Document Number: KTRD9Z1-638-4LiUG
Rev. 1.0, 3/2014

# RD9Z1-638-4Li Reference Design

## Intelligent 4-Cell Lithium Battery Management with CAN/LIN Interface Featuring the MM9Z1_638, MC33901, and MC33879

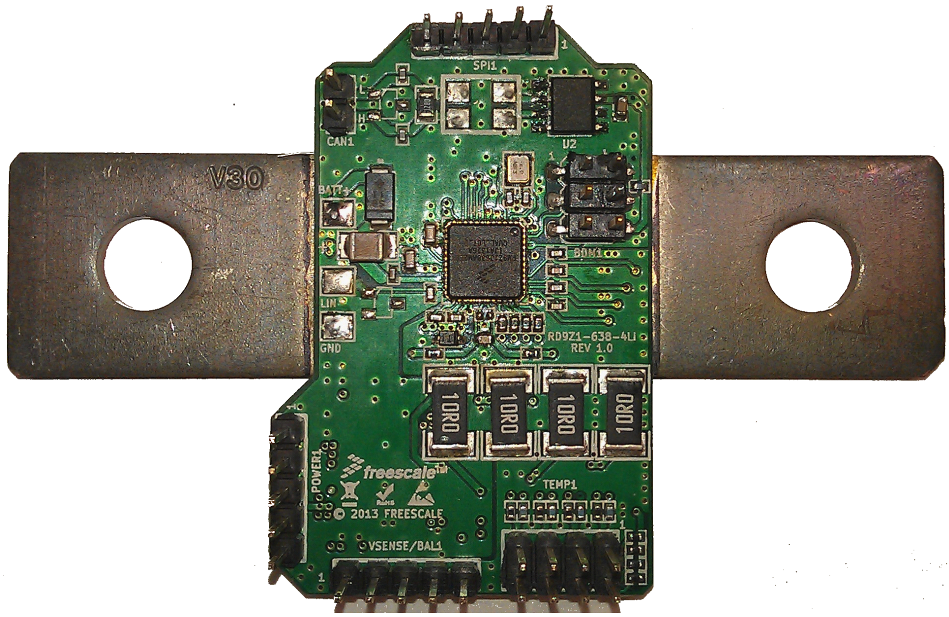



**Figure 1. RD9Z1-638-4Li Reference Design**

# Contents

# 1 Kit Contents/Packing List

- Assembled and tested 100 μΩ shunt board in an anti-static bag
- Warranty card

# 2 Jump Start

- Go to www.freescale.com/analogtools
- Locate your kit
- Review your Tool Summary Page
- Look for

**Jump Start Your Design**

- Download documents, software, and other information

# 3 Important Notice

Freescale provides the enclosed product(s) under the following conditions:

This reference design is intended for use of ENGINEERING DEVELOPMENT OR EVALUATION PURPOSES ONLY. It is provided as a sample IC pre-soldered to a printed circuit board to make it easier to access inputs, outputs, and supply terminals. This reference design may be used with any development system or other source of I/O signals by simply connecting it to the host MCU or computer board via off-the-shelf cables. Final device in an application will be heavily dependent on proper printed circuit board layout and heat sinking design as well as attention to supply filtering, transient suppression, and I/O signal quality.

The goods provided may not be complete in terms of required design, marketing, and or manufacturing related protective considerations, including product safety measures typically found in the end product incorporating the goods. Due to the open construction of the product, it is the user's responsibility to take any and all appropriate precautions with regard to electrostatic discharge. In order to minimize risks associated with the customers applications, adequate design and operating safeguards must be provided by the customer to minimize inherent or procedural hazards. For any safety concerns, contact Freescale sales and technical support services.

Should this reference design not meet the specifications indicated in the kit, it may be returned within 30 days from the date of delivery and will be replaced by a new kit.

Freescale reserves the right to make changes without further notice to any products herein. Freescale makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does Freescale assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation consequential or incidental damages. “Typical” parameters can and do vary in different applications and actual performance may vary over time. All operating parameters, including “Typical”, must be validated for each customer application by customer’s technical experts.

Freescale does not convey any license under its patent rights nor the rights of others. Freescale products are not designed, intended, or authorized for use as components in systems intended for surgical implant into the body, or other applications intended to support or sustain life, or for any other application in which the failure of the Freescale product could create a situation where personal injury or death may occur.

Should the Buyer purchase or use Freescale products for any such unintended or unauthorized application, the Buyer shall indemnify and hold Freescale and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that Freescale was negligent regarding the design or manufacture of the part.Freescale™ and the Freescale logo are trademarks of Freescale Semiconductor, Inc. All other product or service names are the property of their respective owners.

# 4 Introduction

The RD9Z1-638-4Li reference design is a Battery Management System (BMS) for 4-Cell Li-Ion battery applications and features the MM9Z1J638 Battery Sensor Module. The RD9Z1-638-4Li is built to demonstrate the product capabilities in a 4-cell Li-Ion application where high EMC performance is required to obtain high accuracy measurements on key battery parameters. The board features an 8-pin standalone CAN transceiver to interface with others modules. Very high EMC robustness and performances are achieved by the Freescale MC33901 CAN high-speed Transceiver. For cell balancing function and general purpose switches, the board features the Freescale MC33879 Configurable Octal Serial Switch.

# 5 Reference Design Features

The RD9Z1-638-4Li reference design features are as follows:

- Embedded MCU: 16-bit S12Z MCU
- Embedded power management
- Four voltage sensing inputs (VSENSE3 to VSENSE0)
- Internal temperature sensing
- Four external NTCs inputs for temperature sensing (PTB3 to PTB0)
- Battery current sensing via mounted shunt (ISENSE)
- Four passive cell balancing channels, featuring the Freescale MC33879
- Two low-side and two high-side switches for general purpose use, featuring the Freescale MC33879
- High-speed CAN interface, featuring the Freescale MC33901
- LIN 2.2/2.1/2.0 interface
- BDM interface (For MCU programming and debugging)

# 6 Device Features

## 6.1 MM9Z1_638 Features

The MM9Z1_638 is a fully integrated BMS. The device supports precise current measurement via an external shunt resistor. It features four voltage measurements via an internal calibrated resistor divider or use of an external divider. It includes an internal temperature sensor, allowing close proximity battery temperature measurements, plus four external temperature sensor inputs.

- Wide range battery current measurement; On-chip temperature measurement
- Four battery voltage measurements with internal resistor dividers, and up to five direct voltage measurements for use with an external resistor divider
- Measurement synchronization between voltage channels and current channels
- Five external temperature sensor inputs with internal supply for external sensors
- Low-power modes with low-current operation
- Multiple wake-up sources: LIN, timer, high-voltage input, external CAN interface, and current threshold and integration
- Precision internal oscillator and connections for external crystal
- LIN 2.2/2.1/2.0 protocol and physical interface
- msCAN protocol controller, and supply capability for 8 and 14-pin CAN interfaces

## 6.2 MC33901 Features

The MC33901and 34901 are high speed CAN transceivers providing the physical interface between the CAN protocol controller of an MCU and the physical dual wires CAN bus. They are packaged in an 8-pin SOIC with market standard pin out, and offer excellent EMC and ESD performance without the need for external filter components.

- Very low current consumption in standby mode
- Automatic adaptation to 3.3 or 5.0 V MCU communication
- Standby mode with remote CAN wake-up on some versions
- Pin and function compatible with market standard
- Cost efficient robustness
  - High system level ESD performance
  - Very high electromagnetic immunity and low electromagnetic emission without common mode choke or other external components
- Fail-safe behaviors:
  - TXD Dominant timeout, on the MC33901 version
  - Ideal passive when unpowered, CAN bus leakage current <10 µA
  - VDD and VIO monitoring

## 6.3 MC33879 Features

The 33879 device is an 8-output hardware configurable, high-side/ low-side switch with 16-bit serial input control using the serial peripheral interface (SPI). Two of the outputs may be controlled directly via a microcontroller for pulse-width modulation (PWM) applications. The 33879 incorporates SMARTMOS technology, with CMOS logic, bipolar/MOS analog circuitry, and DMOS power MOSFETs. The 33879 controls various inductive, incandescent, or LED loads by directly interfacing with a microcontroller. The circuit's innovative monitoring and protection features include very low standby currents, cascade fault reporting, internal + 45 V clamp voltage for low-side configuration, - 20 V high-side configuration, output specific diagnostics, and independent overtemperature protection.

- Designed to operate 5.5 V < $V_{PWR}$ < 26.5 V
- 16-bit SPI for control and fault reporting, 3.3 V / 5.0 V compatible
- Outputs are current limited (0.6 to 1.2 A) to drive incandescent lamps
- Output voltage clamp, + 45 V (low-side) and - 20 V (high-side) during inductive switching
- On/Off control of open load detect current (LED application)
- Internal reverse battery protection on VPWR
- Loss of ground or supply will not energize loads or damage IC
- Maximum 5.0 µA $I_{PWR}$ standby current at 13 V $V_{PWR}$
- $R_{DS(on)}$ of 0.75 Ω at 25 °C typical
- Short-circuit detect and current limit with automatic retry
- Independent overtemperature protection

## 6.4 S12Z MCU Features

The MM9Z1_638 integrates a S12Z microcontroller and a SMARTMOS analog control IC into a single package solution. The MM9Z1J638 enables precision measurement of key battery parameters in automotive, industrial and other applications. The device integrates a S12Z microcontroller and a SMARTMOS analog control IC into a single package solution. The analog die combines system basis and application specific functions, including 3 dedicated 16-bit sigma delta analog to digital converters (ADC) for synchronous measurement of battery voltage and current.

The Embedded MCU includes these features:

- S12Z CPU core (S12ZCPU)
- 128 KB on-chip flash with ECC
- 4.0 KB on-chip EEPROM with ECC
- 8.0 KB on-chip SRAM with ECC
- Phase locked loop (IPLL) frequency multiplier with internal filter
- 4.0 - 16 MHz amplitude controlled Pierce oscillator
- 1.024 MHz internal RC oscillator
- 50 MHz bus frequency
- One CAN module (msCAN)
- One serial peripheral interface (SPI) module
- On-chip voltage regulator (VREG) for regulation of input supply and all internal voltages
- Die to Die Initiator (D2DI)

# 7 Accessory Interface Board

The RD9Z1-638-4Li reference design may be used with the P&E's USB BDM Multilink (shown below), which provides a USB-to-BDM interface. This accessory will be needed to flash the MCU using Freescale **CodeWarrior** 10.4 or higher. See USB BDM Multilink.


