

Three - Four Cell Lithium-Ion Protector Circuit

FEATURES

- Three or Four Cell Operation
- Two Tier Overcurrent Limiting
- 30 μ A Typical Supply Current Consumption
- 3.5 μ A Typical Supply Current in Sleep Mode
- Smart Discharge Minimizes Losses in Overcharge Mode
- 6.5V to 20V VDD Supply Range
- Highly Accurate Internal Voltage Reference
- Externally Adjustable Delays in Overcurrent Controller
- Detection of Loss of Cell Sense Connections

DESCRIPTION

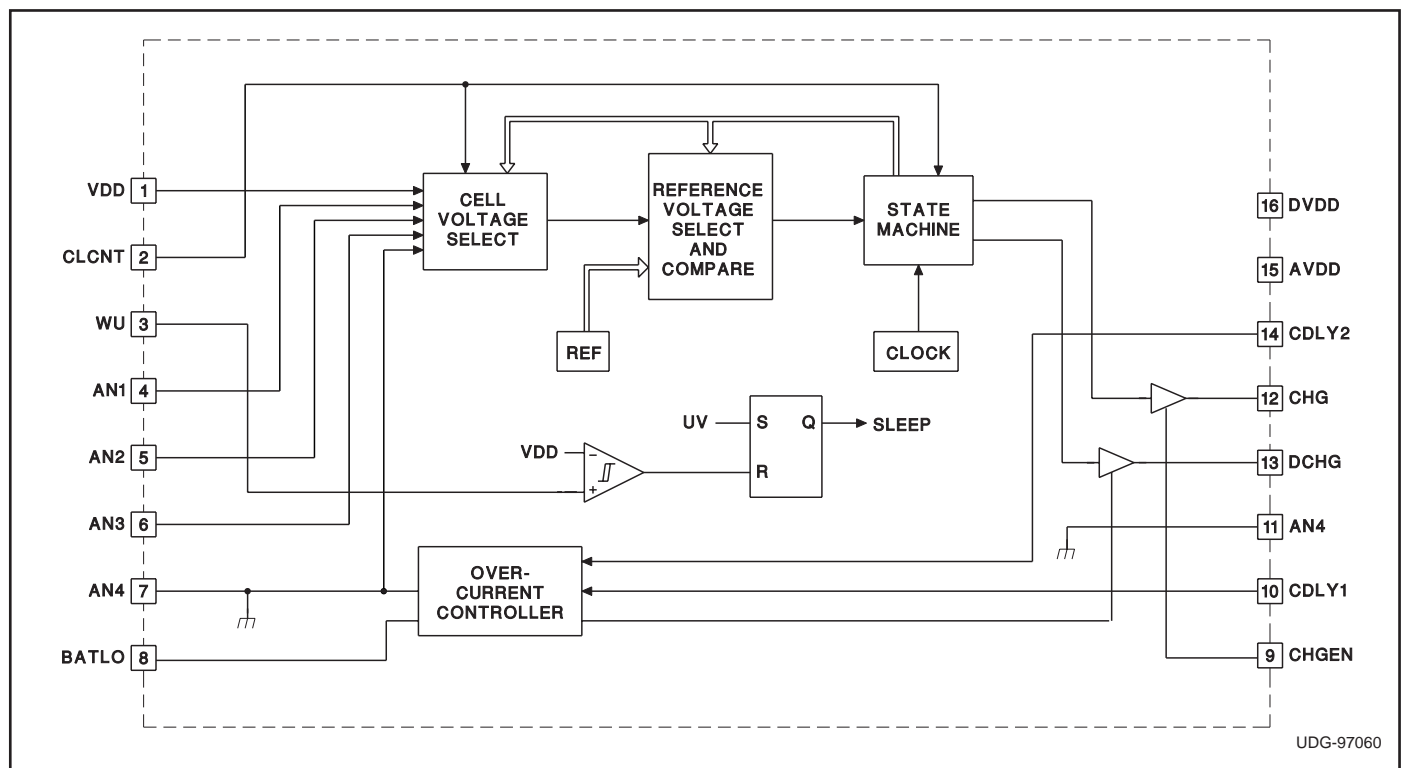
The UCC3957 is a BiCMOS three or four cell lithium-ion battery pack protector designed to operate with external P-channel MOSFETs. Utilizing external P-channel MOSFETs provides the benefits of no loss of system ground in an overdischarge state, and protects the IC as well as battery cells from damage during an overcharge state. An internal state machine runs continuously to protect each lithium-ion cell from overcharge and overdischarge. A separate overcurrent protection block protects the battery pack from excessive discharge currents.

