

**OVERVIEW**

This application note presents a DS2770-based charge controller reference design (see Figure 1) for single-cell Li+ and triple-cell stack NiMH battery packs. It is intended for use with current limited charge sources with an open-circuit voltage no greater than 10V. This design assumes that the DS2770 is configured with an internal current sense resistor and the required protection circuitry for Li+ cells exists for the battery pack.

Three important issues were considered in the design of this circuit: charge currents and transistor biasing, DS2770 over-voltage protection if the battery protector open-circuits, and ESD protection.

This application note presents sample calculations to determine component values for a 4.2V Li+ pack using a 1A charge current and 50mA trickle-charge current; however, these values can be modified to tailor the circuit to the specific application.

**DALLAS REFERENCE DESIGN**

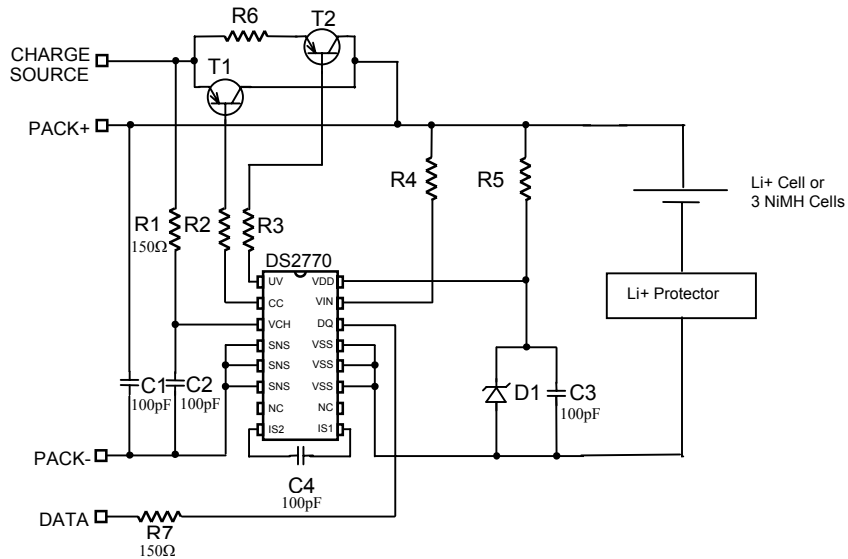


Figure 1. Recommended schematic for single-cell Li+ and triple-cell stack NiMH battery packs.

**CHARGE CURRENTS AND TRANSISTOR BIASING — FAST CHARGING**

The DS2770 provides for two rates of charging depending on the voltage of the battery. If the battery voltage is below 3.0V, a trickle charge is used to recover the battery voltage before fast charging begins. Charging is controlled through transistors T1 and T2, which the DS2770 turns on and off as needed.

Fast charging is controlled by transistor T1. However, it is important to note that the charge current must be limited by the charge source since T1 acts as a low-impedance switch between the charge source and the battery. For the most efficient charging, T1 should be barely in the saturated region. The amount of current flowing from the base of T1 to achieve saturation depends on its Beta ( $\beta_{T1}$ ) and the desired charge current:

$$1) \quad \text{Saturation Base Current} = \text{Desired Charge Current} / \beta_{T1}$$

Resistor R2 limits current into the DS2770 CC pin, and thus controls the T1 base current. When determining the optimum value for R2, use the maximum possible battery voltage ( $V_{BAT}$ ) to get the worst-case scenario. R2 can then be calculated as follows:

$$2) \quad R2 = V_{R2} / I_{R2} = ((V_{BSAT} - V_{CC}) \times \beta_{T1}) / \text{Desired Charge Current}$$

where

$$3) \quad V_{BSAT} \text{ (Saturation Base Voltage)} = V_{BAT} + V_{CE} - V_{EB} = V_{BAT} + 0.2V - 0.7V = V_{BAT} - 0.5V$$

and  $V_{CC}$  is the voltage at the DS2770 CC pin. During charging, the CC pin is internally pulled to GND; however, there is some internal resistance on the CC pin, typically 200 $\Omega$ ; thus,  $V_{CC}$  can be calculated as follows:

$$4) \quad V_{CC} = \text{Saturation Base Current} \times \text{Internal Resistance of the CC pin}$$

