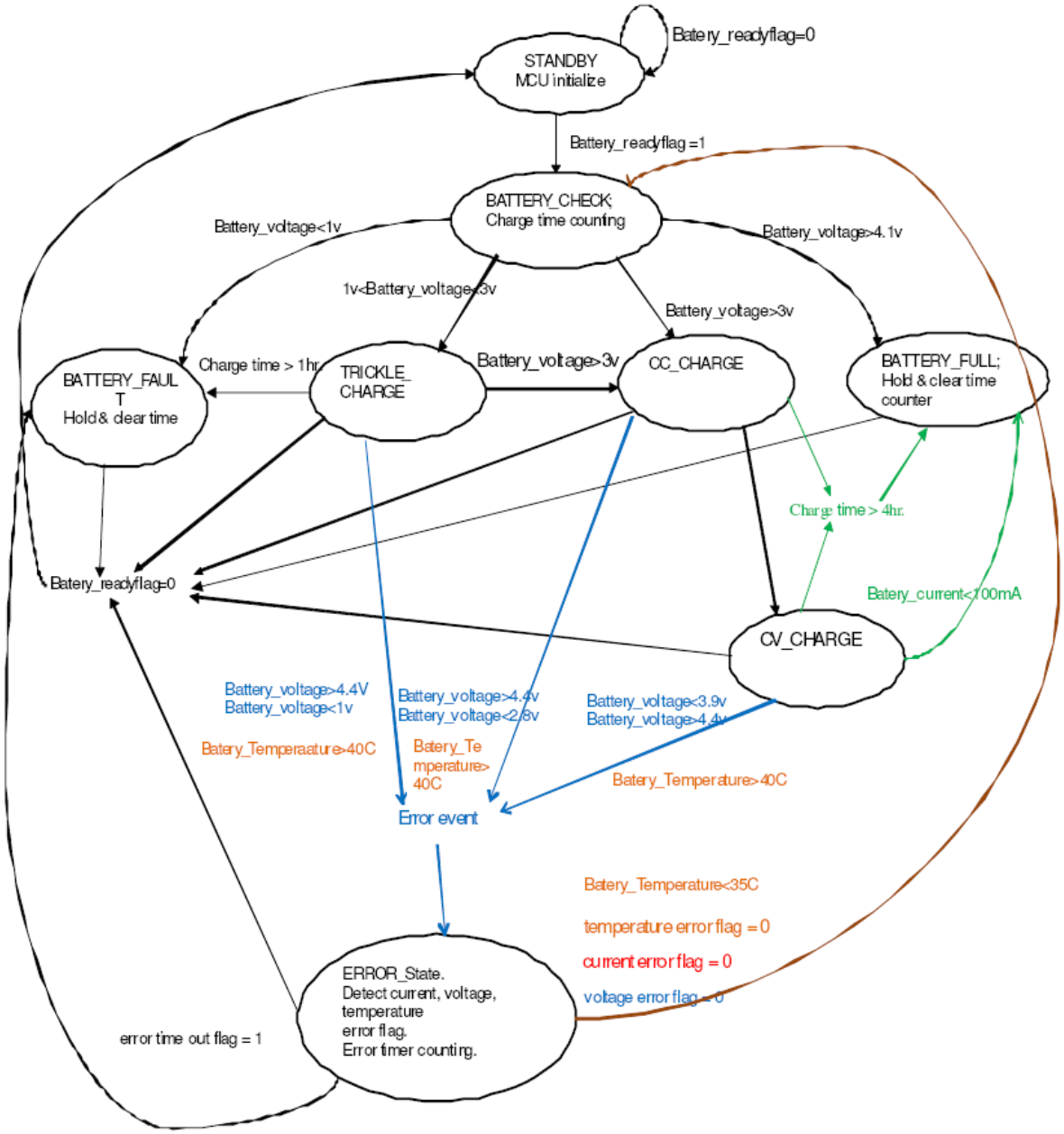
If any battery voltage and temperature parameter is abnormal, charger will enter battery error status and shut down MB39A134, and next charge process will be halted.

In the error status, MCU will wait voltage and temperature parameters return to normal. Charger will go back to the charging status. If maintain time is over 20mins, charger still in the error status, it will enter the battery fault status.

