Designing Battery Chargers using the AQT120

The AQT120 is a controller for implementing a constant current/constant voltage supply suitable for charging batteries to a final voltage at a fixed current. The AQT120 is intended to drive an external PNP pass transistor to implement a lowest-cost system for charging Lithium Ion(Li Ion), Nickel metal hydride (NiMH), lead-acid or similar rechargeable batteries.

Unlike Nickel Cadmium (NiCd) chargers, no sensing of temperature or charge voltage shifts are used to terminate charge. The charging occurs under constant current, and as the battery reaches its final charged value, the current is decreased to near zero and the battery is held at this optimal voltage. This sort of charge cycle is illustrated in figure 1, which shows the constant voltage/constant current characteristics.

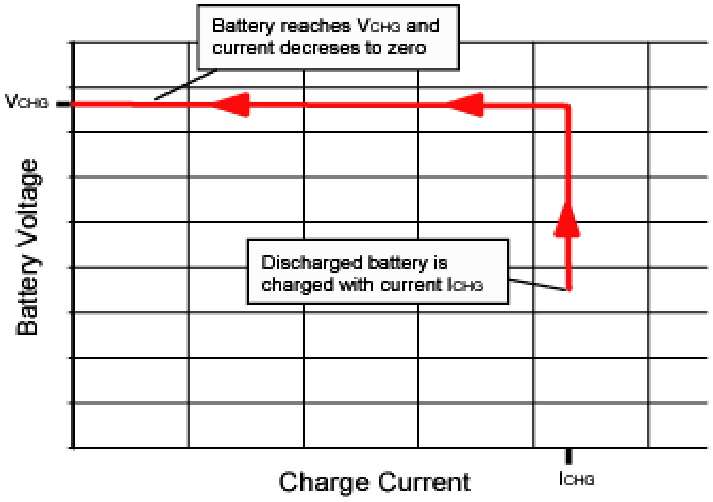

Fig. 1 V/I curve for charging battery

Control Architecture.

The AQT120 regulates a final voltage using a simple 1.25V bandgap reference Vr and an amplifier driving a PNP, as shown in figure 2. A resistor Rs in the ground return generates a drop proportional to the current in the battery. The voltage across this resistor is compared to a 200mV nominal Vsns, and as the current across Rs exceeds Vsns, the value of the main reference voltage is reduced. A simple transconductance amp A2 with a current sinking output can reduce but not increase the voltage at Vr’. A fixed gain of 40 in this path causes the current to increase by about 15% as the error amp is progressively driven from 1.25 to zero volts. Note that the potential at the negative battery terminal is not in common with the negative connection to the power source.