Example: For a 4.2V Li+ battery pack (4.3V maximum during a charge) requiring a 1A charge current, an FM718 transistor with a minimum Beta of 100 is selected for T1. This transistor requires 10mA of base current to be saturated when providing a 1A charge current. Therefore, the voltage at the CC pin will be 2.0V, so a 180 $\Omega$  resistor is chosen for R2.

$$\begin{aligned} R2 &= ((V_{BAT} + V_{CE} - V_{EB} - V_{CC}) \times \beta_{T1}) / \text{Desired Charge Current} \\ &= ((4.3V + .2V - .7V - 2V) \times 100) / 1A \\ &= 180\Omega \\ &\therefore \text{Choose R2 to be } 180\Omega \end{aligned}$$

## CHARGE CURRENTS AND TRANSISTOR BIASING — TRICKLE CHARGING

Trickle charging is gated by T2 and is current limited by R6. The value of R6 depends on the voltage of the charge source (VCH) and the current that is desired for trickle charging. When calculating the value of R6, assume  $V_{BAT} = 0V$ , which would create the worst-case trickle-charge current. Thus, the voltage across R6 is:

$$5) \quad V_{R6} = V_{CH} - V_{BAT} - V_{CE} = V_{CH} - 0.2V$$

where VCH is the charge source voltage and  $V_{CE}$  is the drop across the saturated transistor, and

$$6) \quad R6 = V_{R6} / \text{Maximum Trickle-Charge Current}$$

R6 also needs to be able to dissipate the maximum required power such that the resistor power rating ( $PR_{R6}$ ) is as follows:

$$7) \quad PR_{R6} = (\text{Maximum Trickle-Charge Current})^2 \times R6$$

The T2 base current can be determined using Equation 1, so that it will operate in the saturated region. However, the  $\beta$  is less important for T2 due to the low trickle charge current, so a less expensive transistor with a lower  $\beta$  can be used for this transistor.

During trickle charging, the DS2770 UV pin is pulled to GND, and like the CC pin, there is typically 200 $\Omega$  of internal resistance on the UV pin. Thus, the voltage on the UV pin,  $V_{UV}$ , can be determined in the same manner as  $V_{CC}$  (see Equation 4). In addition, the T2 saturation base voltage can be calculated using Equation 3, with  $V_{BAT} = 3.0V$ , since that is the highest  $V_{BAT}$  voltage during trickle charging. The value of R3 can then be calculated as follows:

$$8) \quad R3 = ((V_{BSAT(T2)} - V_{UV}) \times \beta_{T2}) / \text{Maximum Trickle-Charge Current}$$

Example: A 50mA trickle charge current is desired from the 10V charge source, so R6 is selected to be a 200 $\Omega$  resistor rated at 1 watt. A 4403 transistor with  $\beta = 20$  is selected for T2, which requires a 3mA base current for saturation. In this case  $V_{UV} = 0.6V$ , so a 1k $\Omega$  resistor is used for R3.

$$\begin{aligned} R6 &= (V_{CH} - V_{BAT} - 0.2V) / \text{Maximum Trickle-Charge Current} \\ &= (10V - 0V - 0.2V) / 50mA \\ &= 196\Omega \\ &\therefore \text{Choose R6 to be } 200\Omega \end{aligned}$$

$$\begin{aligned} PR_{R6} &= (\text{Maximum Trickle-Charge Current})^2 \times R6 \\ &= (50mA)^2 \times 200\Omega \\ &= .5 \text{ watts} \\ &\therefore \text{Choose R6 to be rated higher than } \frac{1}{2} \text{ watt, such as a 1-watt 2512 package} \end{aligned}$$

$$\begin{aligned} R3 &= ((V_{BSAT(T2)} - V_{UV}) \times \beta_{T2}) / \text{Maximum Trickle-Charge Current} \\ &= ((3.0V - .6V) \times 20) / 50mA \\ &= 960\Omega \\ &\therefore \text{Choose R3 to be } 1k\Omega \end{aligned}$$

## OVER VOLTAGE

An over-voltage condition could occur while charging if the Li+ protection circuitry opened up the charge path due to any type of protection issue. If this occurs, the VIN and VDD pins would be subjected to the entire charge source voltage (up to 10V in this circuit). A Zener diode, D1, is used to clamp the  $V_{DD}$  voltage to a safe level. The chosen Zener diode value should be greater than the maximum voltage of the battery pack (i.e., 4.3V for Li+ or 5.25V for NiMH) but less than the VDD pin rating (6V).

