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Design Note

# UCC3956 Switch Mode Lithium-Ion Battery Charger Controller, Evaluation Board, Schematic, and List of Materials

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The UCC3956 Evaluation Kit allows the design engineer to evaluate the operation and performance of the Lithium-Ion Battery Charger Controller. The controller is designed to implement a DC to DC buck converter and features a four state charge control algorithm that enables the charger to safely and rapidly restore the battery pack to full capacity. The evaluation board is initially configured to charge a 2-Cell 1200mA Hour battery pack, however, the board can be modified to address a variety of applications. The UCC3956 Data Sheet contains detailed information about the use of the controller.

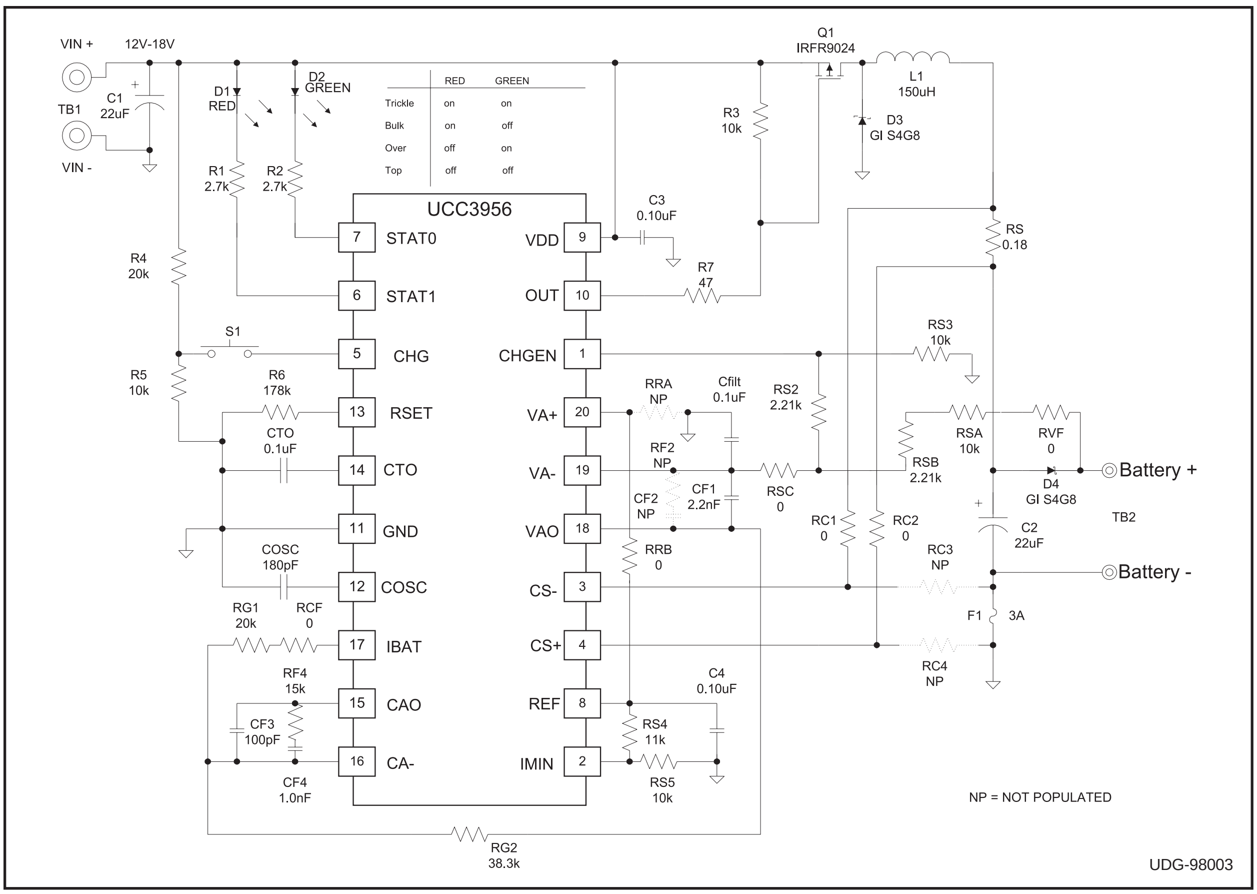


**Figure 1. Evaluation Board Schematic**

## Buck Power Stage

The evaluation board charger schematic is shown in Figure 1. Although the IC will operate with a VDD between 7 and 18 volts, the two cell design will require at least 12 volts to be able to charge the pack to 8.20 volts. To ensure low noise on the board, 22µF Tantalum capacitors (C1,C2) are added to the input and output terminals, while decoupling capacitors (C3, C4) are placed on the controller's reference and VDD. The PWM buck power stage consists of L1, Q1, and D3. The charger is designed to deliver 1.2 amps of bulk current (1C charge rate) and L1 is sized to provide continuous current with 25% ripple. A 3 amp fuse (F1) prevents destructive current from being applied to the battery in the event of a fault, while diode D4 blocks reverse battery current.

### Current Sense Circuitry

Inductor current is sensed across RS with a differential amplifier at the CS+ and CS– pins (notice current flows from CS– to CS+). The evaluation board has been configured with a "high side" current sense resistor, which has a DC operating voltage a diode drop above the positive terminal of the pack. This configuration allows the negative terminal of the pack to be referenced to circuit ground. High side current sensing is selected by populating RC1 and RC2 with zero ohm jumpers and by not populating (NP) RC3 and RC4. Certain applications may require a low side current sense solution. Examples include designs where the battery voltage exceeds the controller's $V_{DD}$ rating, or where a high side sense resistor would have excessive common mode noise. Low side current sensing can be implemented by swapping F1 and RS. In this case, RC3 and RC4 would have zero ohm jumpers, while RC1 and RC2 would not be populated.

