

Using the bq2000/T to Control Fast Charge

Introduction

The bq2000/T are programmable, monolithic ICs for fast-charge management of nickel cadmium (NiCd), nickel metal-hydride (NiMH), and lithium-ion (Li-Ion) batteries in single- or multi-chemistry applications. This application note discusses simple ways to select all necessary components to implement various switch-mode topologies. It also discusses how to configure the bq2000/T inputs to accommodate different application concerns. Please review the bq2000 and bq2000T data sheets before using this application note.

Basic Charge-Control Operation

Charge Initiation

The bq2000/T initiates a charge on either (1) power-up or (2) excursion at the BAT input from above a V_{RCH} threshold to below it. The V_{RCH} threshold is below the threshold of voltage regulation, V_{MCV} , and therefore does not initiate charge of a "full" Li-Ion battery. This feature is especially useful if cell polarization is taken into account because the battery voltage decays to a lower value following fast charge.

Configuring the BAT Input

The BAT input to the bq2000/T is the input to an A/D converter with a resolution of about 3mV. A/D measurement is performed only when the timing oscillator and current regulator have been switched off. The BAT input has the following four voltage thresholds:

1. V_{LBAT} (approximately 1.0V) is the minimum qualified input voltage to initiate full current to the battery at the start of fast charge. Below this level, the bq2000/T follows its pulse-trickle algorithm. This arrangement enables it to "wake up" a pack protector in a Li-Ion pack or trickle up a deeply discharged nickel-based chemistry pack.
2. V_{RCH} (1.9V) is the battery replacement threshold. As described above, an excursion through this threshold triggers battery replacement and reinitiates of fast charge.
3. V_{MCV} (2.0V) is the threshold of voltage regulation. Above this level, the MOD output is forced low, regardless of the condition of the SNS input, resulting in a pulsed current regulation similar in operation to a bang-bang type voltage regulator. When the BAT input voltage exceeds 2.0V more than 85% of the time, charge is terminated.

4. V_{SLP} is the sleep-mode threshold and approximately 1.0V below V_{CC} . If the BAT input is driven to this threshold, power to the IC is turned off and the MOD output is driven low. This threshold is internally provided for implementations in which the IC must remain connected to the battery when charge power is removed. Under this sleep mode, the IC draws 1 μ A or less.

The operation of these four thresholds determines the following design guidelines for configuring the BAT input

To charge a fixed number of nickel-based cells, the BAT input is configured for the voltage of a single cell. Thus for an N-cell pack the resistor ratio of the divider is (N-1):1. See Figure 1. This configuration assures a 3mV PVD sensitivity for fast charge, which is an excellent termination criterion for NiMH cells and good for most NiCd cells. Of course the total divider network represents a load on the battery when power is not present and is sized accordingly. Also, the BAT input must not be driven with more than 20 μ A in the absence of power. (This is the permissible limit for the substrate diode that clamps this input to V_{CC} .)

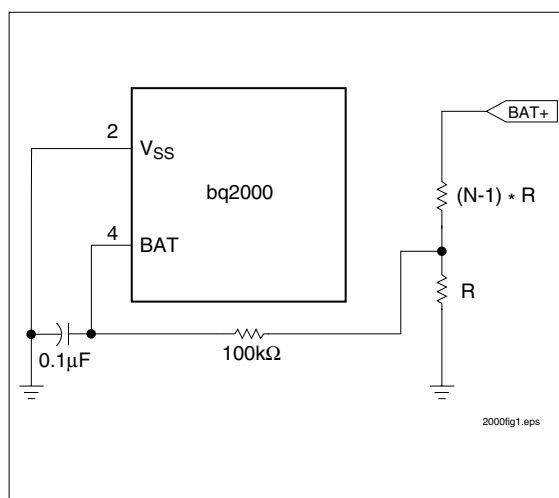


Figure 1. Battery Voltage Divider for Nickel Chemistry—Single Pack

Charging multi-cell packs of nickel-based chemistry and some high-capacity NiCd packs often requires compressing the batteries' signal voltage into the range of the A/D converter to accommodate the cell range or to require a steeper negative slope on the battery as a criterion of ter-

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mination. This compression is accomplished by a single additional resistor in the divider chain from the battery, R_1 . See Figure 2. This extra resistor adds offset to the battery-divider voltage, allowing a larger voltage excursion on the battery for a smaller excursion at the BAT input. The fixed in-circuit voltage to which this additional resistor is tied is V_{CC} .