If any cell voltage exceeds the overvoltage threshold, the appropriate external P-channel MOSFET is turned off, preventing further charge current. An external N-channel MOSFET is required to level shift to this high side P-channel MOSFET. Discharge current can still flow through the second PFET. Likewise, if any cell voltage falls below the undervoltage limit, the second P-channel MOSFET is turned off and only charge current is allowed. Such a cell voltage condition will cause the chip to go into low power sleep mode. Attempting to charge the battery pack will wake up the chip. A cell count pin (CLCNT) is provided to program the IC for three or four cell operations.

A two tiered overcurrent controller and external current shunt protect the battery pack from excessive discharge currents. If the first overcurrent threshold level is exceeded, an internal timing circuit charges an external capacitor to provide a user programmable blanking time.

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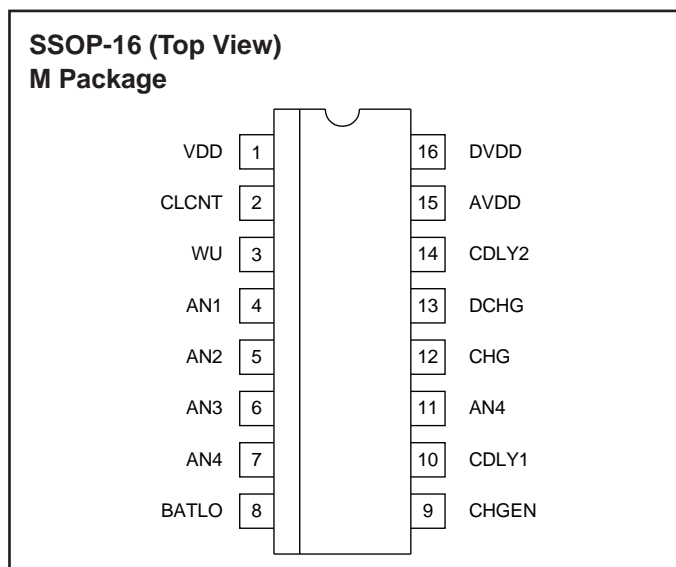
BLOCK DIAGRAM



ABSOLUTE MAXIMUM RATINGS

Supply Voltage	20V
Supply Current	25mA
Output Current (CHG, DCHG)	25mA
WU Input Voltage	28V
BATLO Input Voltage	–0.3V to 2.5V
AN1 and AN3 Input Voltage	VAN4 – VDD
CLCNT and CHGEN	VAN4 – VDD
Storage Temperature	–65°C to +150°C
Junction Temperature	–55°C to +150°C
Lead Temperature (Soldering, 10 sec.)	+300°C

Unless otherwise indicated, voltages are referenced to AN4. Currents are positive into, negative out of the specified terminal. Consult Packaging Section of Databook for thermal limitations and considerations of packages.

CONNECTION DIAGRAM**DESCRIPTION (continued)**

If at the end of the blanking time the overcurrent condition still exists, the external discharge FET is turned off for a period 17 times longer than the first blanking period, and then the discharge FET is turned back on. If at any time a second higher overcurrent threshold is ex-

ceeded for more than a user programmable time, the discharge FET is turned off, and will remain off for the same period as the first tier off time. This two tiered overcurrent protection scheme allows for charging capacitive loads while retaining effective short circuit protection.

ELECTRICAL CHARACTERISTICS: Unless otherwise specified, VDD = 16V and –20°C < T_A < 70°C, T_A = T_J. All voltages measured with respect to the AN4 terminal.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
Supply Section					
Minimum V _{DD}			5.0	5.5	V
Supply Current			30	40	μA
Sleep Mode Supply Current	V _{DD} = 10.4V		3.5	7.5	μA
Output Section					
DCHG Output Current	Driving Logic Low and V _O = 1V	40	70	100	μA
	Driving Logic High and V _O = VDD – 1	–20	–7	–3	mA
CHG Output Current	Driving Logic Low and V _O = 1V	40	70	100	μA
	Driving Logic High and V _O = VDD – 1V	–20	–7	–3	mA
State Transitions					
Normal to Overcharge	UCC3957-1	4.15	4.20	4.25	V
Overcharge to Normal	UCC3957-1	3.95	4.00	4.05	V
Normal to Overcharge	UCC3957-2	4.20	4.25	4.30	V
Overcharge to Normal	UCC3957-2	4.00	4.05	4.10	V
Normal to Overcharge	UCC3957-3	4.25	4.30	4.35	V
Overcharge to Normal	UCC3957-3	4.05	4.10	4.15	V
Normal to Overcharge	UCC3957-4	4.30	4.35	4.40	V
Overcharge to Normal	UCC3957-4	4.10	4.15	4.20	V
Undercharge to Normal		2.5	2.6	2.7	V
Normal to Undercharge		2.2	2.3	2.4	V
OV to CHG Delay	(Note 1)	10	17	23	ms

ELECTRICAL CHARACTERISTICS: Unless otherwise specified, VDD = 16V and $-20^{\circ}\text{C} < T_A < 70^{\circ}\text{C}$, $T_A = T_J$.