### Feedback Components

The feedback design of the 2 cell charger is presented in the application section of the data sheet and will not be repeated here. Resistors RCF and RVF are initially populated with zero ohm jumpers and are assumed to be zero ohms in the equations that follow. In the evaluation of the charger's control loops, these jumpers can be replaced with low value resistors (50 ohm) to facilitate the use of a network analyzer. The current amplifier network for the two cell design consists of a pole-zero-pole response provided by CF3, CF4, and RF4, resulting in a crossover frequency around 10kHz. The voltage amplifier network consists of a single pole response, provided by CF1, with a crossover frequency of 2kHz. Components CF2 and RF2 are not populated, but allow the voltage feedback network to be modified.

### Oscillator Frequency

The PWM frequency is determined by Equation 1. A 180pF COSC and a 178k RSET yield a switching frequency of 100kHz.

$$Frequency = \frac{3.475}{(COSC + 20pF) \bullet RSET} \quad (1)$$

### Charge State Logic

A charge cycle is initiated by pressing the momentary push button switch S1. Resistors R4 and R5 keep the CHG pin voltage between 3 and 6 volts when S1 is closed. The controller has two status output pins, STAT0 and STAT1, which drive LEDs to indicate the states of the charger. An LED decode chart is printed on the evaluation board.

- **TR:** The trickle state is indicated when a reduced current is being delivered by the charger because the pack voltage is depleted below the trickle threshold. This state will also be indicated when power is initially applied to the board before a charge cycle is initiated.
- **BLK:** The constant current or bulk state is indicted when bulk current is being delivered by the charger and the pack voltage is between the trickle and the over-charge thresholds.
- **OVER:** The constant voltage or over-charge state is indicated when the pack voltage reaches 95% of its final value and the over-charge timer is initiated. Bulk current will continue being applied by the charger until the pack voltage reaches 100% of its final voltage, at which time the charge current will begin to decrease.
- **TOP:** The top-off state is indicated when the battery is at its final voltage and its current is below the top-off threshold set at the IMIN pin. The top-off indication notifies the user that the pack is near full capacity (maybe 95%) and is ready to be used. If the battery is not pulled from the charger, it will continue charging until the over-charge timer expires. When the over-charge timer expires, the LEDs will indicate the top-off state until a new charge cycle is initiated or power is cycled on the board.