The design procedure for the varying pack size is as follows:

1. Determine the difference between the end-of-charge voltage for the maximum number of cells and the start-of-charge voltage for the minimum number of cells. This signal, which must be compressed into the A/D voltage window of 1–2V, is $V_{EXCURSION}$. For a 1V window, the gain of the divider network is simply $1/V_{EXCURSION}$.
2. Determine the offset, V_{OFF} , from one of the end-point equations by substituting the gain calculated in step 1. The minimum condition is expressed by the equation

$$(V_{BAT} - V_{OFF}) * \left(\frac{1}{V_{EXCURSION}} \right) + V_{OFF} = 1$$

Substituting the minimum battery voltage for V_{BAT} and Solving for V_{OFF} gives the voltage that would appear at the BAT input in the absence of the battery.

3. Choose a suitable resistor divider from V_{CC} to GND to establish this offset voltage.

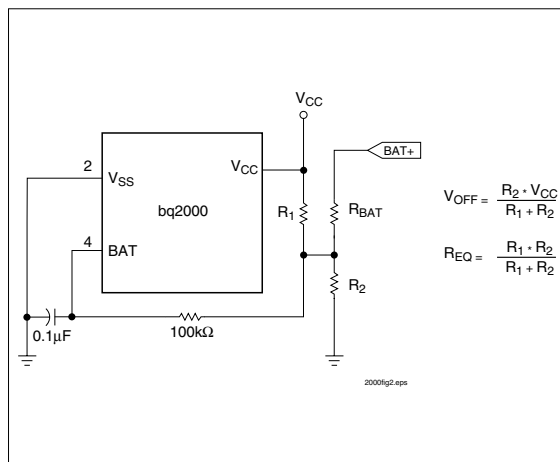


Figure 2. Battery Voltage Divider for Nickel Chemistry—Multi-Pack or High-Capacity NiCd

4. Implement the gain function by determining the equivalent resistance of the parallel combination of the offset setting resistors, R_{EQ} , and setting

$$R_{BAT} = (V_{EXCURSION} - 1) * R_{EQ}$$

where R_{BAT} is the resistor connected between BAT+ and the offset point. See Figure 2.

For high-capacity packs, the goal is to increase the per-cell negative voltage excursion, which will serve as a criterion of fast-charge termination. **Note:** Throughout this application note, the expression PVD is often equated with $-\Delta V$. Although some think of these as different termination criteria, they are actually two ways of saying the same thing. For a voltage to qualify as a “peak”, a subsequent measurement must be less than this “peak” measurement by a discernable amount. Since no circuit can anticipate a subsequent reading, the peak voltage detection occurs upon measuring a subsequent voltage that is discernibly less than the maximum voltage measured to that point in time. In the case of the bq2000/T this sensitivity is -3.8mV , leading to the parallel drawn between PVD and $-\Delta V$, as the later is usually just a less sensitive PVD. The desensitization is accomplished by compressing the total battery voltage excursion during charge into a fraction of the A/D voltage window at the BAT input to the bq2000/T. This design procedure is as follows:

1. Determine the multiplier of the peak voltage sensitivity desired for the battery. A typical desired $-\Delta V$ value for high-capacity cells is -15mV . The multiplier is then $(-15\text{mV}/-3.8\text{mV})$ or about 4. The gain is then determined to be $1/(4 * N)$, where N is the number of cells.
2. The offset is determined from the goal of having the maximum battery voltage correspond to the maximum input voltage. In this example, the resulting offset is $(6 * N)/(4 * N - 1)$, where N is the number of cells. This offset is established at BAT by choosing a resistive divider from V_{CC} to GND. These resistors correspond to resistors R_1 and R_2 as shown in Figure 2.
3. A third resistor, R_{BAT} , is chosen to establish the proper gain with respect to the parallel combination of resistors R_1 and R_2 represented by R_{EQ} . In the example used in step 1, the gain was $1/4N$. This is achieved by setting $R_{BAT} = R_{EQ} * (4N - 1)$.

Finally, Li-Ion batteries can be charged at a constant current only until their characteristic regulation voltage is reached. The bq2000/T accommodates this restriction by regulating the voltage at the BAT input to 2V. The battery resistive divider should ensure that the BAT input reaches its regulation voltage when the battery reaches its characteristic regulation voltage. See Figure 3.