**Figure 2. P&E's USB BDM Multilink**

# 8 Required Equipment

Minimum equipment required:

- 14 V DC Power supply
- USB-enabled PC with Windows XP or higher
- P&E's USB BDM Multilink
- Freescale **CodeWarrior** 10.4 or higher

The following additional equipment is needed to fully use this reference design:

- 4-Cell Li-Ion battery pack with balance plug
- Battery load or current source
- Shunt-compatible power cable and plugs (screws + nuts)
- Four NTC thermistors for external temperature sensing
- CAN Bus network and/or LIN bus Master
- Typical loads for high-side and low-side switches
- Oscilloscope (preferably 4-channel)
- Digital voltmeter and ammeter

Having all of these items will allow testing and debugging of the system.

# 9 Reference Design Configuration

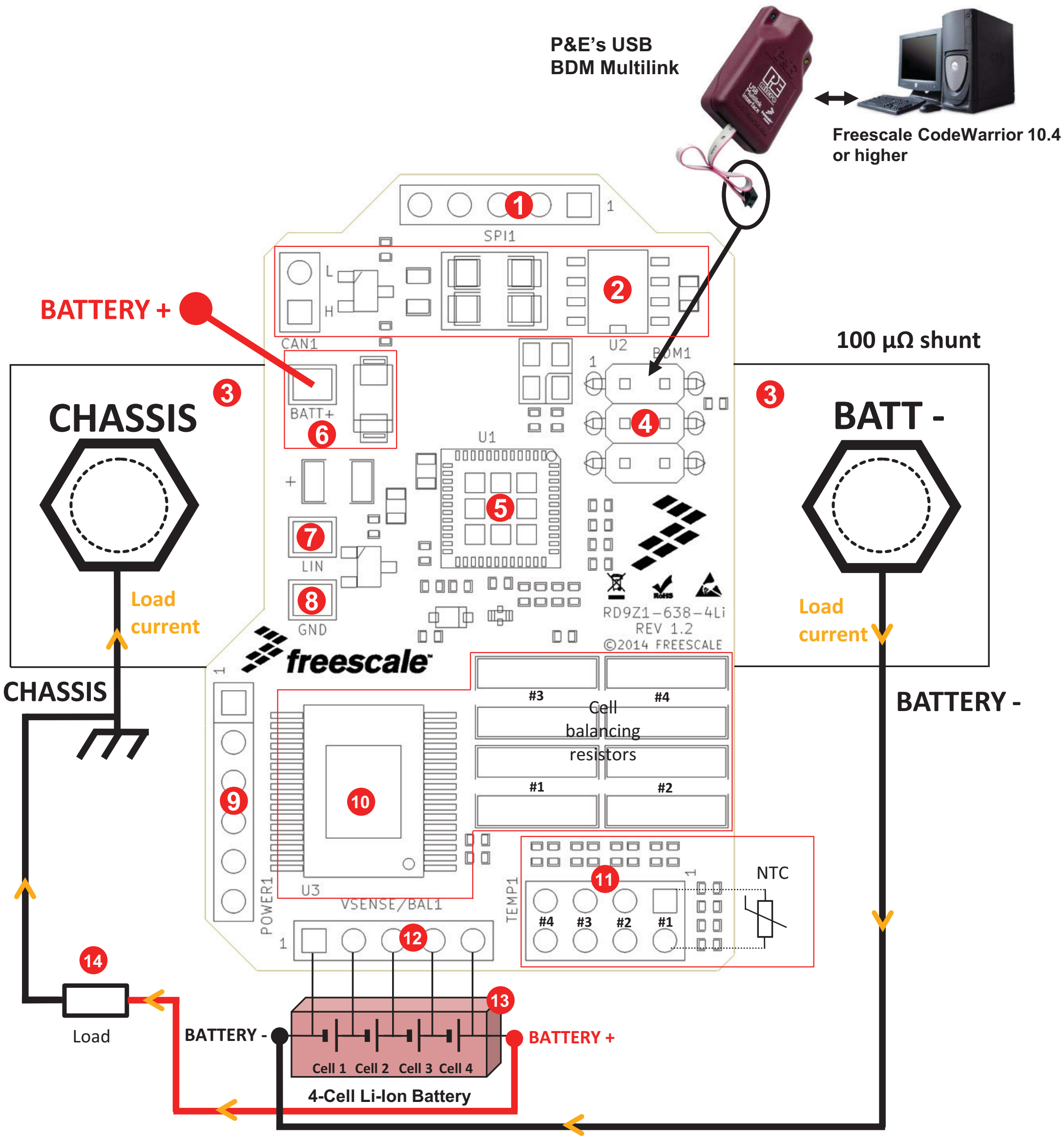



**Figure 3. RD9Z1-638-4Li Board with Battery Setup**

Figure 3 illustrates the setup used in a typical BMS application and shows key components and connector locations. In Figure 3, current goes from battery positive through the load, into the ground (chassis), through the shunt (where it creates voltage measured by the MM9Z1_638) and goes back to the battery minus.

The following list is a description of the numbers listed on Figure 3:

1. SPI Connector (SPI1), for SPI frames visualization or controlling an external device.
2. Freescale MC33901 High Speed CAN Interface (U2) and CANH/CANL connector (CAN1).
3. 100 $\mu\Omega$ shunt for current measurement, providing ground terminal (CHASSIS) and battery minus pole terminal (BATT-).
4. BDM Connector (BDM1), add 470 nF between RESET and GND signal for programming only.
5. Freescale MM9Z1J638 Battery Sensor (U1).
6. Battery positive pole input pad (BATT+), reverse protected by D1 diode.

Note: If no battery is available, connect a 14 V power supply to BATT+, see Figure 4 and Figure 5.

7. LIN pad.
8. GND pad.

Note: If the shunt CHASSIS terminal is not used, connect the power supply ground to GND pad.

9. Supply for external components and general purpose high-side and low-side switches connector (POWER1).
10. Cell balancing circuit, featuring Freescale MC33879 Configurable Octal Serial Switch (U3).
11. External NTC thermistors input connector (TEMP1).

Note: Only one NTC is shown in Figure 3. Connect other thermistors using same pattern.

12. Cell voltage measurement and balancing connector (VSENSE/BAL1).
13. External 4-Cell Li-Ion battery pack.
14. External battery load (for current measurement). A current source can also be used.

The board is protected against reverse battery voltage by diode D1. This diode can withstand up to 1.0 A continuous forward current.

## 9.1 Setup with DC Power Supply (CHASSIS)

This setup is optional and used when no battery is available. In this case, the board is powered by a 14 V DC Power supply.

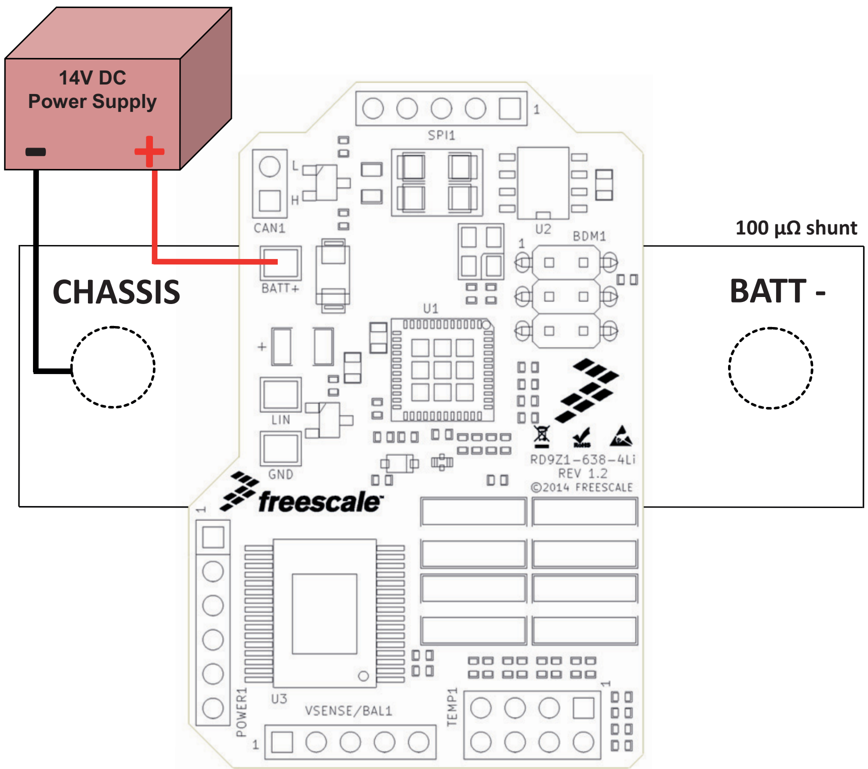



**Figure 4. Setup with DC Power Supply (CHASSIS)**

Note: In this setup, only the load current will be measured by the IC.

To include the board consumption current in this setup, connect the power supply negative terminal (-) to the BATT- shunt terminal instead.

## 9.2 Setup with DC Power Supply (GND Pad)

This setup is optional and used when no battery is available. In this case, the board is powered by a 14 V DC Power supply.

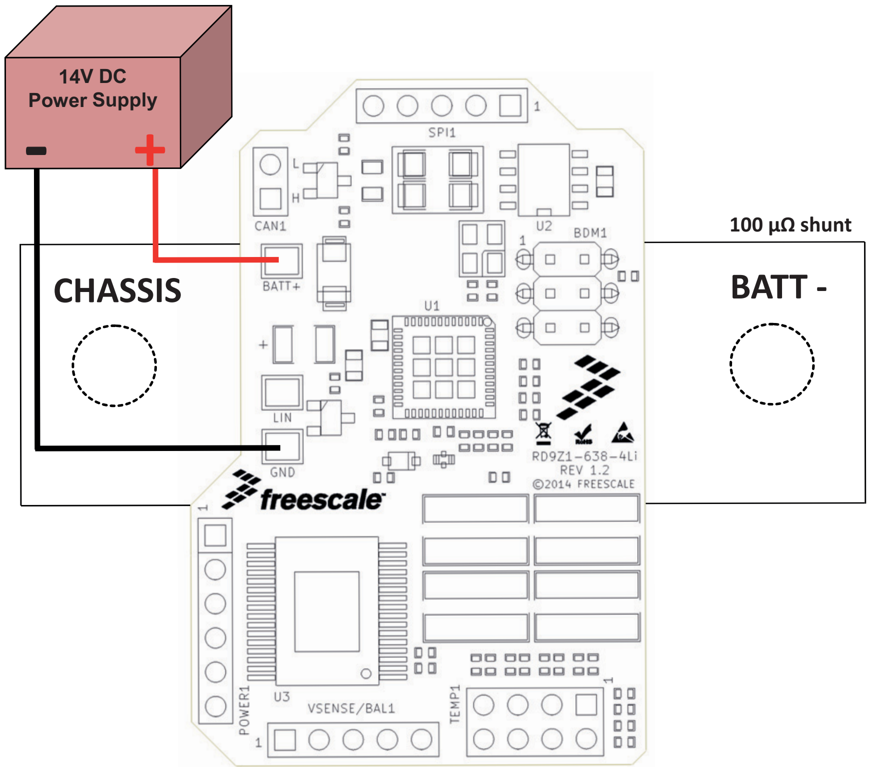



**Figure 5. Setup with DC Power Supply (GND Pad)**

Note: In this setup, only the load current will be measured by the IC.