### Programming the Trickle State

The charger transitions from the trickle to bulk charge state when the CHGEN pin equals 2.05 volts. The corresponding pack voltage is given in equation 2. With RSA = RS3 = 10.0K and RSB = RS2 = 2.21K, the charger will remain in the trickle state with a pack voltage less than 5.0 volts.

$$V_{PACK\_TRICKLE} = \left(\frac{RSA + RSB + RS2 + RS3}{RS3}\right) \bullet 2.05 \quad (2)$$

The programmed level of the trickle current is expressed in Equation 3. A trickle current of 60mA (C/20) is programmed with RG1=20K, RSET=178K and RS=0.18 ohm.

$$I_{TRICKLE} = \frac{RG1}{10 \bullet RSET \bullet RS} \quad (3)$$

### Programming Bulk Current

Bulk current is set by the resistor values at the input to the current error amplifier and the current sense resistor as expressed in Equation 4. A bulk current of 1.2A is programmed with RG1=20K, RG2=38.3K and RS=0.18 ohm.

$$I_{BULK} = \frac{2.05 \bullet RG1}{5 \bullet RG2 \bullet RS} \quad (4)$$

### Programming the Over Charge State

The controller indicates the over charge state and timer is initiated when the battery is at 95% of its final voltage (7.80V in this case). The over charge time period is programmed with CTO expressed in equation 5 (minutes). A capacitance of 0.1uF results in a period of 80 minutes. A capacitor in the pF range can be used when evaluating the timer's functionality (i.e. a 220pF CTO will give a 10 second time-out period).

$$TIMEOUT = 4550 \bullet CTO \bullet RSET \quad (5)$$

The charger will transition from a constant current to a constant voltage mode of operation when the voltage amplifier comes into regulation. This occurs when the voltage at the inverting input (VA–) of the amplifier reaches the value set at the non-inverting input (VA+). The voltage at VA+ is set by resistors RRA and RRB as expressed in equation 6. In the case of the 2 cell charger, RRA is not populated and RRB is a zero ohm jumper, yielding a VA+ voltage equal to the 4.1V reference.

$$V+ = 4.1 \bullet \left( \frac{RRA}{RRA + RRB} \right) \quad (6)$$

The final pack voltage is programmed by a resistor divider tied to the VA– input (the resistor values are also used to set the trickle threshold). Equation 7 gives the formula for the final pack voltage. Capacitor Cfilt is connected to the VA– input to suppress a voltage spike that occurs when the charger transitions from the trickle to bulk state, preventing the overcharge timer from being initiated prematurely. A final voltage of 8.2V is achieved by using the resistor values of Figure 1.

$$V_{PACK\_FINAL} = \left( \frac{RSA + RSB + RS2 + RS3}{RS2 + RS3} \right) \bullet V+ \quad (7)$$

### Programming the Top-off Current Level

The top-off state is indicated when the pack has reached its final voltage and the current to the pack has been reduced below the level set by equation 8. With RS4=11k, RS3=10k, and RS=0.18 ohms, a current level of 120mA (C/10) will turn both LEDs off, indicating the battery is near full charge. Again, if the user does not pull the battery from the charger, it will continue to charge until the timer expires, restoring 100% capacity.

$$I_{TOP\_OFF} = \frac{2.05 \bullet \left( 1 - 2 \left[ \frac{RS5}{RS4 + RS5} \right] \right)}{5 \bullet RS} \quad (8)$$

### Configuring the Charger to Address Different Pack Voltages

A single cell design requires a final pack voltage of 4.1 volts. This can be accomplished with two different approaches. The first approach is to leave VA+ connected to the 4.1V reference and replace RSA and RSB with zero ohm jumpers. An impedance, required for the voltage amplifier network, is provided by populating RSC with a 10K resistor. Resistor values for RS2 and RS3 would need to be changed to set the trickle threshold. The second approach is to maintain the two-cell design values for RSA, RSB and RSC, and to place equal value resistors at RRA and RRB, setting VA+ to 2.05 volts.