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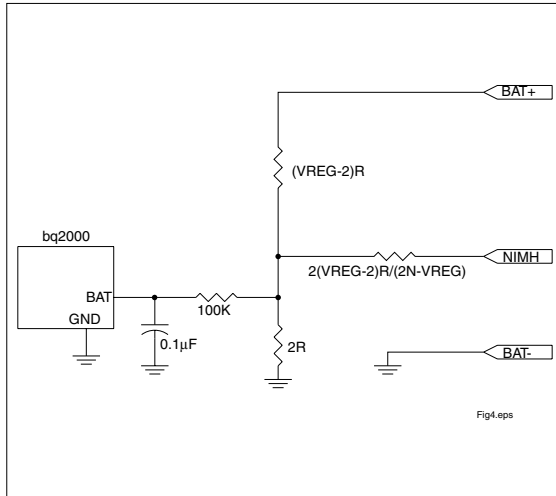


Figure 3. Voltage Regulation Battery Divider for Multi-chemistry Applications

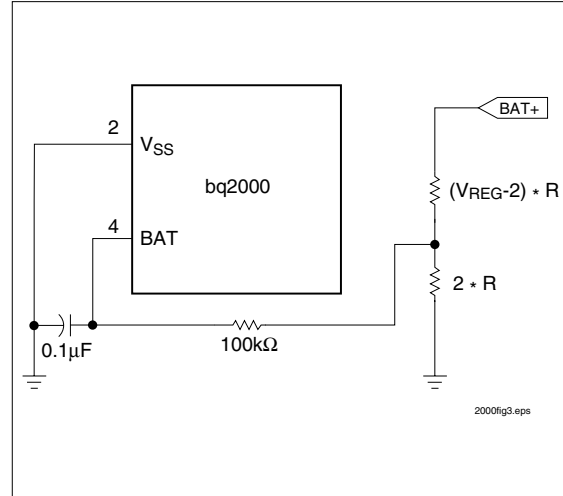


Figure 4. Voltage Regulation Battery Divider

The safest way to design for multi-chemistry packs is to add a mechanical connection to the nickel-based chemistry packs, constituting an additional battery negative connection. The default Li-Ion resistive divider is attenuated by a resistor in the charger, which connects to this point when a nickel battery is installed, but which floats when a lithium battery is installed. This fail-safe mechanism is normally required by cell ratios of 1 lithium to 3 nickel. See Figure 3.

NiMH batteries rarely exceed 1.6V per cell at charge rates consistent with lithium cells. Therefore, the single divider network as shown in Figure 4 is acceptable for cell ratios of 2 lithium to 5 NiMH, as long as the maximum charge voltage of the nickel-based pack is below that of the Li-Ion pack. This design is not recommended for NiCd batteries, however, as they will often achieve voltages in excess of 1.8V/cell, especially toward the end of cycle life. If the nickel-based chemistry cells do reach the regulation voltage during charge, they usually terminate only for maximum time or temperature with the bq2000. The bq2000T is the safest choice for the 2:5 ratio, because it relies on $\Delta T/\Delta t$ as the primary means to terminate nickel-based chemistries. Ratios of 2 lithium to 4 nickel normally fit comfortably within the charge window for their useful lives, for either voltage-based or temperature-based termination.

Configuring the SNS Input

If the SNS input is within $\pm 50\text{mV}$ of the bq2000/T ground (V_{SS}), the MOD output is fully enabled. If the SNS input is greater than 50mV (V_{SNSHI}) or less than -50mV (V_{SNSLO}) compared to the ground of the bq2000/T, then the MOD output is driven low. Since battery and temperature voltages are always measured with respect to ground, the user can take advantage of this feature to implement both high-side and low-side current sense regulators. If no control of MOD is desired, the SNS pin can be grounded and the MOD output used only to switch an external current source on or off. The control feature makes it possible to configure the SNS input to provide either linear or switching regulation of charge current. Furthermore, frequency is most dependent on filter components and hysteresis-setting capacitance and only slightly dependent on power component values. This characteristic makes it possible to "slave" the circuit to an external oscillator of fixed frequency.