All voltages measured with respect to the AN4 terminal.

PARAMETER	TEST CONDITIONS	MIN	TYP	MAX	UNITS
State Transitions (continued)					
UV to DCHG Delay	(Note 1)	10	17	23	ms
Cell Sample Rate	(Note 1)	5	8.5	11.5	ms
Smart Discharge Threshold	BATLO Voltage	12	15	20	mV
Wakeup Input Threshold	With Respect to VDD	50			mV
Charge Enable Input Threshold		0.8	1.3	2.6	V
Short Circuit Protection					
First Tier Threshold Level	V _{BATLO}	120	150	180	mV
Second Tier Threshold Level	V _{BATLO}	300	375	450	mV
First Tier Blanking Time	CDLY1 = 0.1μF	30	50	70	ms
Restart Time	CDLY1 = 0.1μF	300	500	700	ms
Second Tier Blanking Time	CDLY2 = 10pF	200	400	550	μs

Note 1: Tested at probe only.

Note 2: Other OV/UV thresholds are available. Please consult the factory.

PIN DESCRIPTIONS

AN1: Connects to the negative terminal of the top battery cell and the positive terminal of the second battery cell.

AN2: Connects to the bottom terminal of the second battery cell and the top terminal of the third battery cell.

AN3: Connects to the bottom terminal of the third battery cell and the top terminal of the fourth battery cell in a four cell stack. In a three cell pack it connects to the bottom terminal of the third battery and to AN4.

AN4: Connects to the bottom terminal of the battery stack and the top of the current sense resistor.

AVDD: Internal analog supply bypass cap pin. Connect a 0.1μF capacitor between this pin and AN4. This pin is nominally 7.3V.

BATLO: Connects to the bottom of the current sense resistor and the negative terminal of the battery pack.

CHGEN: The charge enable input for the protection IC. This point must be driven high to allow charging of the battery pack. This pin has a very weak pulldown.

CDLY1: Delay control pin for the short circuit protection feature. A capacitor connected between this point and AN4 will determine the time delay from when an overcurrent situation is detected to when the FET is turned off. This capacitor also controls the hiccup mode timeout period.

CDLY2: An external cap can be tied between this pin and AN4 to extend the blanking time on the second current limit tier.

CLCNT: This pin programs the IC for three or four cell operation. Tying this pin low (to AN4) sets four cell operation, while tying it high (to VDD or the preferred DSPLY or ASPLY) sets three cell operation. This pin is internally pulled low, so open circuit conditions will always result in four cell mode.

DCHG: This pin is used to prevent overdischarge. If the state machine indicates that any cell is undervoltage, this pin will be driven high with respect to chip substrate so that the external P-channel MOSFET will prevent further discharge. If all cell voltages are above the minimum threshold, this pin will be driven low.

CHG: This pin is used to control an external N-channel MOSFET, which in turn drives a P-channel MOSFET. If at least one cell voltage is over the OV threshold, this pin will be driven low with respect to AN4. If all cell voltages are below this threshold, this pin will be driven high.

DVDD: Internal digital supply bypass capacitor pin. Connect a 0.1μF capacitor between this pin and AN4. This pin is nominally 7.3V.

VDD: Supply voltage to the IC. Connect this point to the top of the lithium-ion battery stack.

WU: This pin is used to provide a wake up signal to the IC during sleep mode. Connect this pin to the drain of the N-channel level shift MOSFET.

APPLICATION INFORMATION

Overview

The UCC3957 provides complete protection against over-discharge, over-charge and overcurrent for a three or four cell Lithium-Ion battery pack. It uses a “flying capacitor” technique to sample the voltage across each battery cell and compare it to a precision reference. If any cell is in over or under-voltage, the internal state machine takes the appropriate action to prevent further charge or discharge. High-side P-MOSFETs are used to independently control charge and discharge current. Typical application circuits are shown in Figures 1 and 2.