To include the board consumption current in this setup, connect the power supply negative terminal (-) to the BATT- shunt terminal instead.

Note: Connecting power ground to the GND pad will provide the same board functionality as connecting it to the CHASSIS terminal.

# 10 Setting Up and Using the Hardware and Software

In order to perform the demonstration examples, first set up the board hardware and software as follows:

1. Download **CodeWarrior** 10.4 or higher and the example software using the instructions in the "Jump Start" section.
2. Install **CodeWarrior** Suite on a USB-enabled PC running Windows XP or higher.
3. Connect a 470 nF capacitor between RESET and GND signal on the adapter side.
4. Connect the BDM cable from the P&E's adapter (or equivalent) to the BDM1 connector on the board with ribbon cable coming from left side of the board.
5. Connect the battery minus pole (-) or the ground line from the supply to the BATT- terminal on the shunt.

   Note: If the shunt CHASSIS terminal is not used, connect the power supply ground to GND pad.
6. Connect the battery positive pole (+) or the positive voltage output (set at +14 V) of the DC power supply to the BATT+ terminal on the board.
7. Place the project example folder obtained in step 1 into the **CodeWarrior** Suite workspace folder. By default the folder is located at C:\Users\YOUR_USER_NAME\workspace.
8. Launch the **CodeWarrior** Suite.
   a. Go to File>Import in the **CodeWarrior** Suite. Choose Existing Project into Workspace, click Next.
   b. Select "select root directory". Click Browse and locate the workspace folder. The Project starts loading.
   c. Select the Example Software in the Projects section and select Copy Project Into Workspace. Click Finish.
   d. An example project is ready to be used. It is located in the "**CodeWarrior** Projects" window, on the left.
   e. Go to the Project tab and click Build All to compile the project.
   f. Go to the Run tab and click Run. To debug the MCU, click Debug instead of Run.

Once the steps above are all accomplished, go to **Jump Start Your Design** at freescale.com to download RD9Z1-638-4LI_APPSP.zip file.

## 10.1 Hardware Description

This reference design features one MM9Z1J638 (Battery Sensor), one MC33879 (Configurable Octal Serial Switch) and one MC33901 (High Speed CAN Interface) IC.

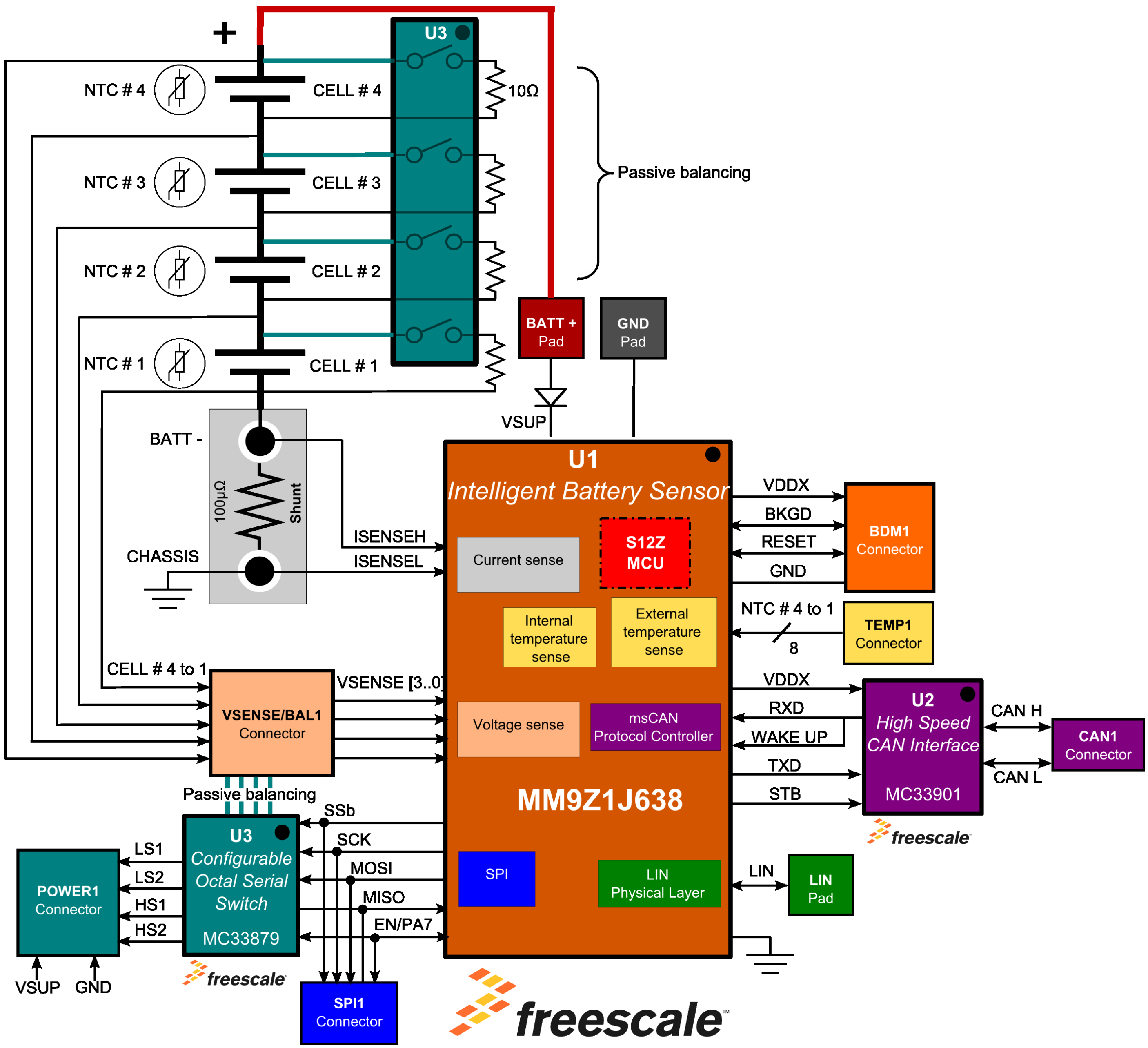



**Figure 6. RD9Z1-638-4Li Block Diagram**

## 10.2 Shunt

The soldered shunt is used for current measurement. The system ground should be connected to the CHASSIS terminal and the battery minus pole to the BATT- terminal. This setup is a low-side current measurement. Therefore, the system ground (GND) is the CHASSIS terminal and should be used as the reference. This setup permits to measure both load and board current. This insures accurate current measurement at any time.

## 10.3 Voltage and Current Measurement

The MM9Z1J638 has four voltage measurement channels called VSENSE. Each VSENSE pin is protected against ESD by a 2.2 kΩ serial resistor. Measurements results are referenced to GND. A software calculation is needed to know each cell voltage, below is the corresponding table.

**Table 1. Software Calculation for Cells Voltage**

| Cell # | Software Calculation |
|---|---|
| 1 | VSENSE0 – $V_{DROP}$ [(1)] |
| 2 | VSENSE1 – VSENSE0 |
| 3 | VSENSE2 – VSENSE1 |
| 4 | VSENSE3 – VSENSE2 |

Notes

1. The software has to include the voltage drop of the shunt (i.e. ISENSE differential voltage) to get the correct cell voltage. In this case, the current acquisition must be ON when voltage acquisition is ON.

When using the MM9Z1J638 in a low-side current sensing setup, the actual voltage for cell #1 is:

$$V_{CELL1} = VSENSE0 + V_{SHUNT}$$

$$\text{Where } V_{SHUNT} = \text{Load current} \times 100\ \mu\Omega = -V_{DROP}$$

$$\text{And where } V_{DROP} = I_{SENSEH} - I_{SENSEL}$$

If current is positive (or $V_{DROP} < 0$), the data returned into ACQ_CURR (current acquisition register) will be negative.

If current is negative (or $V_{DROP} > 0$), the data returned into ACQ_CURR (current acquisition register) will be positive.

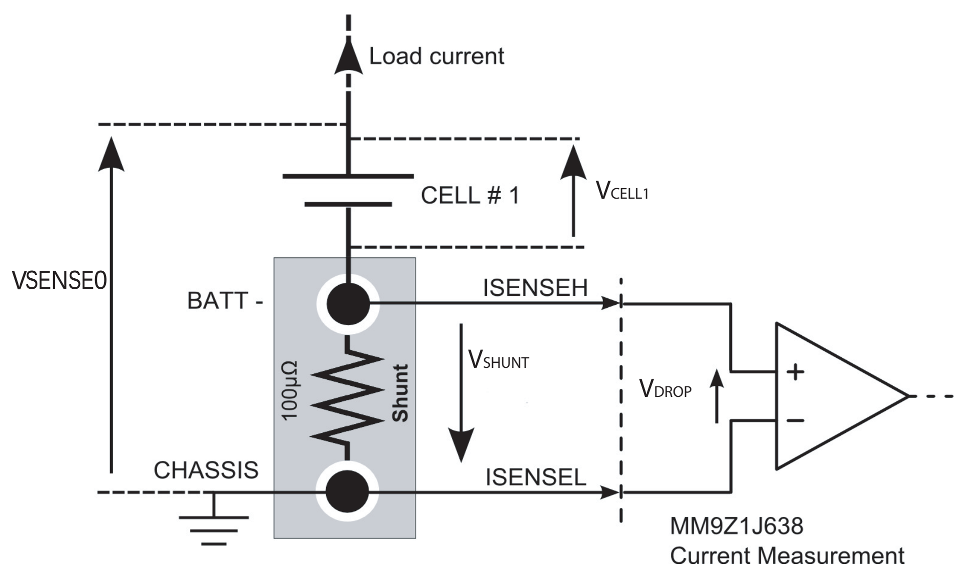



**Figure 7. RD9Z1-638-4Li Low-side Current Sensing**

This reference design provides a very high EMC tolerant current sensing circuit thanks to symmetrical layout traces along with a dual balanced capacitor (C2) improving differential and common attenuation.

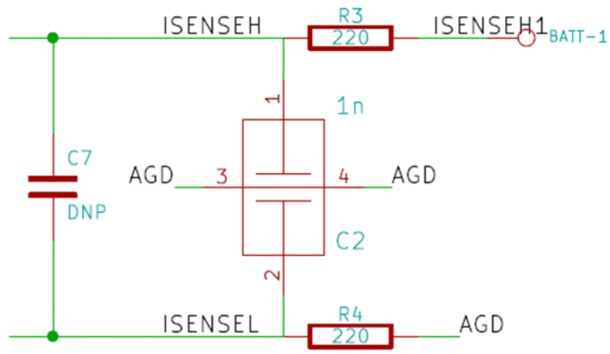



**Figure 8. Current Sensing Circuit**

## 10.4 LIN Interface

This reference design provides a LIN 2.2/ 2.1/ 2.0 protocol and physical interface. This LIN interface has a high robustness against EM disturbances, ESD and has a very low EMC emission level. An ESD diode (D2) can be added to further improve performances.