Low-Side Sensing

For low-side sensing applications, the sense resistor is placed in the path between the battery's negative terminal and power supply ground. See Figure 5. The battery's negative terminal becomes the signal ground for the bq2000/T. Signals and power applied to the bq2000/T are capacitively decoupled and referenced to this point. The resistor selected should have a value equal to 50mV divided by the desired charge current. Thus, at a current of 1A , the sense resistor is $50\text{m}\Omega$. Some applications may

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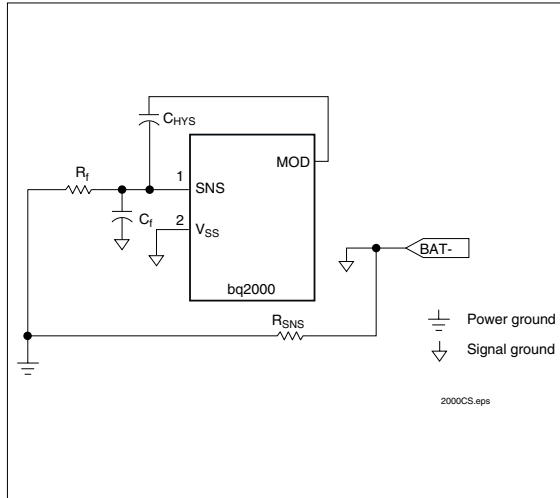


Figure 5. Current-Sensing Circuit

find the resulting sense resistor too small to be practical. These are easily accommodated by making the sense voltage presented to the bq2000/T a suitable fraction of the sense current. In the 1A example, the sense resistor can be made to be 0.1Ω provided the voltage across the sense resistor is divided between two equal resistors at its presentation to the SNS input. The application however, must also be able to tolerate the higher voltage on the sense resistor.

As suggested from the above, the voltage on the sense resistor is presented to the SNS input through a resistance that forms part of a filter. The rest of the filter is a capacitor that decouples the SNS input from the VSS of the bq2000/T. When the user is content with a sense voltage of 50mV, the SNS input is connected to the power supply ground at the grounded terminal of the sense resistor through a resistor sized for the desired operating frequency. See Figure 5. An exact expression for the sizes of the capacitive and resistive components involves the simultaneous solution of two very complex equations. A few simplifying assumptions, however, can allow most users to bound their operating frequencies to within about 5%.

The six values that determine operating frequency are input voltage V_{IN} , inductance L , sense resistor R_{SNS} , filter resistance R_F , filter capacitance C_F , and hysteresis capacitor C_{HYS} . Input voltage is given. The sense resistor converts the current waveform in the inductor to a voltage waveform for presentation to the SNS input. Low detection voltage, while requiring low-valued resistors to sense current, makes possible the sharing of resistors between a charger and gas gauge IC. The hysteresis capacitor and SNS input filter components have the most influence on

operating frequency. The hysteresis capacitor is connected from the MOD output to SNS input directly; however, the voltage hysteresis is attenuated by the ratio between the two capacitors. Since the MOD output swings 5V, the SNS input moves by the ratio $5V * C_{HYS} / (C_{HYS} + C_F)$. This injected hysteresis is of 5–25mV for best results. Below is a simplified design procedure:

1. Select the desired maximum operating frequency F . This is the frequency of operation when the output voltage is exactly half the input voltage. At duty cycles of 75% or 25%, the frequency is 75% of this value.
2. Choose $C_{HYS} = 4.7\text{pF}$ to minimize the capacitive load on the MOD output.
3. Choose

$$R_F * C_F = \frac{1}{(4 * F)}$$

This reduces exponential functions to constants in the equations relating all the values. Choose C_F for the desired hysteresis level, and then calculate R_F from the above relation.

4. Calculate the inductor value L from the relationship below:

$$L = \frac{V_{IN} * R_{SNS} * R_F * C_F^2 * V_{CC} * R_{SNS}}{C_{HYS} * (57.87V)}$$

The constant in the denominator results from the dimensionless exponential functions. Consider the example below:

Battery is 5-NiMH cells.

$$V_{IN} = 12V \quad I = 1A \quad \therefore R_{SNS} = 0.05\Omega$$

$$F_{MAX} = 100\text{KHz} \quad C_{HYS} = 4.7\text{pF}$$

Choose $C_F = 2200\text{pF}$ for a hysteresis of 10.7mV (approximately 20% of the 50mV signal). $R_F = 1.1\text{K}$ from 3 above.

Then $L = 58\mu\text{H}$. The actual current ripple at this frequency is 25%, 5% of this is due to the phase delay through the filter. Since it is desirable to keep the ripple current large to keep the inductor small, the assumption made in 3 above is a good rule of thumb. For a smaller ripple current, increase the size of the capacitive filter staying at or below 4700pF. For a larger ripple, diminish the size of C_F staying at or above 1000pF. The inductor changes in value accordingly.