In normal status, if the charge time reaches the maintain charge time (4hours). The charge process finishes.

## 5.2 State Diagram

Figure 9 : Li-Ion Battery Charger State Diagram



## 5.3 Battery Inserted Detection

When battery insertion is detected, the firmware will go on to check the inserted battery's voltage and temperature. If it falls in the valid range, then proceed to charging mode.

$V_{bat}$ < 1.0V No charging, bad\no battery, all LED off.

$V_{bat}$ > 4.2V Battery full, no charging, green LED on.

1.0V < $V_{bat}$ < 3.0VTrickle charge, red LED flash.

Tickle charging time from 0V to 3.0V is less than 1 hour, otherwise battery is bad, turn all LEDs off.

3.0V < $V_{bat}$ < 4.1VCC\CV charging mode, green LED flash.

$V_{temp}$ < 0°C No charging. Red LED on.

$V_{temp}$ > 45°C No charging. Red LED on.

I_charge > 1C Overcurrent, stop charging, red LED on.

If the current less than 0.1C and $V_{bat}$ >4.1V, announce the battery is full.

## 5.4 Trickle Charge

If the battery voltage is lower than 3.0V, then go to trickle charge. The current for trickle charge is set to 0.1C to 0.2C which equals to the 10% or 20% of the battery's rate capacity, and the max. Charge time is 1 hour. If within 1 hour time, the battery voltage rises above 3.0V. It means the battery is a good battery and the charger can then switch to fast charging mode. If the voltage does not rise up to 3.0V after 1 hour trickle charge, the charger will signify that the battery is a bad battery and stop the charging process.

## 5.5 Fast Charge

The fast charging is divided into two states. They are constant current charging and constant voltage charging. A max charging time is also set for the fast charging mode. If outside 4 hour time, it means the battery is full in fast charge mode.

## 5.6 Constant Current Charging

Constant current charging mode is a close loop control. The firmware continuously checks the charging current by sensing the voltage at the current sense resistors (R24, R25). The battery's voltage is checked frequently. Whenever found the battery's voltage reaches or above 4.1V, the charger will switch to constant voltage charging mode.

## 5.7 Constant Voltage Charging

In constant voltage charging state, the battery voltage is checked and maintained at 4.1V by controlling the duty of PWM output. The charging current will gradually decrease when the battery is close to battery full.

The battery is announced charge full and charging power is cut off when the charging current is less than 100mA.

## 5.8 Safety Protection

During charging, either in trickle charge, constant current charge or constant voltage charge, if it is detected that the battery's voltage, current or temperature is out of range, the charger will cut off the charging power. Table 10 shows the system state transfer and abnormal event when charging.

Table 10. State Transfer Table

| State | Event | next state |
|---|---|---|
| Start | Initialize | battery voltage check |
| battery voltage check | battery_voltage<1v | battery_fault |
| | battery_voltage>4.1v | battery_full |
| | 1v<battery_voltage<3v | trickle charge mode |
| | battery_voltage>3v | CC_charge mode |
| battery_fault | battery_readyflag = 0 | Start |
| battery_full | battery_readyflag = 0 | Start |
| trickle charge mode | charge time>1hr. | battery_fault |
| | battery_readyflag = 0 | Start |
| | battery_voltage>4.4v \| battery_voltage<1v<br>battery_current >0.2C<br>battery_temperature>40 | error handle |
| | battery_voltage>3v | CC_charge mode |
| CC_charge mode | charge_time>4hr. | battery_full |
| | battery_readyflag = 0 | Start |
| | battery_voltage>4.1v | CV_charge mode |
| | battery_voltage>4.4v \| battery_voltage<2.8v<br>battery_current<0.8C \| battery_current>1.2C<br>battery_temperature>40 | error handle |
| CV_charge mode | battery_readyflag = 0 | Start |
| | charge_time>4hr.\| battery_current<100mA | battery_full |
| | battery_voltage>4.4v \| battery_voltage<3.9v<br>battery_current>1.2C<br>battery_temperature>40 | error handle |
| error handle | temperature error flag = 0<br>voltage error flag = 0(need return error occur layer)<br>current error flag = 0(need return error occur layer) | battery voltage check |
| | error time out flag = 1 | battery_fault |

## 5.9 Source File

Code is written in C language and Table 10 summarizes the functions of each source files.