## 10.5 Cell Balancing and General Purpose Switches

This reference design provides a passive cell balancing circuit and four general purpose switches. Below is a simplified circuit diagram.

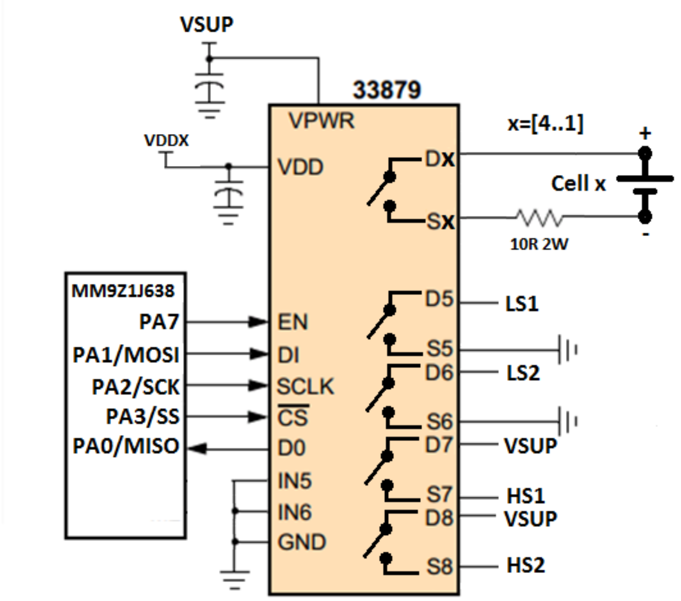



**Figure 9. Cell Balancing and General Purpose Switches Circuit**

The Freescale MC33879 is a Configurable Octal Serial Switch IC. It integrates eight DMOS switches, used following the table below.

**Table 2. MC33879 switches functions**

| Switch Number | Pins | Function |
|---|---|---|
| 1 | D1, S1 | Cell #1 balancing switch |
| 2 | D2, S2 | Cell #2 balancing switch |
| 3 | D3, S3 | Cell #3 balancing switch |
| 4 | D4,S4 | Cell #4 balancing switch |
| 5 | D5, S5 | LS1: Low-side switch to GND |
| 6 | D6, S6 | LS2: Low-side switch to GND |
| 7 | D7, S7 | HS1: High-side switch to VSUP |
| 8 | D8,S8 | HS2: High-side switch to VSUP |

The cell balancing circuit includes four 10 Ω, 2.0 W automotive resistors. These resistors are used to discharge each cell independently in order to keep voltage matching and therefore maximize battery's capacity and lifetime.

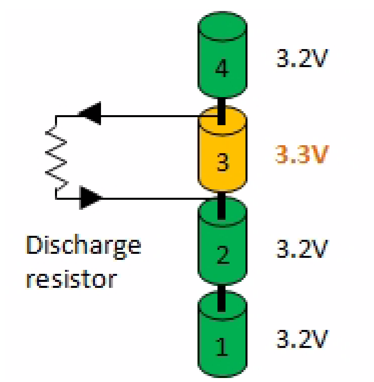



**Figure 10. Balancing Cell #3 of a LiFePo4 Battery**

In this reference design, the MM9Z1J638 controls the MC33879 by sending SPI frames with PA[3..0]. The MC33879 is enabled with PA7 configured as an output and driven high. For low current consumption, the MM9Z1J638 can turn the MC33879 to low-power mode with PA7 configured as an output and driven low.

## 10.6 Example Code for Cell Balancing

The following code example can be used to control the MC33879 with the SPI. The first section "spi.c" contains one function to initialize the SPI communication between the MCU and the MC33879, and the other function sends a 16-bit SPI message. The second section "balancing.c" contains several functions such as open load detect, cell balancing enable, and high-side/low-side switch control used to configure the MC33879.

- spi.c

```
void SPI_MC33879_init (){
SPICR1_LSBFE = 0 ;//MSB first
SPICR1_SSOE = 1 ;//SSb enabled
SPICR1_CPHA = 1 ;//Mode 1 SPI
SPICR1_CPOL = 0 ;//Mode 1 SPI
SPICR1_MSTR = 1 ;//Master mode
SPICR1_SPTIE = 0 ;//SPTEF Interrupt disabled
SPICR1_SPIE = 0 ;//SPI interrupt disabled (use polling)

SPICR2_XFRW = 1 ;//16-bit data width
SPICR2_MODFEN = 1 ;//SSb enabled
SPICR2_BIDIROE = 0 ;//Normal mode
SPICR2_SPISWAI = 1 ;//Stop SCI clock in Wait mode
SPICR2_SPC0 = 0 ;//Normal mode

SPIBR = 0x02;//4Mbit/s baud rate for 32 MHz bus clock : MC33879 recommended baud rate

SPICR1_SPE = 1 ;//SPI enabled
}

void SPI_send_16 (unsigned int data){
  while (!SPISR_SPTEF);          /* Wait for empty data register */
  SPIDR = data;                  /* Load 16-bit word in data transmission register */
}
```

- balancing.c

```
/*
 -Configuring the SPI frame for Open Load Detect and send it to the MC33879
 -Previous configuration of the SPI message is kept

 */
void OL_DETECT_ON (unsigned int* SPI_message) {
*SPI_message = (*SPI_message & 0x00FF) | 0xFF00;
SPI_send_16(*SPI_message);
}

void OL_DETECT_OFF (unsigned int* SPI_message) {
*SPI_message = (*SPI_message & 0x00FF);
```

```
SPI_send_16(*SPI_message);
}
```

/*
-Configuring the SPI frame for balancing and send it to the MC33879
-The code allows to activate only one cell at a time
-Previous configuration of the SPI message is kept
*/

```
void BAL_CELL1_ON (unsigned int* SPI_message) {
*SPI_message = (*SPI_message & 0xFFF0) | 0x0001;
SPI_send_16(*SPI_message);
}
void BAL_CELL2_ON (unsigned int* SPI_message) {
*SPI_message = (*SPI_message & 0xFFF0) | 0x0002;
SPI_send_16(*SPI_message);
}
void BAL_CELL3_ON (unsigned int* SPI_message) {
*SPI_message = (*SPI_message & 0xFFF0) | 0x0004;
SPI_send_16(*SPI_message);
}
void BAL_CELL4_ON (unsigned int* SPI_message) {
*SPI_message = (*SPI_message & 0xFFF0) | 0x0008;
SPI_send_16(*SPI_message);
}
void BAL_4CELL_OFF (unsigned int* SPI_message) {
*SPI_message = *SPI_message & 0xFFF0;
SPI_send_16(*SPI_message);
}
```

/*
-Configuring the SPI frame for low-side high-side control and send it to the MC33879
-Previous configuration of the SPI message is kept
*/

```
void LS1_ON (unsigned int* SPI_message) {
*SPI_message = (*SPI_message & 0xFFEF) | 0x0010;
SPI_send_16(*SPI_message);
}
void LS1_OFF (unsigned int* SPI_message) {
*SPI_message = *SPI_message & 0xFFEF;
SPI_send_16(*SPI_message);
}
void LS2_ON (unsigned int* SPI_message) {
*SPI_message = (*SPI_message & 0xFFDF) | 0x0020;
SPI_send_16(*SPI_message);
```

```
}
void LS2_OFF (unsigned int* SPI_message) {
*SPI_message = *SPI_message & 0xFFDF;
SPI_send_16(*SPI_message);
}
void HS1_ON (unsigned int* SPI_message) {
*SPI_message = (*SPI_message & 0xFFBF) | 0x0040;
SPI_send_16(*SPI_message);
}
void HS1_OFF (unsigned int* SPI_message) {
*SPI_message = *SPI_message & 0xFFBF;
SPI_send_16(*SPI_message);
}
void HS2_ON (unsigned int* SPI_message) {
*SPI_message = (*SPI_message & 0xFF7F) | 0x0080;
SPI_send_16(*SPI_message);
}
void HS2_OFF (unsigned int* SPI_message) {
*SPI_message = *SPI_message & 0xFF7F;
SPI_send_16(*SPI_message);
```

## 10.7 CAN Interface

This reference design provides a high-speed CAN interface featuring Freescale MC33901 standalone IC. The circuit design allows the following features:

- The MCU can turn the CAN Interface into Normal (low) or Standby mode (high) (PA6)
- The CAN Interface can report a wake-up request during standby mode to the MCU (PTB4)
- Flexibility to add a Common Mode Choke (CMC1) to improve EMC performances (OEM emission specifications are met without choke)
- Flexibility to add an ESD protection diode (without diode: +/-8 kV HBM on CANH and CANL)

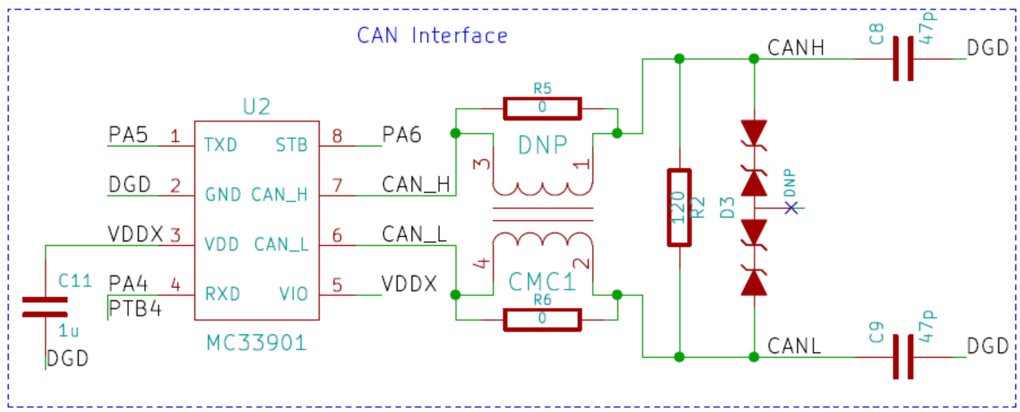



**Figure 11. CAN Interface Circuit**

## 10.8 External Temperature Sensing

This reference design provides a 4-channel temperature sensing with protected inputs. NTCx and _NTCx are the input terminals for NTC thermistors.

Note: Recommended external thermistors are NCP18XH103F0SRB.