Connecting the Cell Stack

When connecting the cell stack to the circuit, it is important to do it in the proper order. First, the bottom of the stack should be connected to AN4. Next, the top of the stack should be connected to VDD. The cell taps can then be connected to AN1-AN3 in any order.

Choosing Three or Four Cells

For three cell packs, the cell count pin (CLCNT) should be connected to the DSPLY pin, and the AN3 pin should be tied to the AN4 pin. For four cell applications, the CLCNT pin should be grounded (to AN4) and the AN3 pin will be connected to the positive terminal of the bottom cell in the stack.

Under-voltage Protection

When any cell is found to be over-discharged (below the Normal to Undercharge threshold), the state machine turns off both high-side FETs and enters the sleep mode, where current consumption drops to about 3.5uA. It remains in sleep mode until the application of a charger is sensed by the Wake Up (WU) pin being raised above VDD.

Charging

Once a charger has been applied, the Charge FET will be turned on as long as the Charge Enable input (CHGEN) is pulled up to the DSPLY pin. If the CHGEN input is left open (or connected to AN4), the Charge FET will remain off.

During charge, the Discharge FET will be off (current will be conducted through its body diode) until the cell voltages are all above the Undercharge to Normal threshold. Once the cell voltages are above this threshold, the Discharge FET will be turned on, minimizing power dissipation.

Open Wire Protection

The UCC3957 provides protection against broken cell sense connections within the pack. If the sense connection to one of the cells (pins AN1, 2 or 3) should become

disconnected, weak internal current sources will make the cells connected to that wire appear to be in over-charge and charging of the pack will be prevented.

Over-voltage Protection and the “Smart Discharge” Feature

If any cell is charged to a voltage exceeding the Normal to Overcharge threshold, the Charge FET will be turned off, preventing further charge current. Hysteresis keeps the Charge FET off until the cell voltages have dropped below the Overcharge to Normal threshold. In most protector designs, the Charge FET is held off completely within this voltage band. During this time, discharge current must be conducted through the body diode of the Charge FET. This forward voltage drop can be as high as 1V, causing significant power dissipation in the Charge FET and wasting precious battery power.

The UCC3957 has a unique “Smart Discharge” feature that allows the Charge FET to come back on (for discharge only) while still in the overcharge hysteresis band. This greatly reduces power dissipation in the Charge FET. This is accomplished by sensing the voltage drop across the current sense resistor. If this drop exceeds 15mV (corresponding to 0.6 amps of discharge current using a .025 sense resistor), the Charge FET is turned back on. This threshold assures that only discharge current will be conducted. In an example using a 20m FET with a 1V body diode drop and a 1 amp load, the power dissipation in Q1 would be reduced from 1 watt to 0.02 watts. Note that a similar technique is not used during charge (when the Discharge FET is off due to cells being in undervoltage) because the charge current should be low while the cells are in undervoltage.

Protection Against a Runaway Charger

The use of a small N-channel level shifter (Q3 in the application diagrams) allows the IC to interface with the high-side Charge FET (Q1), even in the presence of a runaway charger. Only the drain-source voltage rating of the charge FET limits the charge voltage that the protection circuit can withstand. The Wakeup (WU) pin is designed to handle input voltages greater than VDD, as long as the current is limited. In the examples shown, the Charge FET's gate-source resistor (R1) provides this current limiting. Note that in Figure 2, a resistor and zener (R2 and VR1) have been added to protect Q1 against any possibility of a voltage transient exceeding its maximum gate-source rating.

Overcurrent Protection

The UCC3957 protects the battery pack from an overload or a hard short circuit using a two-tier overcurrent protection scheme. The overcurrent protection is de-