Resistor R5 limits the current flow through D1 in the event of an over-voltage condition. The voltage drop across R5 will be based on the charge source voltage and the value of D1. Therefore, the value of R5 should be determined based on the power rating that is required for D1 ( $PR_{D1}$ ), which will also be the power rating for R5, such that:

$$9) \quad R5 = (V_{CH} - V_{D1})^2 / PR_{D1}$$

Example: A 5.6V Zener diode rated at 1/20 watt is chosen for D1. With a 10V charge source and 5.6V Zener diode a 4.4V drop is created across R5. Therefore, to limit the current flowing through D1 and R5, R5 must be at least 390 $\Omega$  and rated at 1/20 watt.

$$\begin{aligned} R5 &= (V_{CH} - V_{D1})^2 / PR_{D1} \\ &= (10V - 5.6V)^2 / (1/20 \text{ watt}) \\ &= 387\Omega \end{aligned}$$

$\therefore$  Choose R5 to be 390 $\Omega$  rated at 1/20 watt in a 0201 package

Note: R5 should not exceed 1k $\Omega$  in order to maintain power to the DS2770.

When an over-voltage condition occurs, the internal circuitry of the DS2770 will clamp the VIN pin to one diode drop (0.7V) above VDD. Resistor R4 protects the VIN pin and must be sized to keep the VIN input current below 0.6mA, which is the maximum that VIN can safely tolerate. Thus, the minimum acceptable value for R4 can be determined as follows:

$$10) \quad R4 = (V_{CH} - (V_{DD} + .7V)) / 0.6mA$$

Since the battery voltage is actually measured at the VIN pin, there is some concern that resistor R4 might create an error in the voltage reading. However, this error is minimal as the VIN pin's input impedance is a minimum of 15M $\Omega$ , so adding a resistor up to 15k $\Omega$  only effects readings by 0.1%. Power dissipation is not a concern for R4 since very little current can flow through this path.

Example: With a 10V charge source and a 5.6V Zener on VDD, R4 must be between 6.2k $\Omega$  and 15k $\Omega$  to provide adequate VIN protection while keeping the measurement accuracy within 0.1%.

$$\begin{aligned} R4 &= (V_{CH} - (V_{DD} + .7V)) / 0.6mA \\ &= (10V - (5.6V + .7V)) / 0.6mA \\ &= 6.17K\Omega \end{aligned}$$

$\therefore$  Choose R4 to be 6.2K $\Omega$

Note that during over-voltage conditions, the internal clamping to VDD protects VIN; however, this clamping will cause the real-time readings of voltage, current and temperature to be unreliable. Once the error condition is removed, the readings will become stable again.

## ESD PROTECTION

The CHARGE SOURCE, PACK+, PACK-, and DATA terminals shown in Figure 1 are connections to the battery pack and are exposed to possible ESD events. To guard against these events, R1 and R7 are 150 $\Omega$  resistors that protect the DS2770 VCH and DQ pins from events on the CHARGE SOURCE and DATA terminals. Resistors R4 and R5 protect VIN and VDD from events on the PACK+ terminal in addition to providing the functionality described in the previous section. Use of these components

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produces a circuit that meets the ESD requirements of the IEC1000-4-2 model with  $\pm 15\text{kV}$  air and  $\pm 8\text{kV}$  contact.

## **OTHER COMPONENTS**

Four 100pF capacitors are included in this reference design. C1 filters the voltage on the PACK+ and PACK- terminals, and C3 is a bypass capacitor for the battery voltage on the VDD pin. C4 creates a low-pass filter for the current-sense inputs as specified in the DS2770 datasheet.

With some charge sources, the source voltage may drop momentarily when charging is initiated due to the high current load. If VCH drops below the battery voltage, the DS2770 will interpret this to mean that the charge source has been removed, and it will terminate charging until another Start Charge condition is encountered. R1 and C2 are included in the circuit to prevent this initial voltage drop from being misinterpreted by the DS2770. The values may be adjusted for charge sources with high ripple or noise content.

## **SUMMARY**

This application note presents a charge controller reference design that includes components for charging and for safety. The design provides the components necessary for fast and trickle charging as well as protecting the DS2770 in the event the protector opens up during a charge. The circuit was also tested for ESD-hardness in accordance with the IEC1000-4-2 ESD model.