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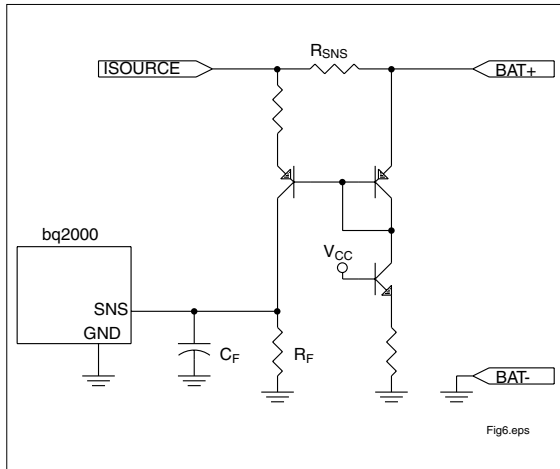


Figure 6. Voltage-to-Current Converter Design for High-Side Sensing

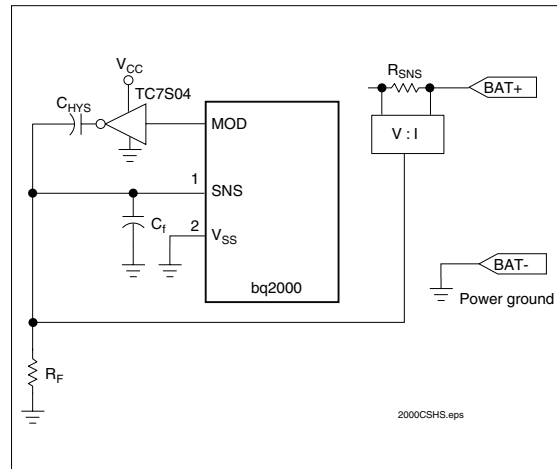


Figure 7. Current-Sensing Circuit—High Side

High-Side Sensing

High-side sense requires that the sense resistor be placed in the circuit between the switching inductor and the battery positive terminal. From there, the signal must be translated down to the SNS input to the bq2000/T. While this translation may seem difficult at first, the AC signal integrity needs to be good only about the regulation point. This limitation makes a three transistor voltage mirror possible. See Figure 6. One transistor of NPN polarity provides constant-current bias to a diode-connected PNP transistor with the sense resistor in its emitter. A second PNP transistor with a suitably large emitter resistor is connected in parallel with the diode connected PNP and sense resistor, but with its collector open. This collector drives the filter resistor R_F to the regulation voltage above ground. In this case, the V_{SS} of the bq2000/T is itself connected to power ground, and all signals and power are decoupled to power ground. The filter capacitor C_F is connected in parallel with R_F in this case. The last remaining difficulty is providing the hysteresis signal from MOD as in this case the signal output from MOD must be inverted to properly drive the SNS input. Most buck-mode switching regulators have such an inversion in the circuit that can be conveniently capacitively coupled to the SNS input. Failing that, it is possible to add a single inverter to the circuit such as a TC7S04F. See Figure 7. Such a single-gate circuit is necessary in synchronized battery-charger designs.

Synchronizing the bq2000/T to a Fixed Oscillator

Synchronizing the bq2000/T is actually quite simple. First, design the filter components and choose the inductor for a maximum operating frequency below the desired frequency for synchronizing the bq2000/T. The big difference between configuring for synchronization or for high-side or low-side sensing is that the hysteresis capacitor in synchronization is not connected directly to the MOD output, but rather to the output of either a single AND gate in the case of low-side sensing or to the output of a NAND gate in the case of high-side sensing. One of the inputs to the gate is MOD and the other is the desired synchronizing frequency. Possible single-gate devices are the TC7S00FU and the TC7S08FU. See Figure 8.

Configuring the TS Input

The TS input to the bq2000/T is characterized by three operational thresholds that determine qualification and termination conditions. The thresholds on the TS input are all ratiometric to the power supply. This design allows resistor biasing to V_{CC} and V_{SS} of a single negative temperature coefficient (NTC) thermistor with consistent temperature thresholds at any operating voltage as shown in Figure 11. We recommend a filter capacitor at this input of no more than $0.01\mu F$, combined with a $100k\Omega$ resistor, to prevent noise terminations at elevated operating temperatures.