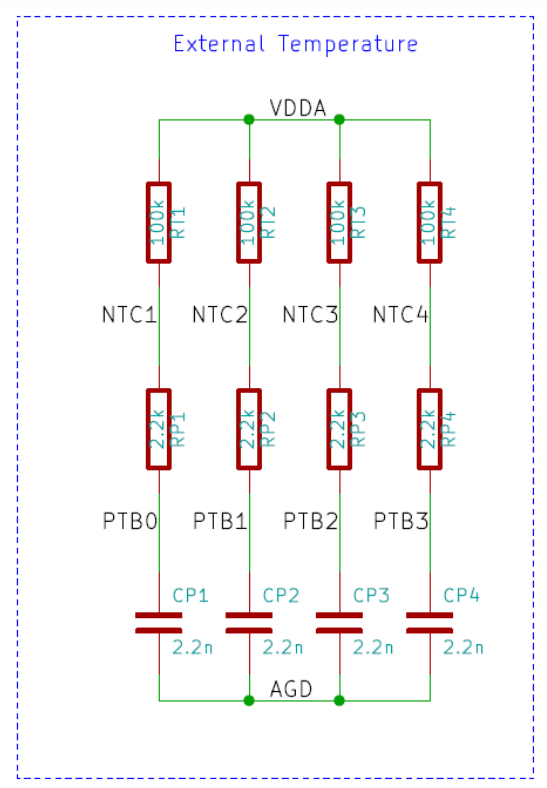



Figure 12. External Temperature Circuit

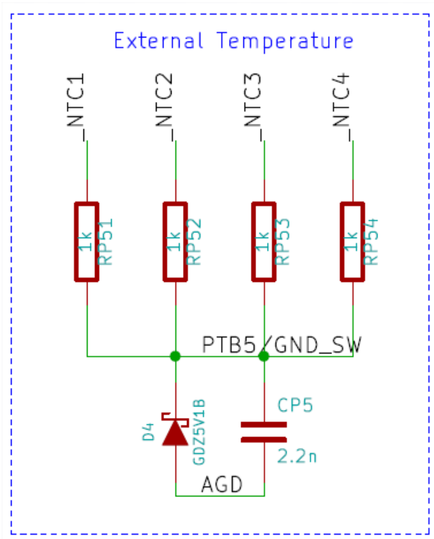



Figure 13. External Temperature Circuit (continued)

## 10.9 Connectors Overview

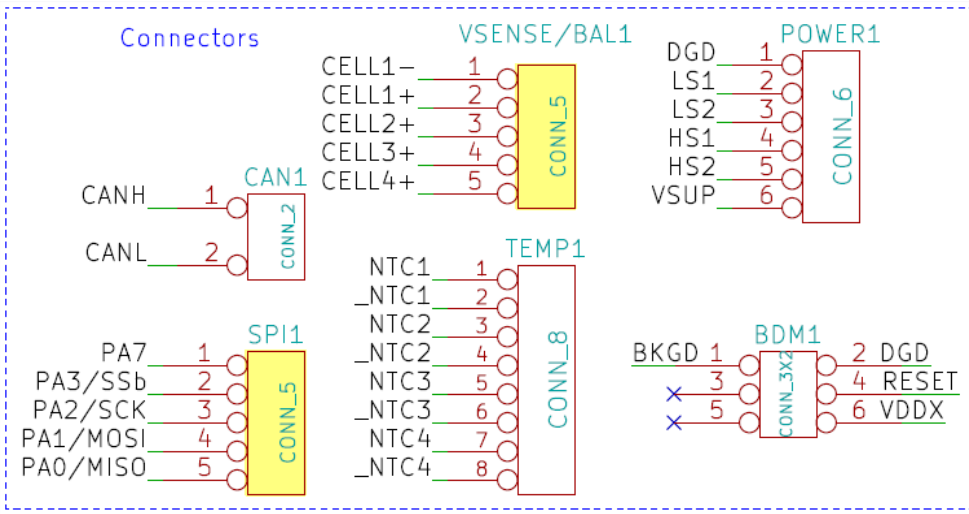



**Figure 14. Connectors Circuit**

## 10.10 BDM1 Connector

BDM1 should be connected to P&E's USB BDM Multilink adapter (or equivalent) in order to enable programming and debugging the MM9Z1J638 with Freescale **CodeWarrior** Suite.

For programming the MM9Z1J638, connect a 470 nF capacitor between RESET and GND signal on the adapter side. It is due to the RESET pin being connected to the RESET_A pin with the analog watchdog enabled. The programming capacitor shall be removed after programming.

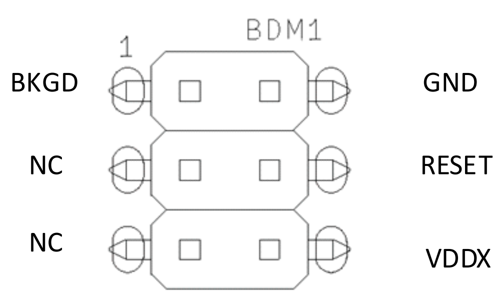



**Figure 15. BDM1 Connector**

Note: The VDDX Maximum load current available for external supply, with $V_{SUP}$ > 5.5 V and for all external loads (including MC33879 and MC33901), is 100 mA.

## 10.11 SPI1 Connector

SPI1 can be connected to:

1. A 4-channel oscilloscope to visualize SPI communication between the MM9Z1J638 and the MC33879 (Cell balancing).
2. An external SPI device such as an I/O extender for driving LED in order to display the battery state of charge.

   PA7 is a general purpose I/O from the MM9Z1J638. It is routed to the MC33879 enable pin and therefore can be used to enable or disable cell balancing feature. This is useful when using SPI to control an external device.

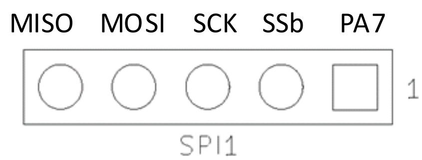



**Figure 16. SPI1 Connector**

## 10.12 VSENSE/BAL1 Connector

Always connect the board power before connecting the VSENSE/BAL1 connector to any voltage source, including the battery.

Note: This connector is used for sensing and balancing of cells. Therefore, it is not used to power any component on the board.

VSENSE/BAL1 should be connected to battery cells (Cell #4 to #1) through a balance plug. This connector is shared with the passive balancing circuit see Schematic). Connect cell terminals to corresponding terminal name, for example cell #1 is connected to CELL1- and CELL1+, cell #2 is connected to CELL1+ and CELL2+, etc. To properly measure cells voltage, the battery negative terminal must be connected to the BATT- shunt terminal (or to the GND Pad in case the board current is not measured). This ensures the measurement reference is connected to the board.

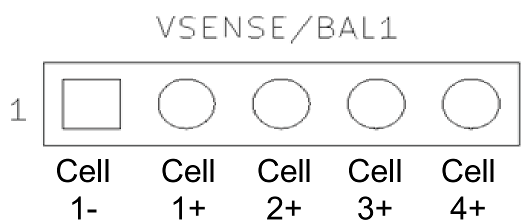



**Figure 17. VSENSE/BAL1 Connector**

## 10.13 TEMP1 Connector

TEMP1 should be connected to cells NTC (Negative Temperature Coefficient) thermistors. Connect each thermistor between NTCx and _NTCx terminal.

Note: There is no polarity for thermistors.

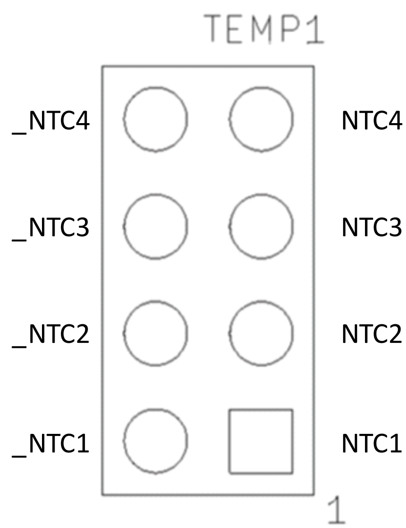



**Figure 18. TEMP1 Connector**

## 10.14 POWER1 Connector

POWER1 can be connected to general purpose external devices such as a LED, Power MOSFET (circuit breaker), etc. POWER1 provides also access to board supply VSUP/GND to power external devices.

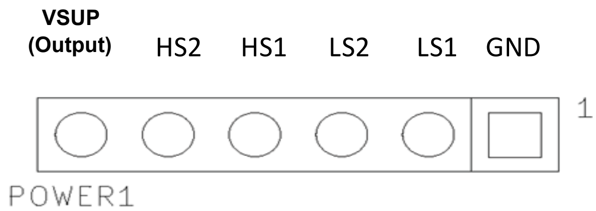



**Figure 19. POWER1 Connector**

**Table 3. Power1 Terminals Description**

| Terminal | VSUP | HS1/HS2 | LS1/LS2 |
|---|---|---|---|
| Description | Board supply, reverse protected | High-side switches to VSUP | Low-side switches to GND |
| | | $R_{DS(ON)}$ of 0.75 Ω | |
| Maximum Safe Operating Current | 0.8 A (limited by D1) | 0.4 A each (limited by D1) | 0.6 to 1.2 A each |

## 10.15 BATT+, LIN and GND Pads

BATT+ pad should be connected to the battery positive (+) terminal in order to power the board. An 18 or 16-gauge wire should be used and soldered directly on the pad footprint. This insures enough flexibility over the application constraints. LIN pad should be connected to a LIN bus, if any. GND pad is an optional connection path for ground, in case the shunt is not connected to the chassis. Preferably, the "CHASSIS" side on the shunt should be used for grounding.

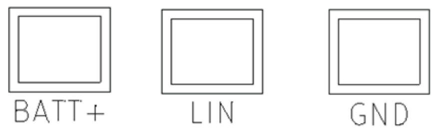



**Figure 20. BATT+, LIN and GND Pads**

## 10.16 CAN1 Connector

CAN1 should be connected to the CAN bus in order to communicate the battery actual parameters to other modules.