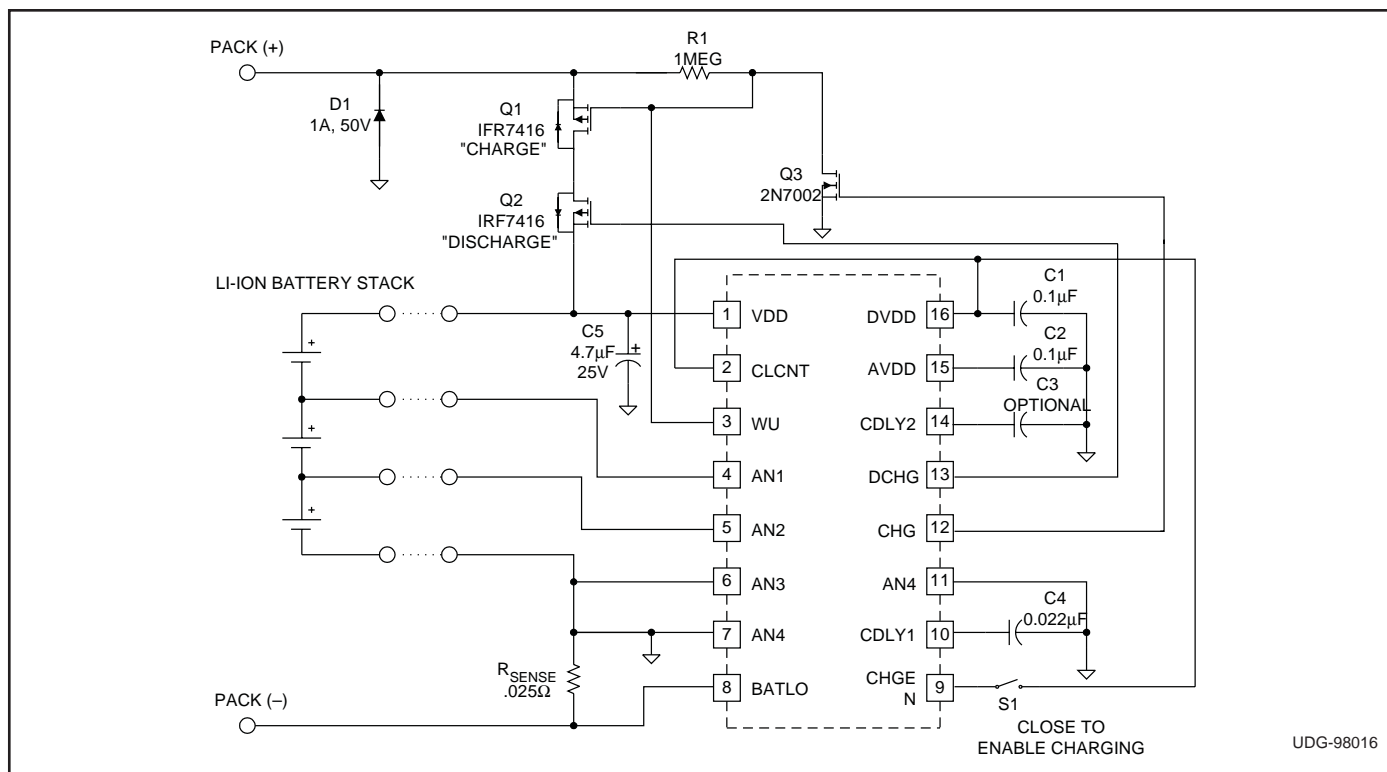


Figure 1. Three cell lithium-ion protector application diagram, showing optional charge enable switch.

Note: D1 protects Q2 from inductive kick at turn-off.