Table 11. Software Source File

| Files | Functions |
|---|---|
| Main.c | Charger main program |
| MB95200.ASM | Registers and memory definitions |
| STARTUP.ASM | Initialization MCU |
| VECTORS.C | Define Interrupt vector and Interrupt level setting |
| MB95200.H | Define MCU register and IO ports |

# 6 Conclusion

The MB39A134+LPC Li-Ion Battery Charger demonstrates Cypress Pulse Width Modulator (the MB39A134) used in a battery charger application.

The Li-Ion Battery Charger supports max four cells to charger, 8-25V input voltage and 0.2A -5A charge current. It can protect the cells and charger when the charger is under overvoltage, overcharge, overcurrent and over temperature statuses.

# 7 Additional Information

For more Information on Cypress Semiconductor products, visit the following web sites:

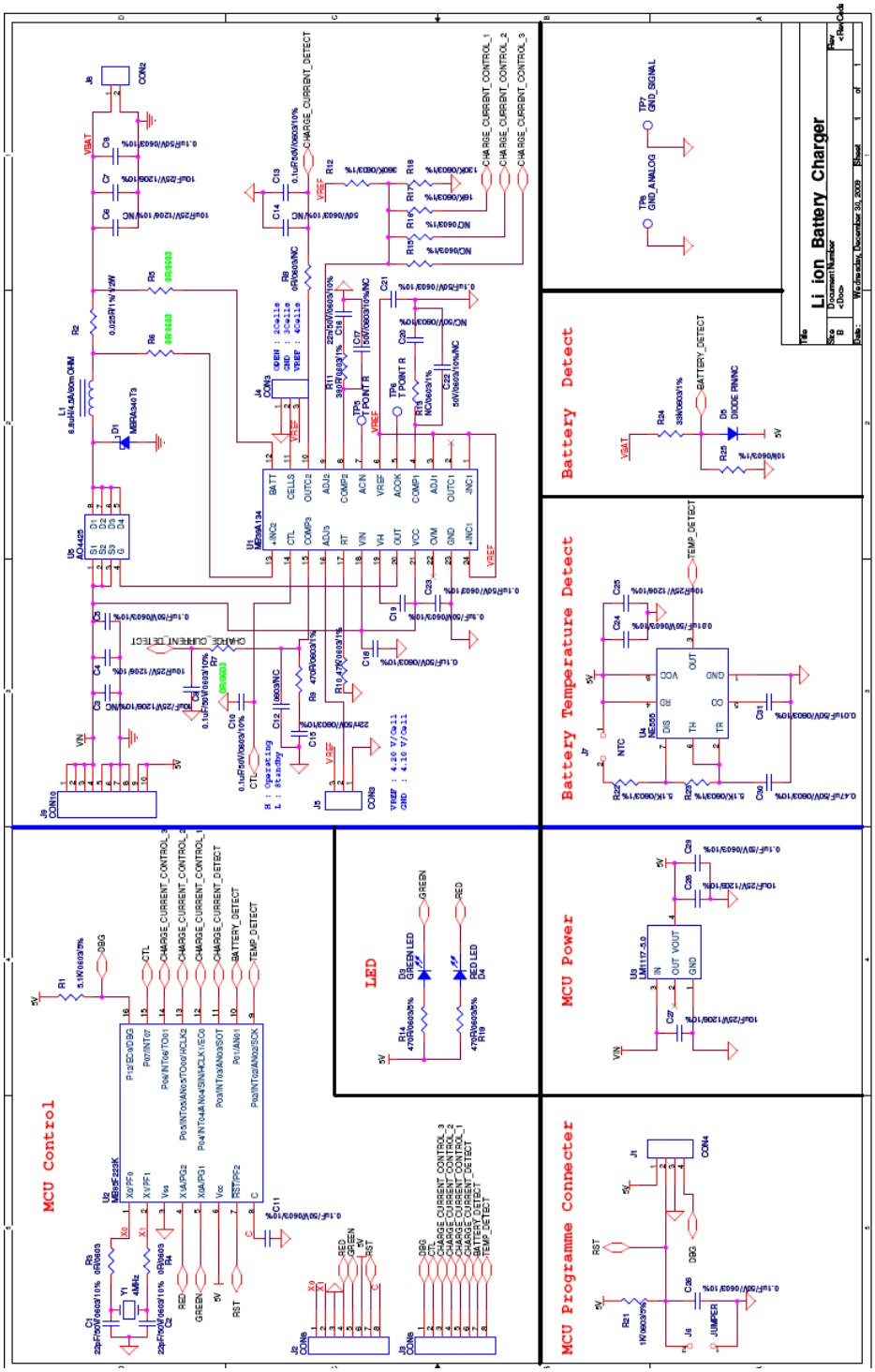
English version:

http://www.cypress.com/supporttools/8fx

http://www.cypress.com/8fx-mb95200

# 8 Schematic

Figure 10. Schematic



## 8.1 Evaluation Board Layout

Figure 11. PCB Layout

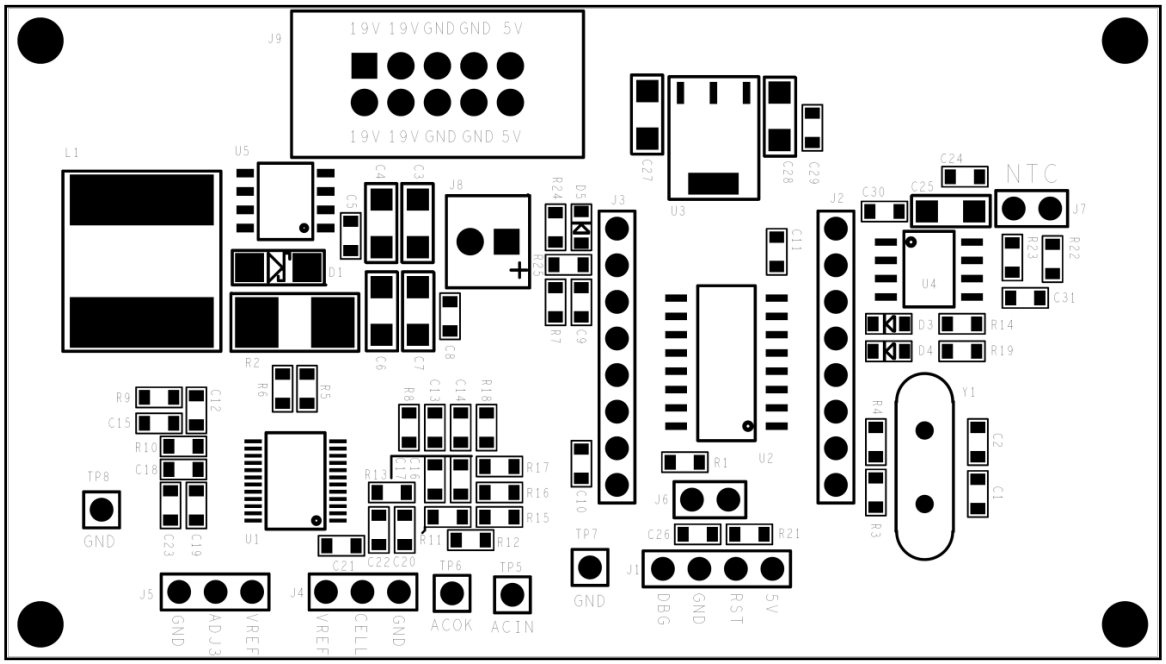



Figure 12. PCB Layout Top Layer

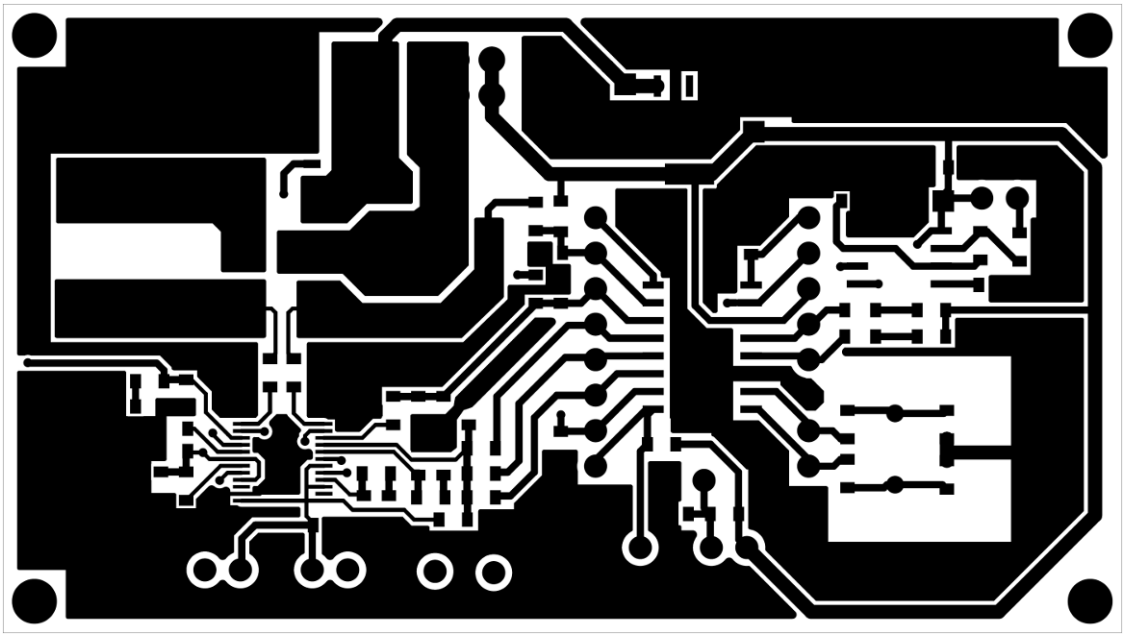
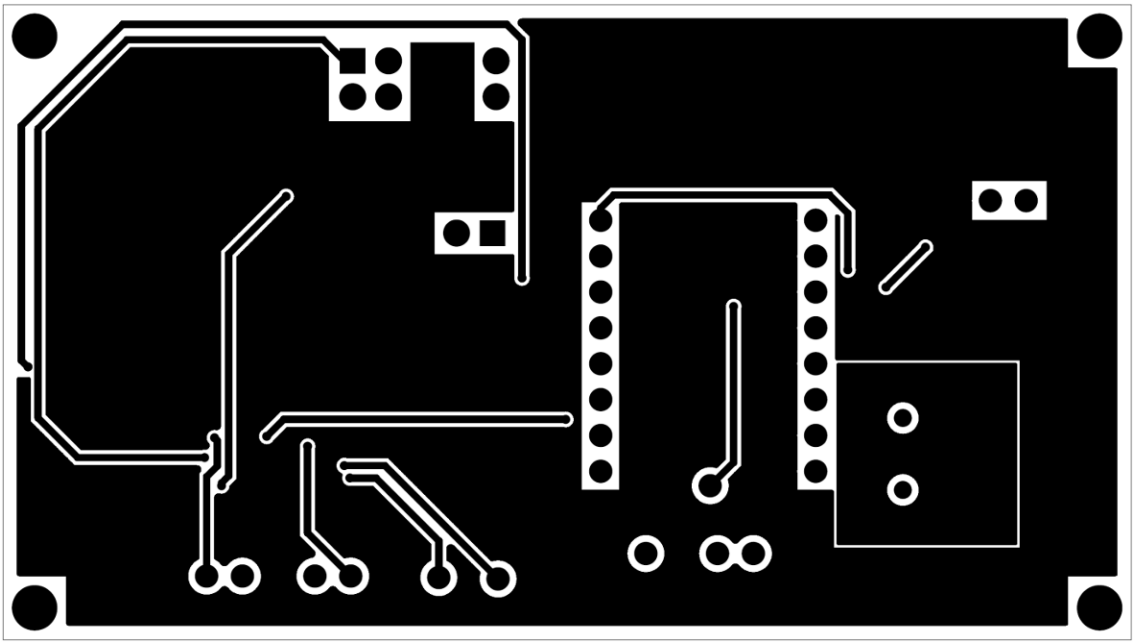