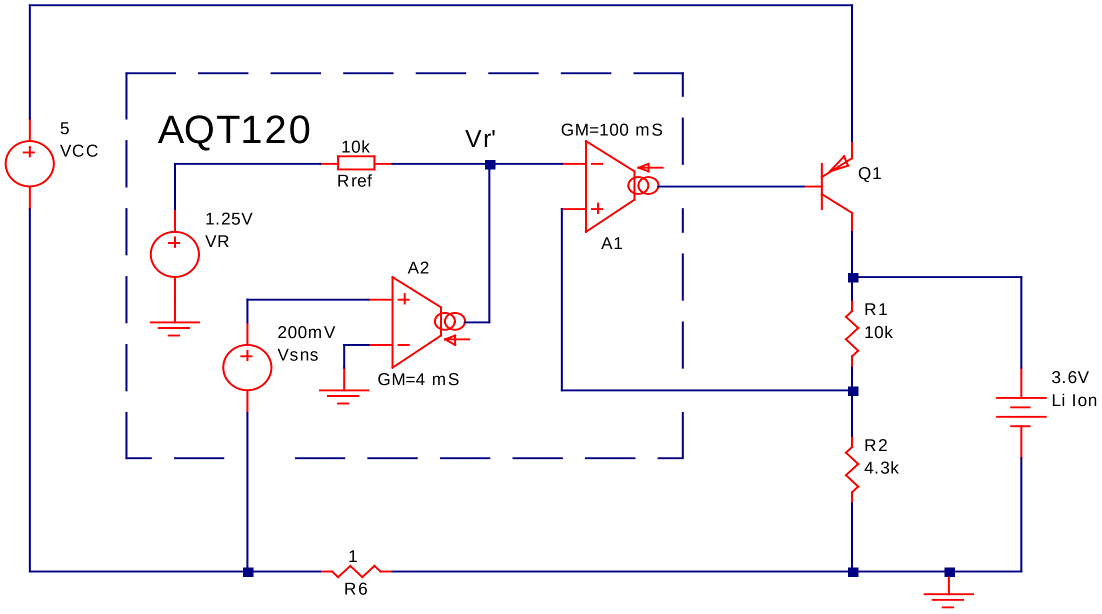

Fig. 2 Basic AQT120 control scheme

This architecture allows the voltage-control loop to dominate under all conditions, with the constant-current operation working by reducing the voltage to which the circuit regulates. There are however two interacting loops, so there is some concern about stability over all load conditions.

Selecting charging currents, voltages

Battery chargers are best optimized for a particular battery. A given battery is rated for its nominal voltage and its capacity C (in mA-hours). The charge and discharge rates are typically expressed in terms of the capacity C. For example, discharging a 500mA-hour battery with a load of 2A would be said to be discharging at a rate of 4C. Typically, a fast charger delivers 1C (a little over 1 hour to charge) and a less stressful charge might be done at C/10.

In order to fully charge a cell, the following are typical values:

Battery	Nominal	Full Charge	Discharge
Li Ion:	3.6	4.1 - 4.2	2.7
NiMH:	1.3	1.4	1.0
Pb-acid	2	2.3 - 2.45	1.6

Table 1. Battery Voltages (per cell)

The "Full Charge" voltage should not be exceeded. In the case of lead-acid batteries, a continuous "float" current can be applied while the battery is fully charged (typically less than 0.1C). Other battery chemistries should have the charge current terminated or reduced to very low levels. The Discharge voltage indicates the level below which the battery should not be discharged. More conservative limits should be used in series connected cells, whether an array of batteries or a single battery containing multiple cells. In such a case, individual cells will not track perfectly so individual cells could be overcharged or too deeply discharged.

AQT120 Applications

Figure 3 shows a simple application for a single cell Lithium ion battery. Throughout this application note we will presume that the goal is to charge a single cell to 4.2V at a current of 500 mA. This output voltage is set by

$$V_{CHG} = V_{REF} * \frac{R1 + R2}{R2} = 1.25V * \left(1 + {}^{R1}\!/_{R2}\right)$$

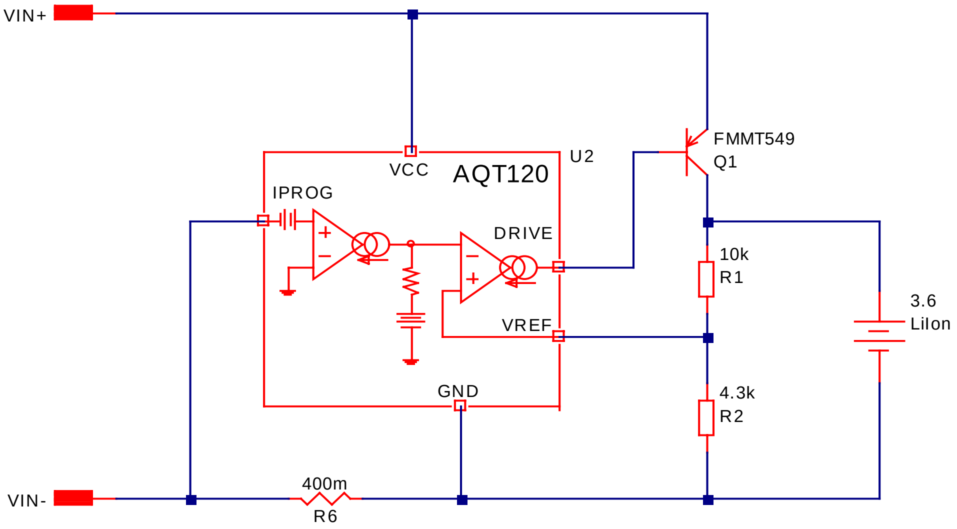

Fig. 3 Simple Application for AQT120

If the battery is discharged, the AQT120 will drive Q1 charging the battery. If the current flowing through R6 exceeds 500mA, the Iprog pin will exceed its threshold of -200mV and the output voltage will be reduced to maintain the 500mA charge current.

$$I_{CHG} = \frac{V_{SNS}}{R_{SNS}} = {}^{200mV}\!/_{R6}$$

The V/I curve of this simple circuit is shown in figure 4. Note that the output impedance in the constant current mode is finite; decreasing the voltage increases the amount of charge current. This is not desirable in itself, but is a result of finite gain in the current control loop. This finite gain improves stability, and this output impedance can be improved with the addition of an external network, as shown below.