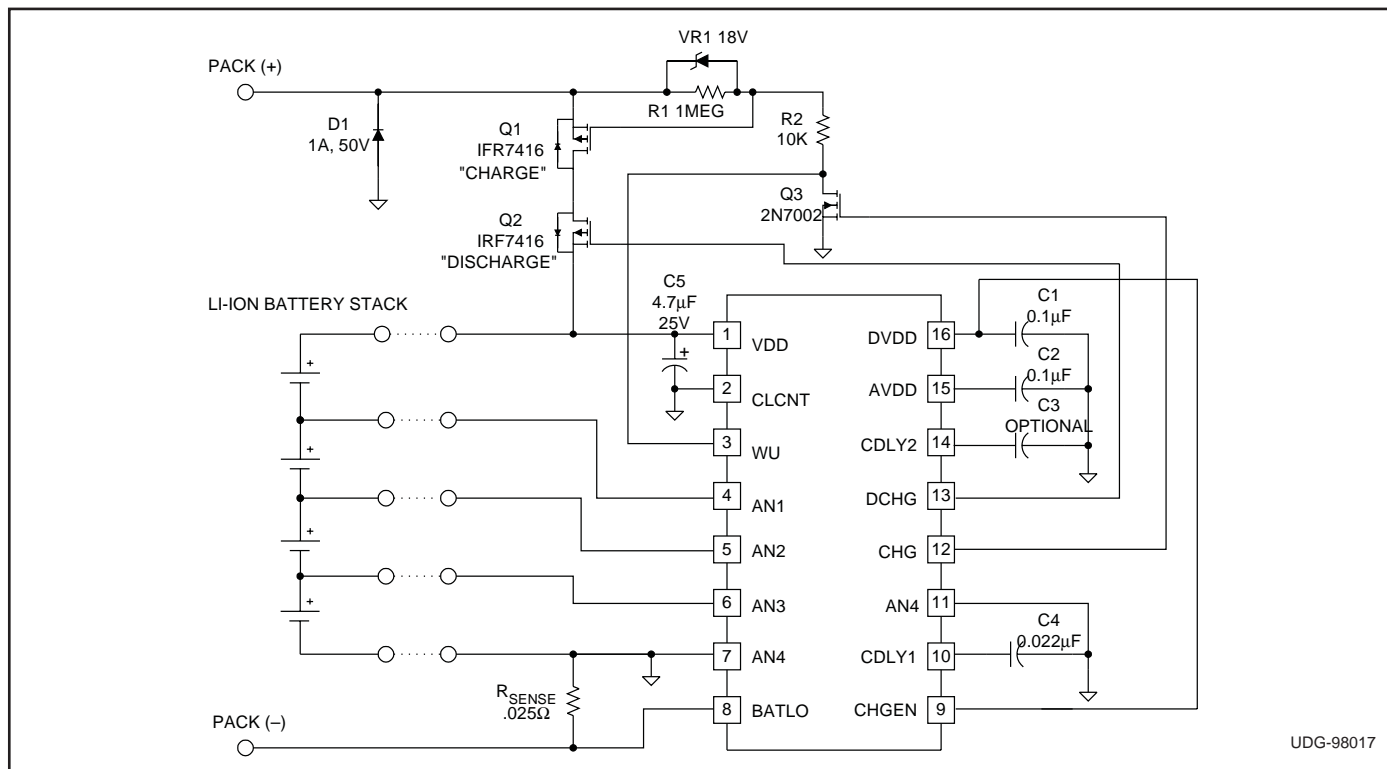


Figure 2. Four cell protector with optional components to protect the charge FET from excessive gate-source transients.

Note1. VR1 and R2 are optional. They protect Q1 from excessive open-circuit charger voltage.

Note 2. D1 protects Q2 from inductive kick at turn-off.

APPLICATION INFORMATION (continued)

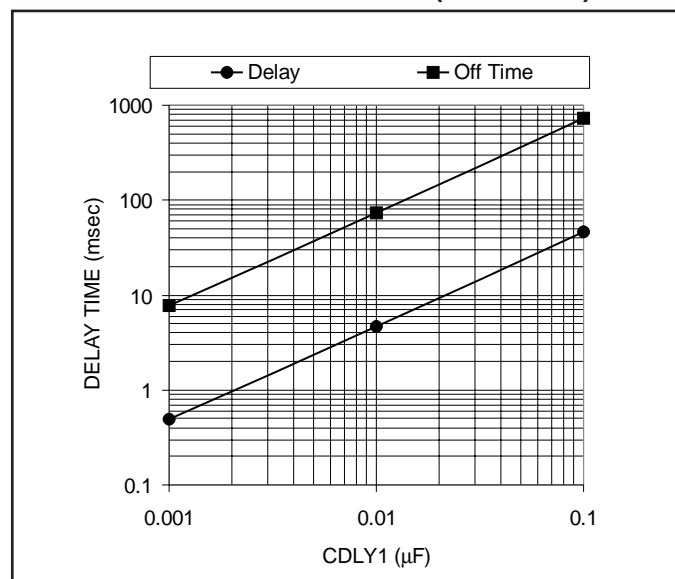


Figure 3. Typical tier 1 Overcurrent delay time and off time vs. CDLY1.

signed to go into a hiccup mode when the voltage drop across an external sense resistor (connected to the AN4 and BATLO pins) exceeds a certain threshold. In this mode, the Discharge FET is periodically turned off and on until the fault is removed. Once the fault is removed, normal operation is automatically resumed.

To facilitate charging large capacitive loads, there are two overcurrent threshold voltages, each with its own user programmable time delay. This two-tier approach provides fast response to short circuits, while enabling the battery pack to provide short duration surge currents. It also facilitates the charging of large filter caps without causing nuisance overcurrent trips.

The first tier threshold is 150mV nominal, corresponding to 6 amps using a .025 sense resistor as shown in the examples of Fig's 1 & 2. If the pack discharge current exceeds this amount for a period of time, determined by the capacitor on the CDLY1 pin, then the hiccup mode will be entered. The first tier hiccup duty cycle is fixed at approximately 6%, minimizing power dissipation in the event of a sustained overload. The absolute on and off times of the Discharge FET (Q2) are controlled by the CDLY1 capacitor. A curve relating the delay (on) time to this capacitor value is shown in Figure 3. The off time is approximately 17 times longer than the on time.