Figure 13. PCB Layout



## 8.2 Bill of Materials

| Item | Quantity | Reference | Part |
|---|---|---|---|
| 1 | 2 | C1,C2 | 22pF/50V/0603/10% |
| 2 | 2 | C3,C6 | 10uF/25V/1206/10%/NC |
| 3 | 5 | C4,C7,C25,C27,C28 | 10uF/25V/1206/10% |
| 4 | 12 | C5,C8,C9,C10,C11,C13,C18, C19,C21,C23,C26,C29 | 0.1uF/50V/0603/10% |
| 5 | 1 | C12 | 0603/NC |
| 6 | 3 | C14,C17,C22 | 50V/0603/10%/NC |
| 7 | 2 | C15,C16 | 22n/50V/0603/10% |
| 8 | 1 | C20 | NC/50V/0603/10% |
| 9 | 2 | C24,C31 | 0.01uF/50V/0603/10% |
| 10 | 1 | C30 | 0.47uF/50V/0603/10% |
| 11 | 1 | D1 | MBRA340T3 |
| 12 | 1 | D3 | GREEN LED |
| 13 | 1 | D4 | RED LED |
| 14 | 1 | D5 | DIODE PIN/NC |
| 15 | 1 | J1 | CON4 |
| 16 | 2 | J2,J3 | CON8 |
| 17 | 2 | J4,J5 | CON3 |
| 18 | 1 | J6 | JUMPER |
| 19 | 1 | J7 | NTC |
| 20 | 1 | J8 | CON2 |
| 21 | 1 | J9 | CON10 |
| 22 | 1 | L1 | 6.8uH/4.5A/60mOHM |
| 23 | 1 | R1 | 5.1K/0603/5% |
| 24 | 1 | R2 | 0.025R/1%/1/2W |
| 25 | 5 | R3,R4,R5,R6,R7 | 0R/0603 |
| 26 | 1 | R8 | 0R/0603/NC |
| 27 | 1 | R9 | 470R/0603/1% |
| 28 | 1 | R10 | 47K/0603/1% |
| 29 | 1 | R11 | 390R/0603/1% |
| 30 | 1 | R12 | 360K/0603/1% |
| 31 | 3 | R13,R15,R16 | NC/0603/1% |
| 32 | 2 | R14,R19 | 470R/0603/5% |
| 33 | 1 | R17 | 16K/0603/1% |
| 34 | 1 | R18 | 130K/0603/1% |
| 35 | 1 | R21 | 1K/0603/5% |
| 36 | 2 | R22,R23 | 5.1K/0603/1% |
| 37 | 1 | R24 | 33k/0603/1% |

| Item | Quantity | Reference | Part |
|---|---|---|---|
| 38 | 1 | R25 | 10k/0603/1% |
| 39 | 2 | TP5,TP6 | T POINT R |
| 40 | 1 | TP7 | GND_SIGNAL |
| 41 | 1 | TP8 | GND_ANALOG |
| 42 | 1 | U1 | MB39A134 |
| 43 | 1 | U2 | MB95F223K |
| 44 | 1 | U3 | LM1117-5.0 |
| 45 | 1 | U4 | NE555 |
| 46 | 1 | U5 | AO4425 |
| 47 | 1 | Y1 | 4MHz |

## Document History

Document Title: AN205003 - F²MC-8FX Family Li-ion Charger Based on MB95F223

Document Number: 002-05003

| Revision | ECN | Orig. of Change | Submission Date | Description of Change |
|---|---|---|---|---|
| ** | - | HUAL | 12/27/2009 | Initial release. |
| | | | 01/05/2010 | Added theory of operation and update hardware design and software |
| | | | 01/11/2010 | Update state diagram and safety protection |
| | | | 03/21/2012 | Update the features and Hardware Block Diagram |
| *A | 5265599 | HUAL | 05/11/2016 | Migrated Spansion Application Note from MCU-AN-500075-E-13 to Cypress format. |
| *B | 5817679 | AESATMP8 | 07/14/2017 | Updated logo and Copyright. |

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