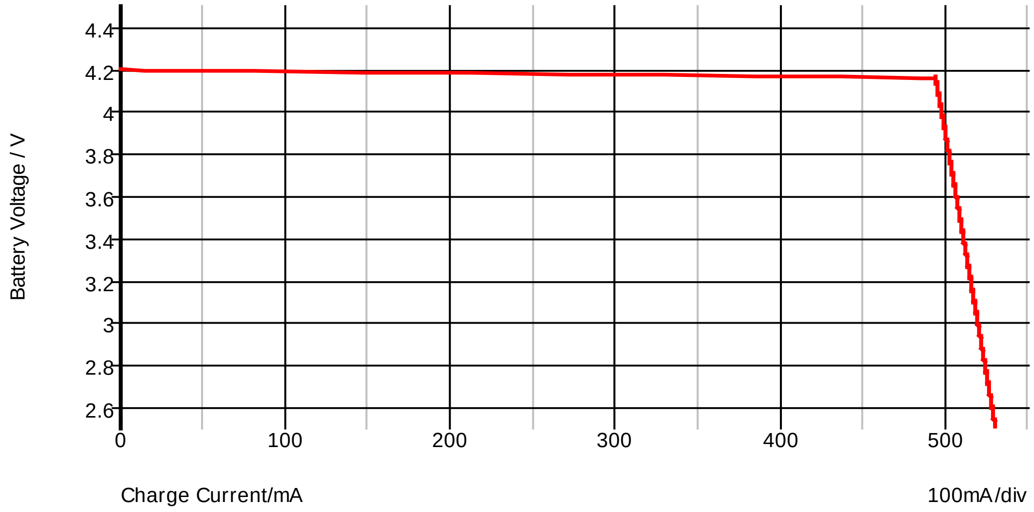

Fig. 4 V/I curve of simple application

The application of figure 5 is more typical, and is similar to the nominal condition on the demo board. A number of minor improvements are included:

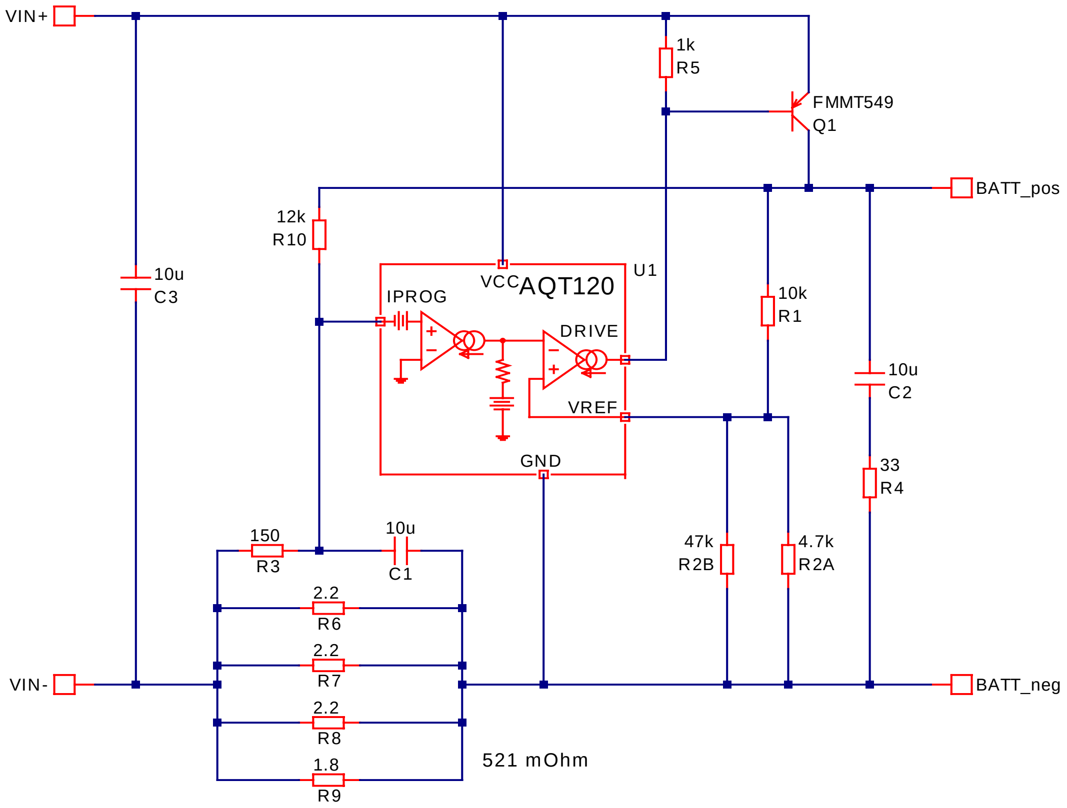

Fig. 5 Typical Application for AQT120

A number of minor improvements are included:

1. Decoupling cap C3 is needed only if the supply for the circuit is provided through a long cable or from a fairly high impedance source. This can be an issue with some usage of the demo board, but is not typical in most real applications, where the AQT120 circuit may be placed adjacent to the main filter caps for this input supply.

2. A base bleed resistor R5, though not critically needed, helps guarantee that the discrete transistor Q1 can be adequately turned off under full charge even in the presence of high temperature leakages etc.

3. R2 has been replaced with R2A and R2B, allowing the use of standard values to achieve arbitrary divider ratios. In this case, the resistor values are all E12 series rather than E24 which would be otherwise required to implement the divider.

4. The low value R6 (430 Ohms)has been implemented with a parallel combination of resistors R6, R7 and R8. (A resistor position R9 is also available on the demo board as further parallel segments to create low value resistors from standard values.) Using values above 1 Ohm reduces resistor dissipation to levels appropriate for SMT components and also improves availability. (Resistors below 1 Ohm often are not stocked in distribution). With charge currents of 500mA, the total resistor dissipation is slightly over 100mW.

5. In the condition of no battery, the output voltage of the circuit may tend to oscillate. The output network C2/R4 provides an appropriate load when the battery is disconnected. (This is similar to an LDO regulator and its required output cap).

6. In charge mode, depending on the battery impedance, the constant current loop may not be perfectly stable. A small signal oscillation on the charge current may be acceptable, but can be prevented by adding network R3/C1. Because the Iprog pin is not a high impedance input, the value of R3 must be kept fairly low; as shown R3 will have a drop of approximately 15 mV at the current limit threshold. This requires a small adjustment in the value of the current sense resistor.

7. R10 provides a positive feedback path which increases the output impedance to create a more constant charge current. Taking into account the impedance of the IPROG pin, a good rule of thumb for the selection of R10 is:

$$R10 \approx \frac{V_{CHG}}{75\mu A + \frac{35mV}{R3}}$$

   Choosing higher value allows some finite positive output impedance. Choosing a lower value will tend to give a negative output impedance.

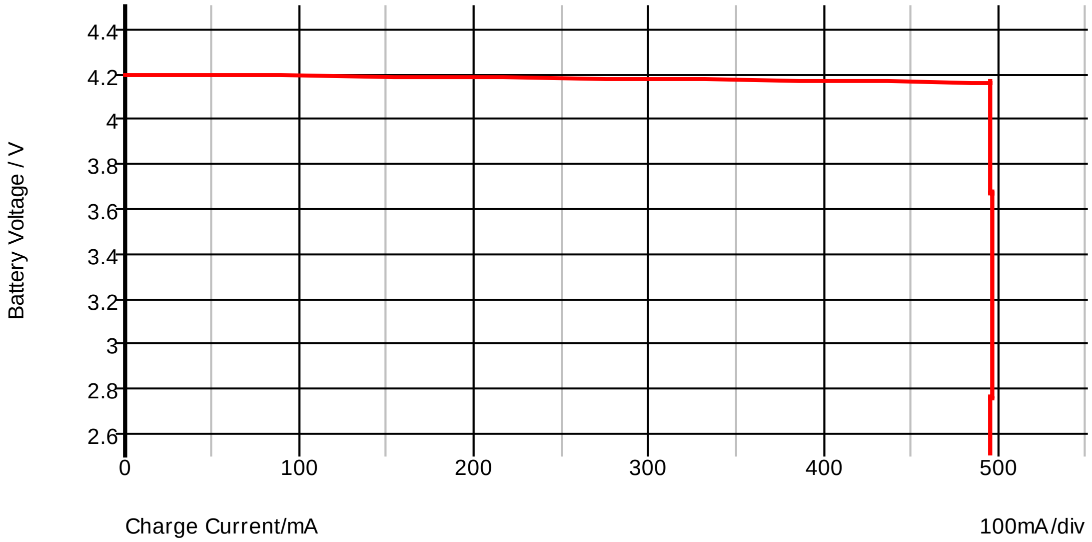

Fig. 6 V/I curve of typical application

After adding these various improvements, the calculation of the charge current becomes somewhat more complex. The combination of the addition of R3 and R10 shifts the value of the charge current:

$$I_{CHG} = \frac{200mV + \left(100uA + \frac{V_{CHG}}{R10}\right)R3}{R_{SNS}}$$

Where Rsns is the parallel combination of R6 through R9, as applicable. The 100uA is the nominal current flowing out the IPROG pin at the threshold.

Providing Foldback and Trickle Charge

It is desirable in certain circumstances to charge fully drained batteries at a low current until they establish a reasonable voltage. A simple means to provide this functionality is shown in figure 7. When the battery voltage is charged, the MOSFET is fully on and the added resistors R11 and R12 are effectively shorted out. In fact, the Rds(on) of the FET becomes a portion of the current sense resistor, but R11 and R12 act as a divider to present only 20% of that drop the the Iprog pin. This minimizes the need for extremely low Rds(on).

As the battery voltage drops, the MOSFET is turned off. Approaching the condition where the battery appears to be dead, the current sense resistor becomes R12 plus the original parallel combination of resistors R6 through R9. This order of magnitude increase in the sense resistor lowers the charge current to 10% of its original value, as shown in figure 6. Unfortunately, the transition from full charge to trickle charge is a function of the MOSFET threshold, so care must be taken. For single cell Li Ion batteries, a logic-level FET is required. For multiple cell configurations, it may be desired to provide a divider or level-shifting network to adjust the transition point.