The second tier overcurrent threshold is nominally 375mV, corresponding to 15 amps using a .025 sense resistor. If the pack current exceeds this value for a period of time, determined by the capacitor on the CDLY2 pin, then the hiccup mode will be entered with a much lower duty cycle, typically less than 1%. The relationship

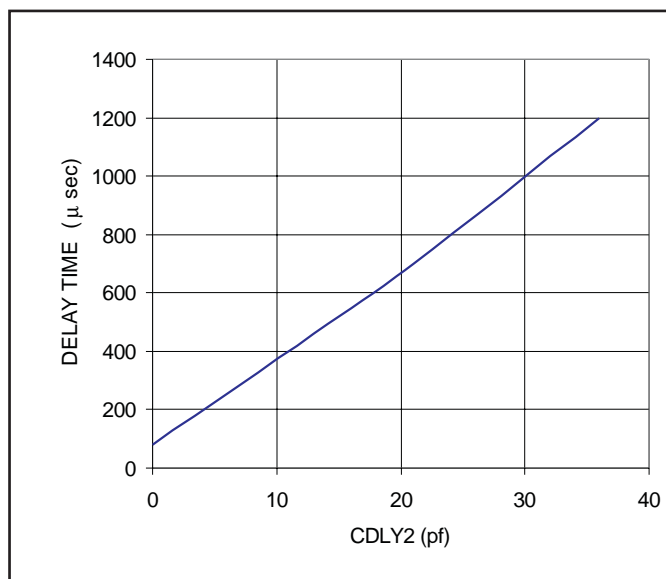


Figure 4. Typical tier 2 Overcurrent delay time vs. CDLY2.

of this time delay (on time) to the CDLY2 capacitor value is shown in the curve of Figure 4. The off time during this hiccup mode is still determined by the CDLY1 capacitor, as previously described. This technique greatly reduces the stress and power dissipation in the FETs during short circuit conditions.

In the examples shown in Fig's 1 & 2 (with $\text{CDLY1} = .022 \text{ F}$), the first tier overcurrent on time will be about 10msec, while the off time will be about 170msec, resulting in a 5.9% duty cycle for currents over 6 amps (but less than 15 amps). If no CLDY2 capacitor is used, the second tier on time will be less than 200 sec (assuming no stray capacitance), resulting in a duty cycle of about 0.1% for currents over 15 amps. If $\text{CDLY2} = 22\text{pF}$, the typical on time for currents exceeding 15 amps will be about 800usec, resulting in a duty cycle of 0.5%.

Protecting Against Inductive Kick at Turn-off

In the case of a short circuit, the di/dt that occurs when the Discharge FET is turned off can result in a significant voltage undershoot at the pack output due to stray inductance. This undershoot can potentially exceed the breakdown voltage rating of the Discharge FET. A clamp diode (D1 in Fig's 1, 2 & 3), or a capacitor across the pack output, protects against this possibility. A diode also provides protection from a reverse polarity charger.

During turn-off, a voltage overshoot can occur at the top of the cell stack, due to wiring inductance and the cells' internal ESL (Equivalent Series Inductance). During very high di/dt conditions, such as that which occurs when turning off in response to a short circuit, this voltage overshoot can be significant and potentially damage the

APPLICATION INFORMATION (continued)