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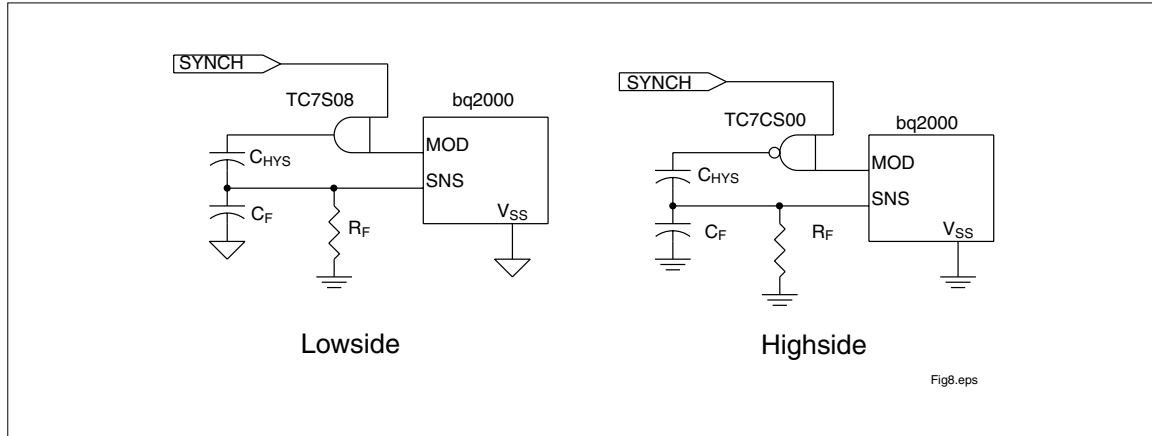


Figure 8. Synchronization Circuit for Low- and High-Side Designs

The following are descriptions of the three thresholds:

1. V_{LTF} set at $0.5 * V_{CC}$ is the cold temperature/pause threshold. At voltages above this threshold, the bq2000/T pulse-trickles and flashes the LED pin to indicate that the bq2000/T is in the pause or inhibit mode. This process suspends fast charge in progress by freezing the contents of elapsed-time counters, defeating all termination algorithms and resetting all data-gathering. When restored to a normal operating range, the bq2000/T resumes a suspended fast charge or top-off in progress but rebuilds discarded historical data before the fast-charge termination algorithms can take effect.
2. V_{HTF} set at $0.25 * V_{CC}$ is the maximum starting temperature threshold. If fast charge starts at input voltages below this threshold on the TS input, the bq2000/T flashes the LED pin as it does in the pause mode to indicate that charge is pending. This threshold has no effect after fast charge has started.
3. V_{TCO} set at $0.225 * V_{CC}$ is the cutoff temperature for fast charge and top-off. At voltages below this threshold on the TS input, a fast charge or top-off in progress terminates and does not resume. This is considered a "done" condition. Note that this condition is superceded at the start of fast charge by the starting temperature threshold described above. A very hot battery placed in the charger causes the bq2000/T to flash the LED pin to indicate charge pending, even if the cutoff temperature is exceeded. The bq2000/T does not pulse-trickle charge an overheated battery until it cools below the cutoff temperature threshold. Then the battery is pulse-trickled until it cools below the starting tem-

perature threshold, following which it starts fast charging.

A simple configuration procedure is as follows:

If no temperature limits or inhibit (pause) function are desired, bias the TS input to a voltage level between 1.25 and 2.0 volts. This biasing can be done with a simple divider network between V_{CC} and V_{SS} . See Figure 9.

If temperature limits are not required, but an inhibit function is, use the same bias network, but terminate the second resistor to the inhibit signal rather than to V_{SS} . A logic high inhibits, while a low enables. See Figure 10.

Finally, if a full-featured design is desired, choose two resistor values to bias a NTC thermistor taking note of its cold temperature value, R_C , and its high temperature value R_H . The resistor from V_{CC} to the thermistor, R_1 , and from the thermistor to V_{SS} , R_2 , can be calculated from the formulas given below:

$$R_1 = \frac{22 * R_H * R_C}{9 * (R_C - R_H)} \quad R_2 = \frac{22 * R_H * R_C}{(9 * R_C) - (31 * R_H)}$$