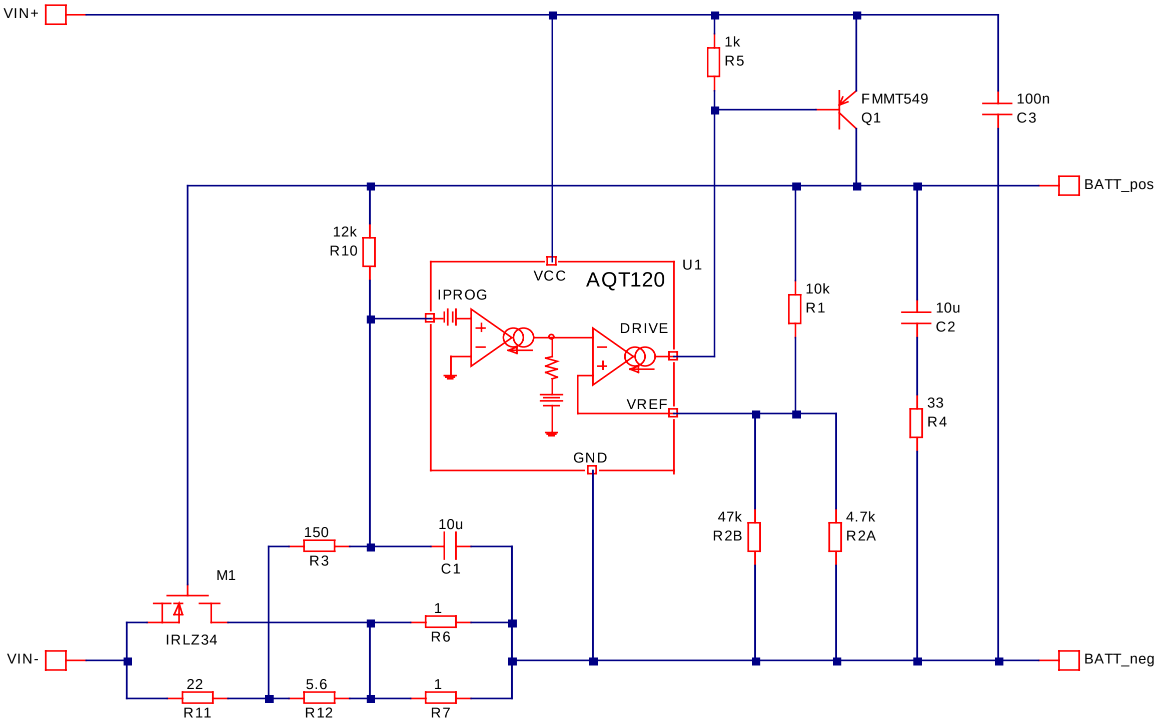

Fig. 7 Adding foldback/trickle charge to AQT120

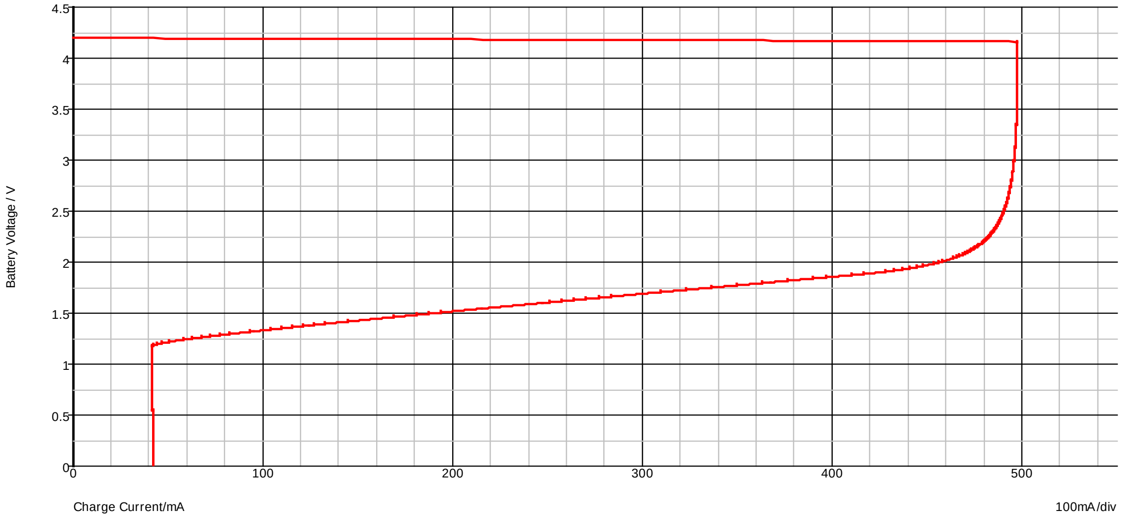

Fig. 8 V/I with foldback and trickle charge

Demo Board

Acutechnology has available a demonstration board for the AQT120. The full schematic is shown in figure 9. The values indicated are the nominal values as supplied, which are similar to the schematic of figure 5. Several positions are generally left unstuffed, including an LED to indicate charging status. The LED terminals are nominally shorted on the back of the board. The small trace between the LED terminals must be cut to enable this option. (When the base of Q1 is driven to charge the battery, the LED will light.)

Note that the size of the components are not minimized. The use of 1206 sized resistors for instance is primarily to allow easier engineering work on the board, as smaller components are, in our experience, best left to automated manufacturing equipment. As described above, the power dissipation in the resistors has been minimized to allow for smaller components to be utilized.

The board is typically stuffed with tantalum electrolytics for C1 and C2. Ceramic or aluminum capacitors may generally be substituted. The use of an aluminum electrolytic capacitor of particularly high ESR for C2 might eliminate the need for R4. No problems have been observed using low ESR ceramic capacitors. Although the price of suitable ceramic capacitors has been falling, as of this writing, they are not the most cost effective solution.