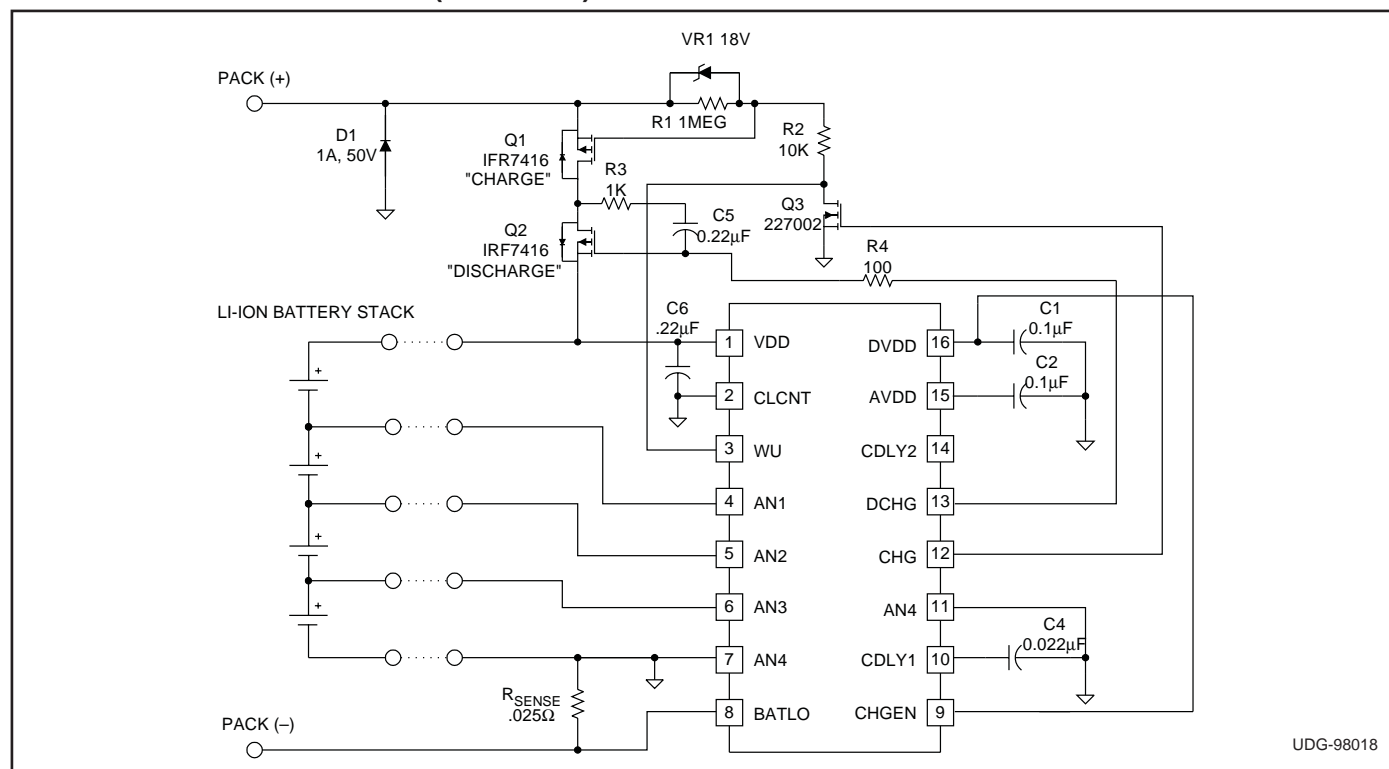


Figure 5. Four cell protector with slew rate limiting the discharge FET.

Note 1: VR1 and R2 are optional. They protect Q1 from excessive open-circuit charger voltage.

Note 2: R3 and C5 are chosen based on capacitive load that must be driven.

Note 3: R4 minimizes inductive kick at turn-off.

IC or the Discharge FET (Q2). For this reason, it is strongly recommended that a capacitor (C5 in Fig's 1 & 2) be placed across the cell stack, from VDD to AN4, and that stray inductance be minimized in the battery current path. An alternative to adding a capacitor across the cell stack is to reduce the di/dt. This is discussed in the next section.

Controlling Discharge FET Turn-on / Turn-off Times

By slew rate limiting the pack output voltage at turn-on, the surge current into large capacitive loads can be greatly reduced.

This allows the designer to select shorter overcurrent delay times, minimizing the stress on Q1 and Q2 in the event of a shorted pack output. A simple method of implementing slew rate limiting is shown in Figure 5. It consists of an RC network (R3 and C5) between gate and drain of the Discharge FET (Q2) to control its turn-on time. This circuit relies on the relatively high sink impedance (about 20K) of the UCC3957's DCHG output. The

values shown for R3 and C5 will provide a pack output voltage rise time of about 4.5msec when the Discharge FET (Q2) is turned on. Note that the addition of R3 and C5 has made it possible to eliminate the CDLY2 capacitor, for the quickest response to a true short circuit. While this circuit will not prevent a large surge current when inserting a "live" battery pack into a highly capacitive load, it will allow it to restart (after one hiccup cycle) if this initial surge current trips the overcurrent protection.

Increasing the turn-off time of the Discharge FET (Q2) reduces the inductive kick that results during turn-off after an overcurrent condition. This is accomplished by adding a resistor (R4) in series with the DCHG output. This reduction of di/dt at turn-off will minimize (or eliminate) the need for a capacitor across the battery stack. It is recommended that this resistor value not exceed a few hundred ohms, or the ability to turn off quickly enough into a short may be compromised.

Due to the relatively low charge currents (typically a few amps max), controlling the turn-on and turn-off times of the Charge FET is not beneficial. In fact, the turn-off time of the Charge FET will be slow due to the large value of R1, the gate-source resistor.

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