If the denominator of R_2 becomes zero, or nearly so, R_2 can be left out, effectively making it infinite; however, this equation places a limit on the effective range of temperature for any given thermistor. In most cases, this does not present a problem as it corresponds to about a 30°C range. The thermistor value at which charge is inhibited because of overtemperature can now be represented by this term:

$$R_{THERM} = \frac{1.25 * R_1 * R_2}{3.75 * R_2 - 1.25 * R_1}$$

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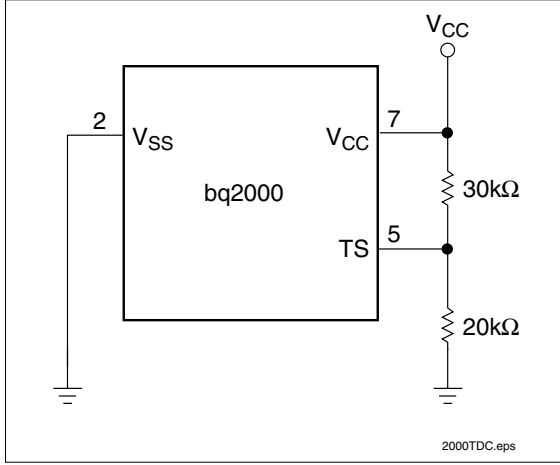


Figure 9. Temperature Defeating Configuration

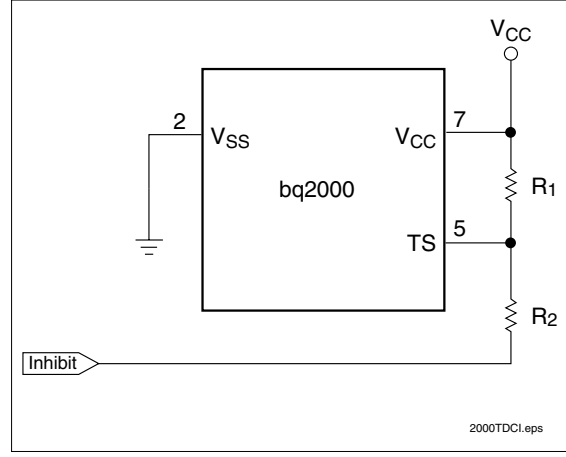


Figure 10. Temperature Defeating Configuration with Inhibit

Constraining the High-Temperature Start of Charge

Some applications emphasize not starting charge above a certain temperature more than exactly where charging terminates for an overtemperature condition. If this is the case, the following two equations can be substituted for those above, with the understanding that R_H now represents the high-temperature prequalification resistance of the NTC thermistor, and the term to the extreme right represents the thermistor value at cutoff:

$$\frac{1.125 * R_1 * R_2}{3.875 * R_2 - 1.125 * R_1}$$

Where:

$$R_1 = \frac{2 * R_H * R_C}{R_C - R_H}$$

$$R_2 = \frac{2 * R_H * R_C}{R_C - 3 * R_H}$$

Configuring the TS Input to the bq2000T for $\Delta T/\Delta t$ Termination

A Thevenin-equivalent circuit can be used to represent the bias on the thermistor connected to the TS input. As such, a circuit has only two characteristics capable of modification, and only two constraints can be imposed on

the voltage excursion resulting from the thermistor's variation with temperature. Thus, in the case of the bq2000T, the most critical specification is the charge range, usually the high-temperature cutoff, while the second constraint is the rate of change of temperature with time, which is the criterion of charge termination. Generally, the temperature at which the $\Delta T/\Delta t$ condition should apply is approximately 5°C above the expected ambient. This condition is ratiometric to the supply voltage but corresponds to a rate of 31mV/min with a 5V V_{CC} voltage ($V_{CC}/161$). The following system of equations calculates two resistor values (R_1 , connected between V_{CC} and the thermistor and R_2 , connected in parallel with the thermistor), which bias the thermistor connected inside the battery pack to the negative terminal of the battery:

$$\frac{R_{T30} * R_2 * 5}{(R_{T30} * R_2) + R_1 * (R_{T30} + R_2)}$$

$$\frac{R_{T31} * R_2 * 5}{(R_{T31} * R_2) + R_1 * (R_{T31} + R_2)} = 0.031$$

$$\frac{R_{THI} * R_2 * 5}{(R_{THI} * R_2) + R_1 * (R_{THI} + R_2)} = 1.125$$

where R_{T30} and R_{T31} represent the thermistor value at 30°C and 31°C respectively, and R_{THI} represents the high temperature cutoff resistance. Selecting a low beta thermistor such as the Semitec 103ET-2 together with a 40°C cutoff affords a range of 0 to 40°C with a 1°C per minute sensitivity at 30°C. The same sensitivity can be attained with a range of 0 to 50°C by selecting a high beta thermistor such as the Semitec 103GT-1. Note that,