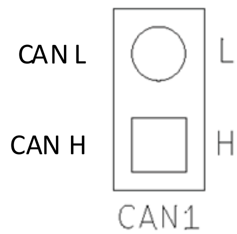
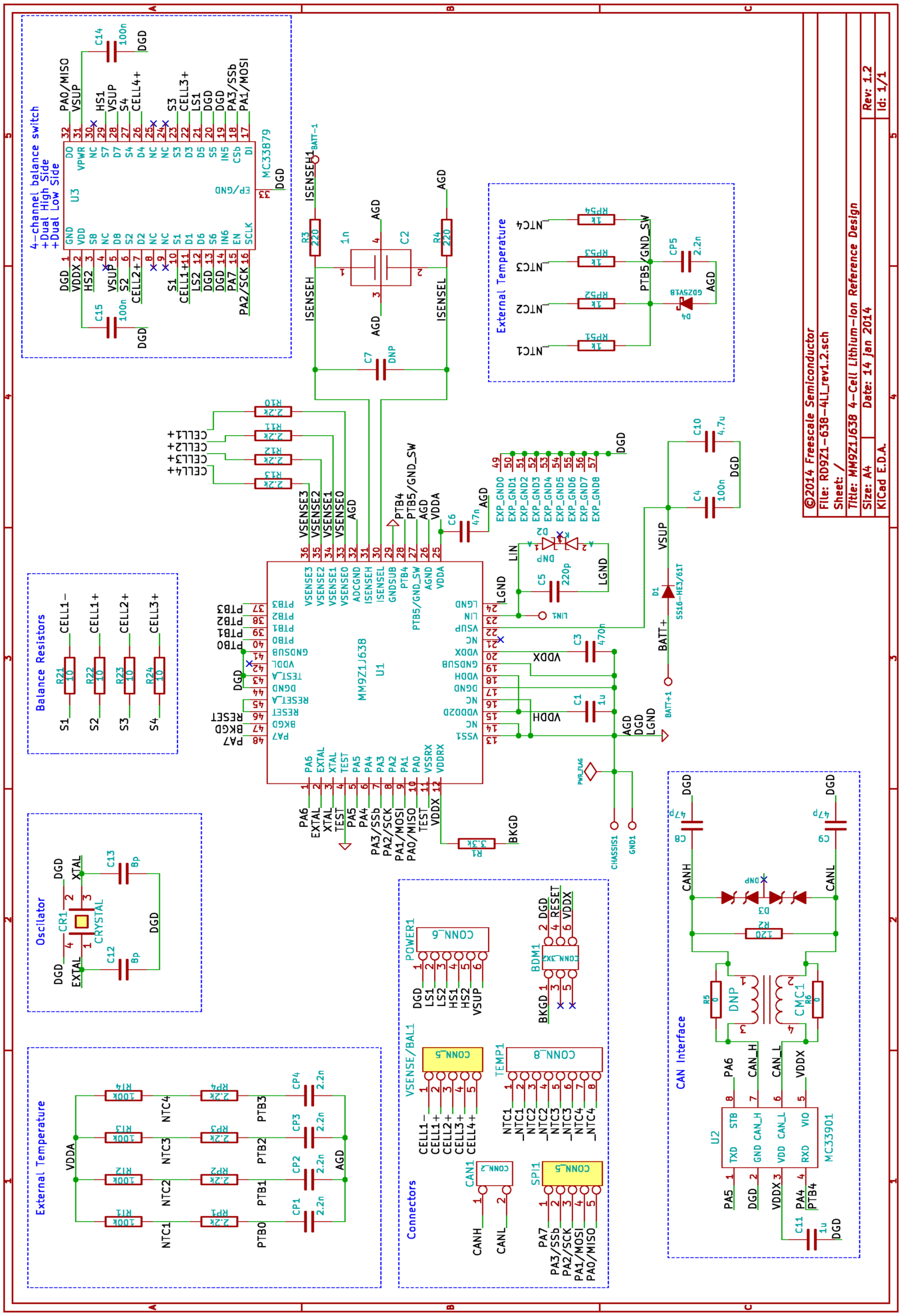