Three and four cell designs will require a higher value for RSA+RSB. Since a four cell design will have a final pack voltage of 16.8V, the input voltage of the charger may exceed the maximum rating of the controller. In this case, a level shifting circuit will be needed to drive Q1 and a Zener regulator will be needed at $V_{DD}$.

For more complete information, pin descriptions and specifications for the UCC3956, please refer to the datasheet or contact your Unitrode Field Applications Engineer.

| Reference Designator | Part Description | Distributor or Manufacturer Part Number |
|---|---|---|
| C1, C2 | 22µF Tantalum SMD-7343 | Allied 213-6137 |
| C3, C4, CFILT, CTO | 0.1µF Ceramic SMD-1206 | Digikey PCC104BCT-ND |
| CF1 | 2200pF Ceramic SMD-1206 | Digikey PCC222BCT-ND |
| CF3 | 100pF Ceramic SMD-1206 | Digikey PCC101CCT-ND |
| CF4 | 1000pF Ceramic SMD-1206 | Digikey PCC102BCT-ND |
| COSC | 180pF Ceramic SMD-0805 | Digikey PCC181CGCT-ND |
| D1 | Red LED | Digikey HLMP-1700QT-ND |
| D2 | Green LED | Digikey HLMP-1790QT-ND |
| D3, D4 | 3A Schottky Diode SMD | General Instruments SS34 |
| F1 | 3A Slow Blow Fuse SMD-7343 | Digikey FF1169CT-ND |
| L1 (provided) | 150µH Inductor, 1.5A | Coilcraft DO-5022P-154 |
| (Alternate for lower current) | 150µH Inductor, 1.0A | Coilcraft DO-3316P-154 |
| (Alternate for low noise) | 150µH Toridal Inductor, 1.7A | Pulse Engineering (619)674-8100 PE-25645 |
| Q1 (provided) | P-channel 0.28 RDSON SMD | International Rect. IRFR9024 |
| (Alternate thru hole) | P-channel 0.28 Rdson TO-220 | International Rect. IRF9Z24 |
| R1,R2 | 2.67k Resistor SMD-1206 | Digikey P2.76KFCT-ND |
| R3, R5, RSA, RS3, RS5 | 10.0k Resistor SMD-1206 | Digikey P10.0KFCT-ND |
| R4, RG1 | 20.0k Resistor SMD-1206 | Digikey P20.0KFCT-ND |
| R6 | 178k Resistor SMD-1206 | Digikey P178KFCT-ND |
| R7 | 47Ω Resistor SMD-1206 | Digikey P47FCT-ND |
| RCF, RVF, RRB, RSC, RC1, RC2 | 0Ω Jumper SMD-1206 | Mouser 71-CRCW1206-0 |
| RF4 | 15.0k Resistor SMD-1206 | Digikey P15.0KFCT-ND |
| RG2 | 38.3k Resistor SMD-1206 | Digikey P38.3KFCT-ND |
| RS2, RSB | 2.21k Resistor SMD-1206 | Digikey P2.21KFCT-ND |
| RS | 0.18Ω Resistor SMD-2512 | Digikey P.18VCT-ND |
| RS4 | 11.0k Resistor SMD-1206 | Digikey P11.0KFCT-ND |
| S1 | Momentary Push Switch | Digikey CKN9002CT-ND |
| TB1, TB2 | Terminal Blocks | Digikey ED1601-ND |
| U1 | Charger Controller | Unitrode UCC3965 SOIC-20 |
| CF2, RC3, RC4, RRA, RF2 | Not populated | |

**Table 1. Parts list for the 2 Cell Charger in Figure 1.**

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