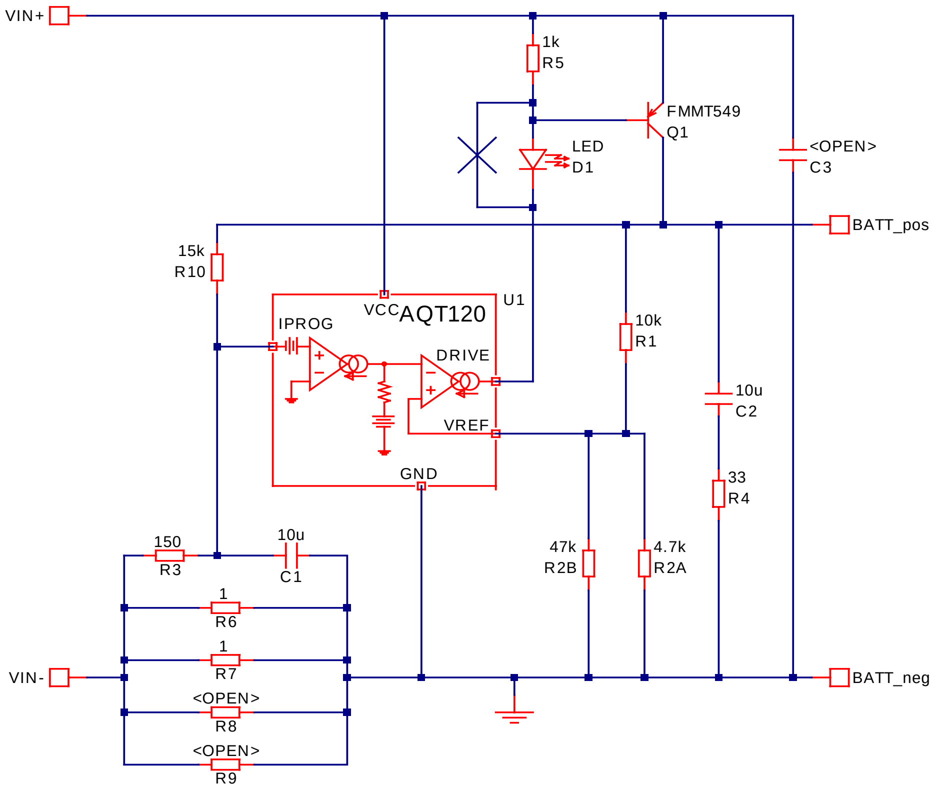

Fig. 9 Demo Board Schematic

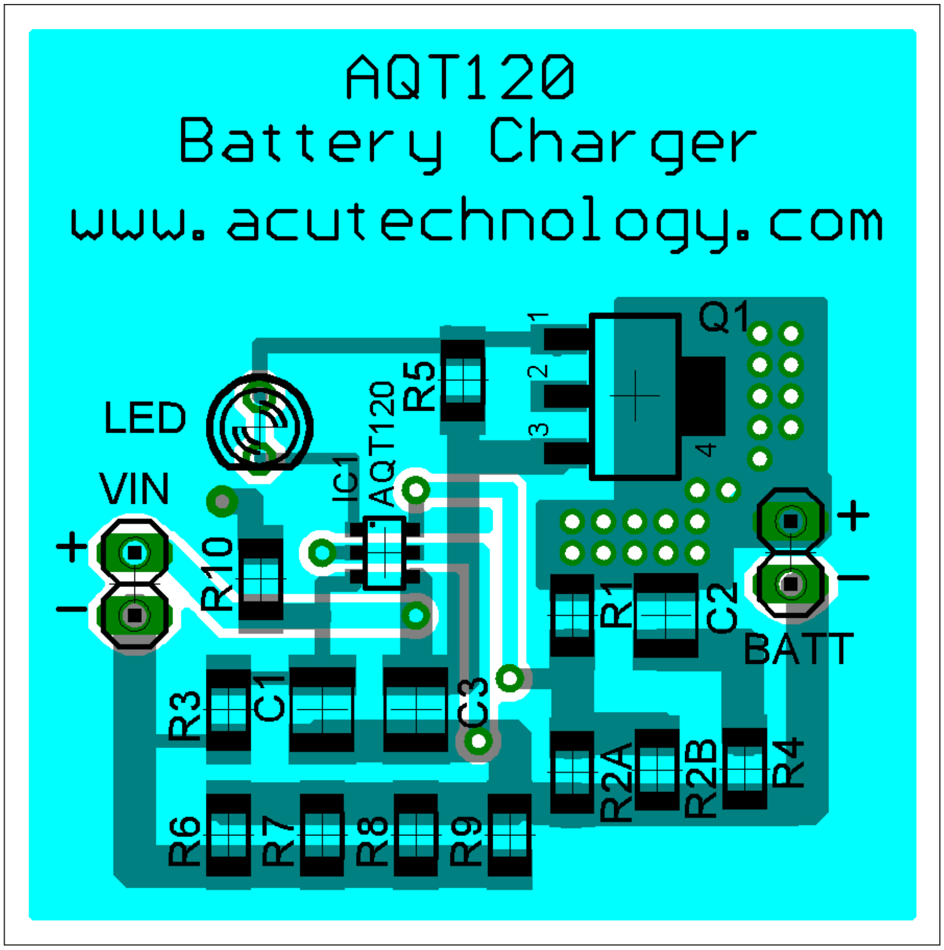

Fig. 9 Demo Board Layout

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10 Nov 2004
Rev. 0