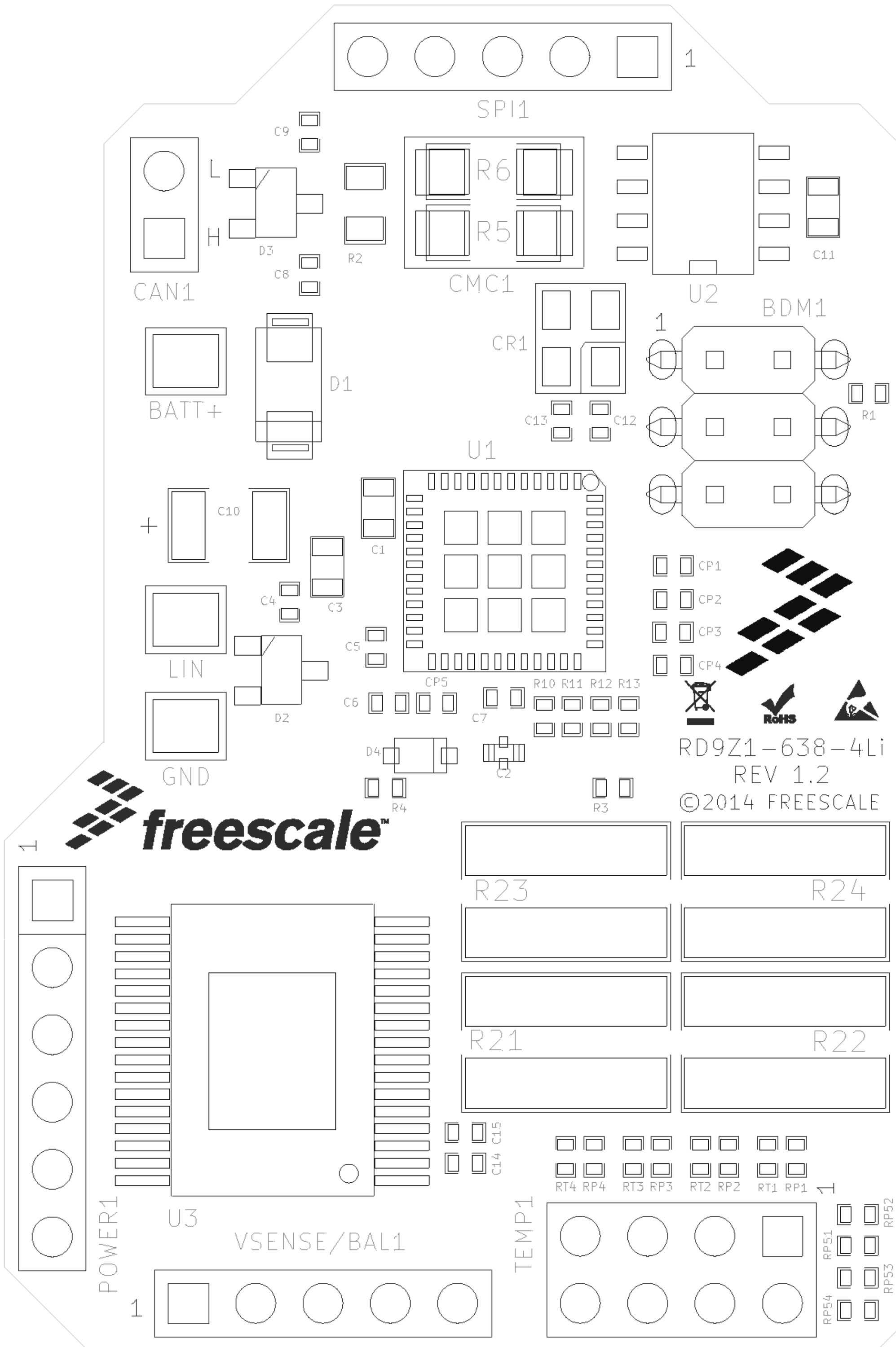

**Figure 21. CAN1 Connector**

## 11 Schematic

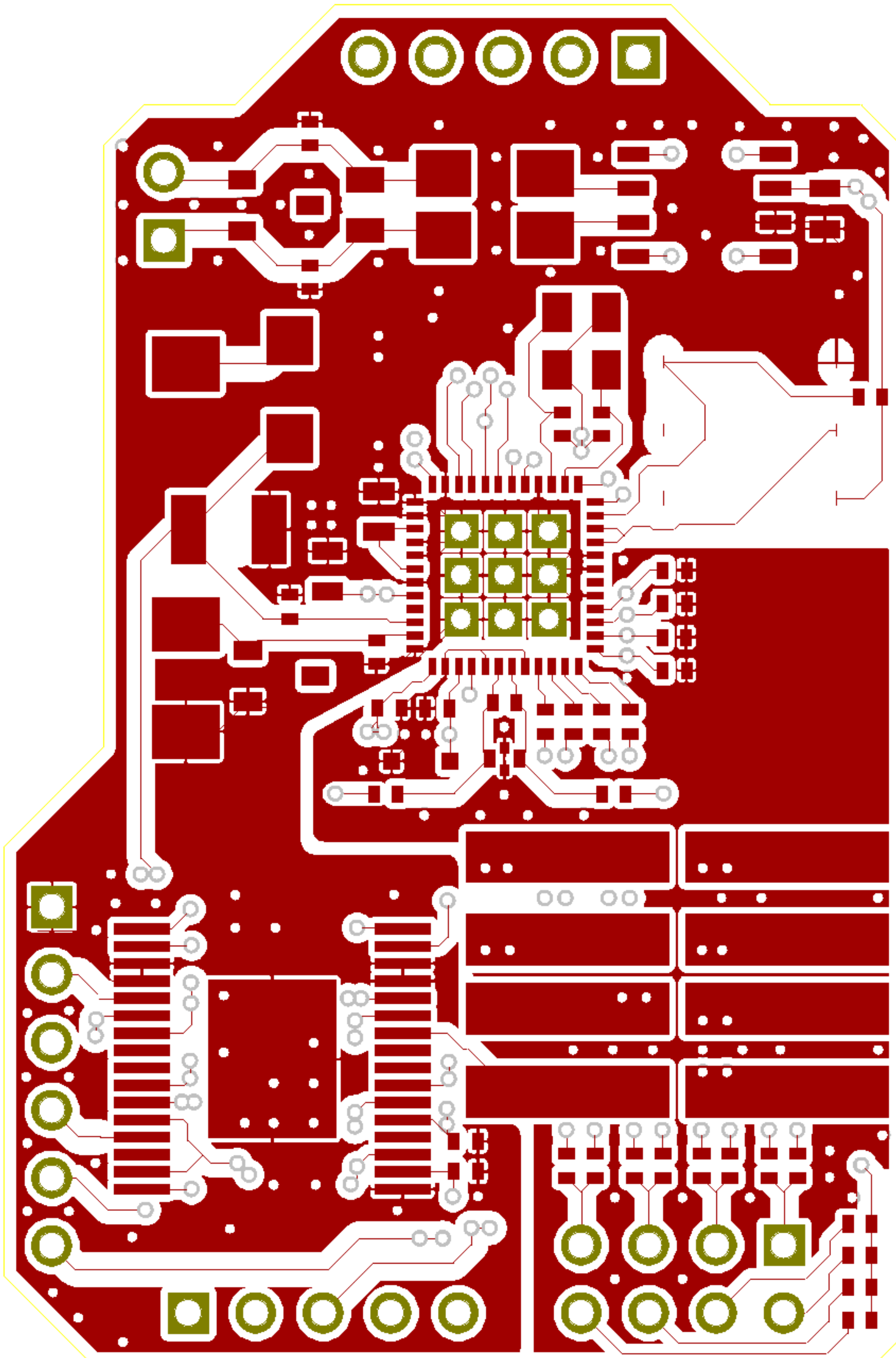


# 12 Board Layout

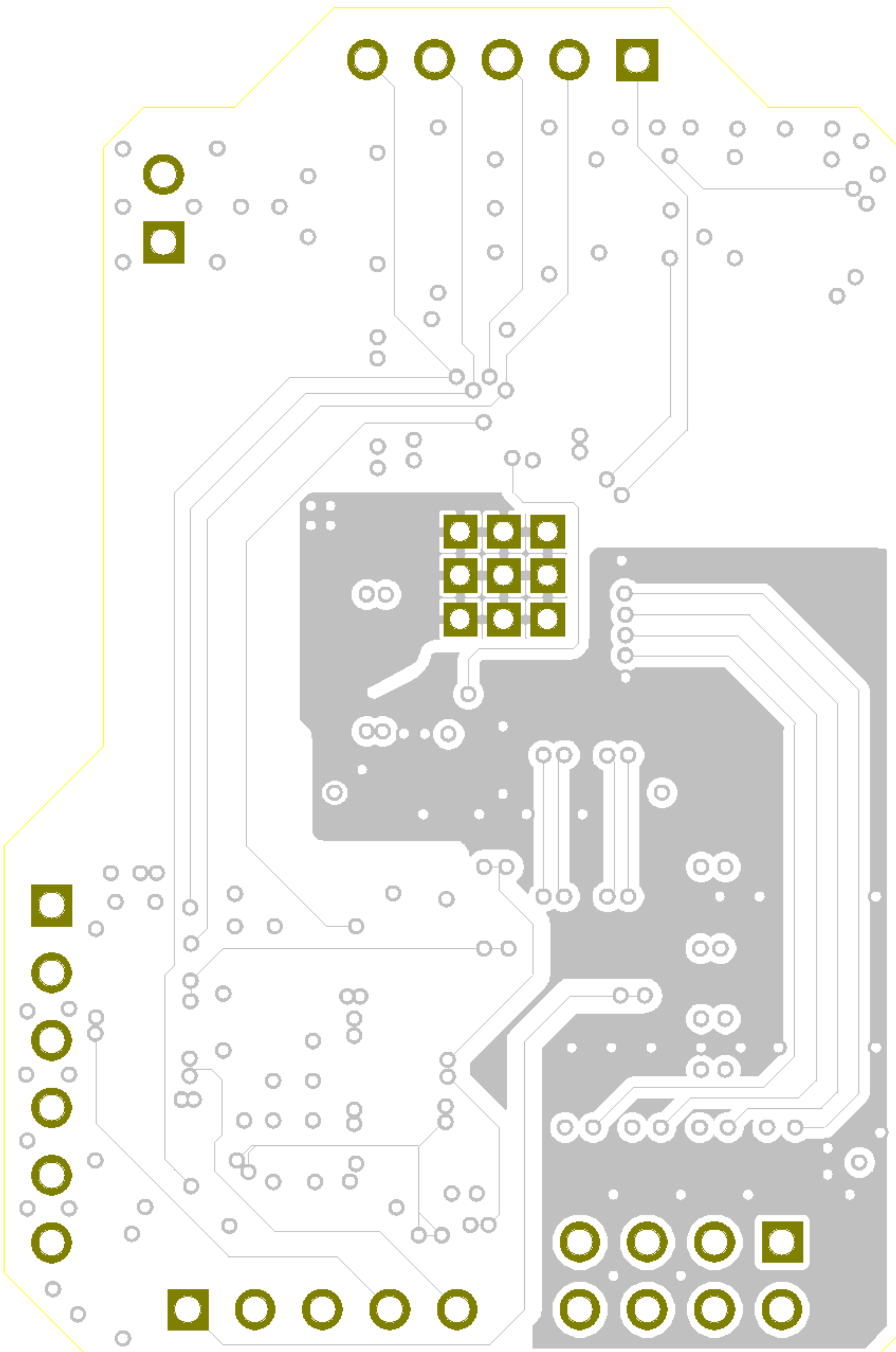
## 12.1 Assembly Layer Top



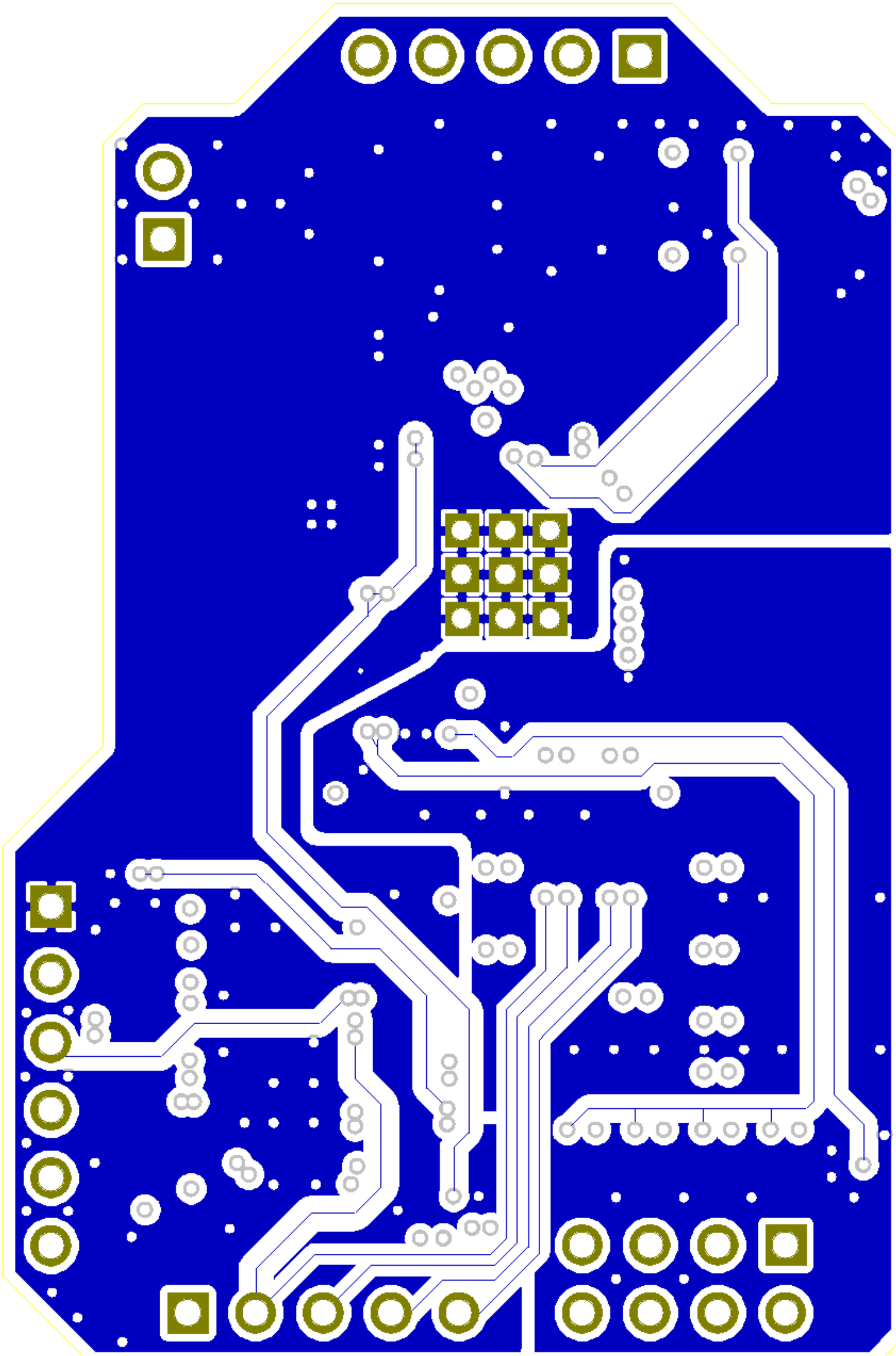
## 12.2 Top Layer Routing



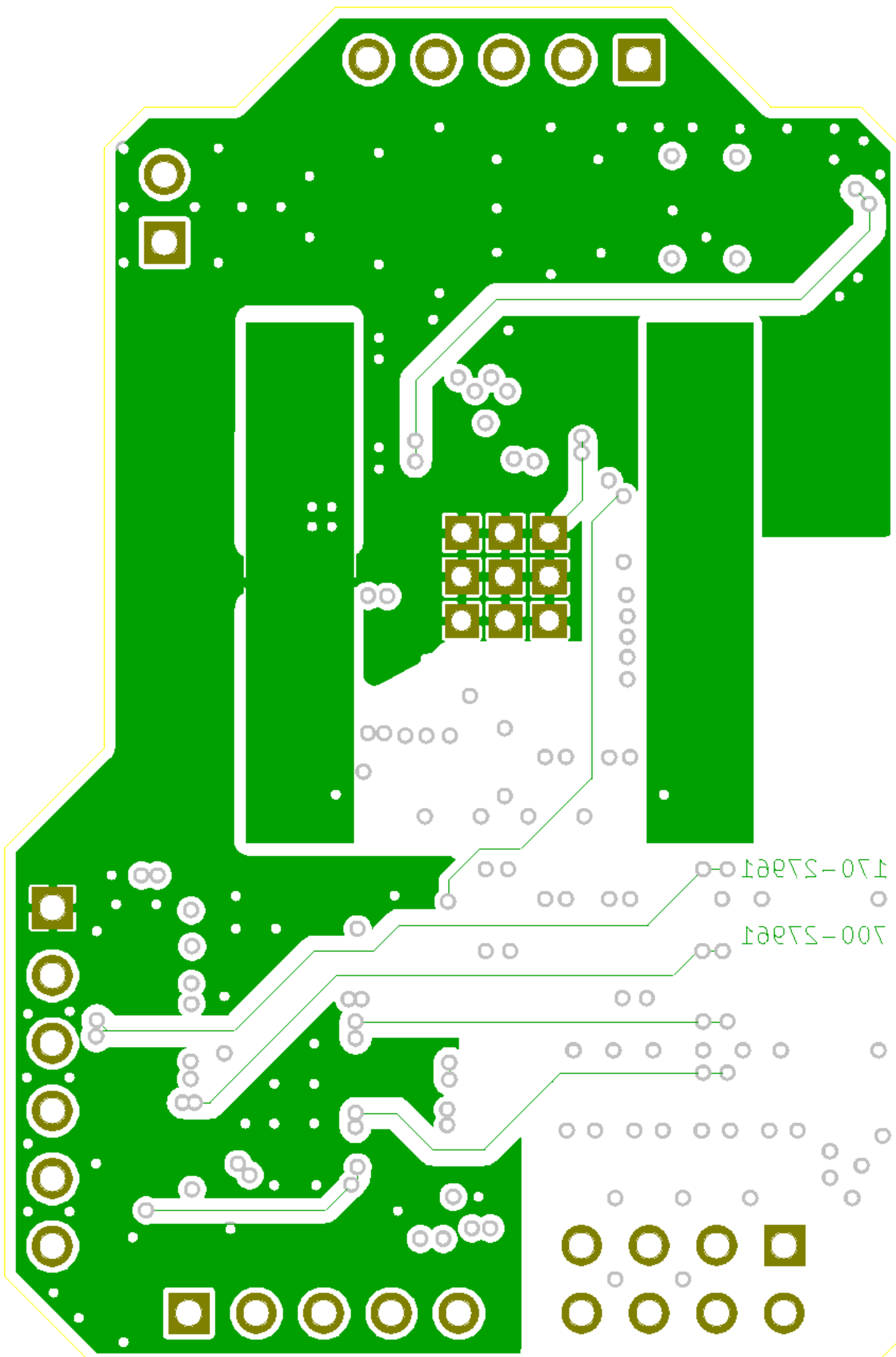
## 12.3 Layer 2 Routing



## 12.4 Layer 3 Routing



## 12.5 Bottom Layer Routing



Note: This image is an exception to the standard top-view mode of representation used in this document. It has been flipped to show a bottom view.

# 13 Bill of Materials

**Table 4. Bill of Materials** (1)

| Qty | Schematic Label | Value | Description | Package | Assy Opt |
|---|---|---|---|---|---|
| **Integrated Circuits** | | | | | |
| 1 | U1 | N/A | Freescale MM9Z1J638BM2EP | 48-PIN QFN | (3) |
| 1 | U2 | N/A | Freescale MC33901WEF | 8-PIN SOICN | (3) |
| 1 | U3 | N/A | Freescale MC33879APEK | 32 SOICW-EP | (3) |
| **Crystal Oscillators** | | | | | |
| 1 | CR1 | 16MHZ | CX3225SA16D0PST<br>16 MHZ ±50 × 10-6 Hz 8 pF - 40 °C to + 150 °C<br>AEC-Q200 ROHS Lead-free | N/A | |
| **Diodes** | | | | | |
| 1 | D1 | N/A | SS16-HE3/61T<br>60 V 1 A DO-214 AC - 65 °C to + 150 °C AEC-Q101<br>ROHS Lead-free | DO-214AC (SMA) | |
| 1 | D2 | DNP | MMBZ27VCLT1 recommended | SOT-23 | (2) |
| 1 | D3 | DNP | PESD1CAN recommended | SOT23 (TO-236AB | (2) |
| 1 | D4 | N/A | GDZ5V1B<br>5.1 V SOD-323 - 55 °C to + 150 °C AEC-Q101 ROHS<br>Lead-free | SOD-323 | |
| **Capacitors** | | | | | |
| 2 | C1<br>C11 | 1uF | GCM188R71C105KA64<br>16 V 10% X7R 0603 - 55 °C to + 125 °C AEC-Q200 ROHS<br>Lead-free | SM0603 | |
| 1 | C2 | 1nF | 500X07W102MV4T<br>50 V 20% X7R 0402 - 55 °C to + 125 °C ROHS Lead-free | X2Ycap-0402-b | |
| 1 | C3 | 470nF | CGA3E3X7R1E474K080AB<br>16 V 10% X7R 0603 - 55 °C to + 125 °C AEC-Q200 ROHS<br>Lead-free | SM0603 | |
| 2 | C4<br>C14 | 100nF | CGA2B3X7R1H104K050BB<br>50 V 10% X7R 0402 - 55 °C to + 125 °C AEC-Q200 ROHS<br>Lead-free | SM0402 | |
| 1 | C5 | 220pF | GCM155R71H221KA37D<br>*50* V 10% X7R 0402 - 55 °C to + 125 °C AEC-Q200 ROHS<br>Lead-free | SM0402 | |
| 1 | C6 | 47nF | GCM155R71C473KA37D<br>16 V 10% X7R 0402 - 55 °C to + 125 °C AEC-Q200 ROHS<br>Lead-free | SM0402 | |

**Table 4. Bill of Materials [(1)] (continued)**

| | | | | | |
|---|---|---|---|---|---|
| 1 | C7 | DNP | GCM155R71H222KA37D<br>50 V 10% X7R 0402 - 55 °C to + 125 °C AEC-Q200 ROHS Lead-free | SM0402 | [(2)] |
| 2 | C8<br>C9 | 47pF | CGA2B2C0G1H470J<br>50 V 5% C0G (NP0) 0402 - 55 °C to + 125 °C AEC-Q200 ROHS Lead-free | SM0402 | |
| 1 | C10 | 4.7uF | GCM32ER71H475KA55L<br>50 V 10% X7R 1210 - 55 °C to + 125 °C AEC-Q200 ROHS Lead-free | SM1210 | |
| 2 | C12<br>C13 | 8pF | CGA2B2C0G1H080D<br>50 V +/-0.5 pF C0G (NP0) 0402 - 55 °C to + 125 °C AEC-Q200 ROHS Lead-free | SM0402 | |
| 1 | C15 | 100nF | GCM155R71C104KA55<br>16 V 10% X7R 0402 - 55 °C to + 125 °C AEC-Q200 ROHS Lead-free | SM0402 | |
| 5 | CP1<br>CP2<br>CP3<br>CP4<br>CP5 | 2.2nF | GCM155R71H222KA37<br>50 V 10% X7R 0402 - 55 °C to + 125 °C AEC-Q200 ROHS Lead-free | SM0402 | |
| **Resistors** | | | | | |
| 1 | R1 | 3.3k | CRCW04023K30FKED<br>50 V 1% 0402 - 55 °C to + 155 °C AEC-Q200 ROHS Lead-free | SM0402 | |
| 1 | R2 | 120 | CRCW0805120RFKEA<br>150 V 1% 0805 - 55 °C to + 155 °C AEC-Q200 ROHS Lead-free | SM0805 | |
| 2 | R3<br>R4 | 220 | CRCW0402220RFKED<br>50 V 1% 0402 - 55 °C to + 155 °C AEC-Q200 ROHS Lead-free | SM0402 | |
| 2 | R5<br>R6 | 0 | CRCW12060000Z0EA<br>1206 - 55 °C to + 155 °C AEC-Q200 ROHS Lead-free | SM1206 | |
| 8 | R10<br>R11<br>R12<br>R13<br>RP1<br>RP2<br>RP3<br>RP4 | 2.2k | CRCW04022K20FKED<br>50 V 1% 0402 - 55 °C to + 155 °C AEC-Q200 ROHS Lead-free | SM0402 | |
| 4 | R21<br>R22<br>R23<br>R24 | 10 | RCL122510R0FKEG<br>2 W 1% 1225 - 40 °C to + 125 °C AEC-Q200 ROHS Lead-free | SM1225 | |

Table 4. Bill of Materials [(1)] (continued)

| | | | | | |
|---|---|---|---|---|---|
| 4 | RP51<br>RP52<br>RP53<br>RP54 | 1k | CRCW04021K00FKED<br>50 V 1% 0402 - 55 °C to + 155 °C AEC-Q200 ROHS Lead-free | SM0402 | |
| 4 | RT1<br>RT2<br>RT3<br>RT4 | 100k | CRCW0402100KFKED<br>50 V 1% 0402 - 55 °C to + 155 °C AEC-Q200 ROHS Lead-free | SM0402 | |
| **Inductor** | | | | | |
| 1 | CMC1 | DNP | B82789 recommended (100 uH) | SM1812_choke | [(2)] |
| **Connectors** | | | | | |
| 1 | BDM1 | CONN_3X2 | 15-91-3060<br>2.54 mm smd 3x2 ROHS Lead-free | 2.54mm smd 3x2 | |
| 1 | CAN1 | CONN_2 | 826936-2<br>2.54 mm 2x1 ROHS Lead-free | 2.54mm 2x1 | |
| 1 | POWER1 | CONN_6 | 826936-6<br>2.54 mm 6x1 ROHS Lead-free | 2.54mm 6x1 | |
| 2 | VSENSE/BAL1<br>SPI1 | CONN_5 | 826926-5<br>2.54 mm 5x1 ROHS Lead-free | 2.54mm 5x1 | |
| 1 | TEMP1 | CONN_8 | 5-146258-2<br>2.54 mm 4x2 ROHS Lead-free | 2.54mm 4x2 | |
| **Shunt** | | | | | |
| 1 | N/A | 0.1mOhm | BAS-M-R00001-5.0E | N/A | [(3)] |
| **Cables** | | | | | |
| 1 | N/A | N/A | WH18-02-25<br>Red 18AWG 15 cm wire | N/A | |
| 1 | N/A | N/A | WHS18-00-25<br>Black 18AWG 15 cm wire | N/A | |
| 1 | N/A | N/A | BU-P5167-2<br>Red Banana Jack | N/A | |
| 1 | N/A | N/A | BU-P5167-0<br>Black Banana Jack | N/A | |

Notes

1. Freescale does not assume liability, endorse, or warrant components from external manufacturers that are referenced in circuit drawings or tables. While Freescale offers component recommendations in this configuration, it is the customer's responsibility to validate their application.
2. Do not populate
3. **Critical components.** For critical components, it is vital to use the manufacturer listed.

# 14 References

Following are URLs where you can obtain information on related Freescale products and application solutions:

| Freescale.com Support Pages | Description | URL |
|---|---|---|
| MM9Z1_638 | Product Summary Page | http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=MM9Z1_638 |
| MM9Z1_J638 | Data Sheet | http://www.freescale.com/files/analog/doc/data_sheet/MM9Z1_638D1.pdf |
| MC33901 | Product Summary Page | http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=MC33901 |
| MC33901 | Data Sheet | http://cache.freescale.com/files/analog/doc/data_sheet/MC33901.pdf |
| MC33879 | Product Summary Page | http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=MC33879 |
| MC33879 | Data Sheet | http://cache.freescale.com/files/analog/doc/data_sheet/MC33879.pdf |
| P&E's USB BDM Multilink | Tool Summary Page | http://www.freescale.com/webapp/sps/site/prod_summary.jsp?code=USBMULTILINKBDM |
| Analog Home Page | Home Page | http://www.freescale.com/analog |
| Automotive Home Page | Home Page | http://www.freescale.com/automotive |

## 14.1 Support

Visit www.freescale.com/support for a list of phone numbers within your region.

## 14.2 Warranty

Visit www.freescale.com/warranty for a list of phone numbers within your region.

# 15 Revision History

| Revision | Date | Description of Changes |
| --- | --- | --- |
| 1.0 | 3/2014 | • Initial Release |

### *How to Reach Us:*

**Home Page:**
freescale.com

**Web Support:**
freescale.com/support



Document Number: KTRD9Z1-638-4LiUG
Rev. 1.0
3/2014