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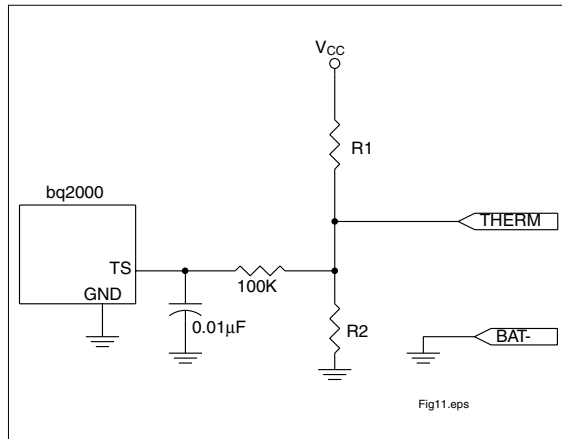


Figure 11. Configuring the TS Input

in solving these equations, $R_1 \geq R_2$ implies that there will be *no* cold temperature fault.

For ease of design, a table of values for R_1 and R_2 is presented below for various popular thermistors and temperature ranges.

Thermistor	Range (°C)	R_1	R_2
Semitec 103AT-2	-1.6–40	17.8K	45.3K
	0.7–45	14.7K	33.2K
	4–50	12.4K	23.7K
	8–55	10.5K	23.2K
Semitec 103ET-2	0–40	19.1K	69.8K
	1.8–45	15.8K	45.3K
	4.6–50	13.3K	34.8K
	8.2–55	11.5K	29.4K
Semitec 103GT-1	-10.8–40	13.7K	17.4K
	-6–45	11.3K	14.7K
	-0.2–50	9.31K	12.7K
	6.9–55	7.87K	11.5K
Philips 2322-640-63103 or Fenwal197-103LA6-A01	-7.9–40	14.7K	21K
	-4–45	12.1K	17.4K
	1.3–50	10K	15K
	7.2–55	8.45K	13.3K
Keystone RL0703-5744-103-S1	-9.6–40	14K	18.7K
	-5.2–45	11.5K	15.8K
	0.6–50	9.53K	13.7K
	7.1–55	8.06K	12.4K

Selecting the Timing Components

The RC pin of the bq2000/T provides for an infinitely variable time-out range, so the user is not bound to binary multiples and submultiples of a 1C charge rate. The time-out set by these pins expressed in minutes is determined by the formula $R * C * 35988$, where R is in ohms and C is in Farads. The value of R also determines the rate of maintenance trickle following charge for nickel-based chemistries. A C value of 0.13µF or greater selects a top-off algorithm to follow fast charge for pulse-trickle duty cycles of 8.33% or less. top-off is characterized by an interval equal to the time-out during which the battery is pulse-charged at a 1/16th duty cycle.

The main consideration in selecting the timing components is the rate at which charge is being restored to the battery expressed as a fraction (or multiple) of its rated capacity. As most battery manufacturers deliver batteries that exceed their rated capacities, the recommended time-out period is that which allows 33% more charge than the rated capacity to be returned to the battery during the timed charge interval. Thus, for a battery charged at a 1C rate, the timeout interval is 80 minutes. This interval allows for up to a 20% overcapacity that may occur in new batteries, a small allowance for charge efficiency, and a small overcharge to insure cell balance. Batteries charged at rates below C/4 may need to add significant additional time to accommodate charge inefficiency. Note that the 14-hour time-out normally recommended for NiCd batteries charged at C/10 is because of the poor charge efficiency at this rate of charge. Li-Ion or Lead Acid batteries require voltage regulation as part of the charge algorithm and normally take longer to charge, and the bq2000/T has incorporated a time-out doubler that is activated if the battery achieves voltage regulation.

Here then is a design procedure :

- Express the charge rate as a fraction or multiple of the capacity.
- Divide 80 minutes by this fraction or multiple to determine the desired time-out expressed in minutes.
- Divide this result by 35,988 to determine the R-C product.
- If top-off is desired, choose $C \geq 0.13\mu\text{F}$. If not, choose $C \leq 0.07\mu\text{F}$.
- Calculate R from time-out = $R * C * 35,988$. An additional condition on top-off is that $R < 300\text{K}$. (Even with the time-out capacitor and a resistor of less than 300k, a time-out of 23 hours can be realized.)

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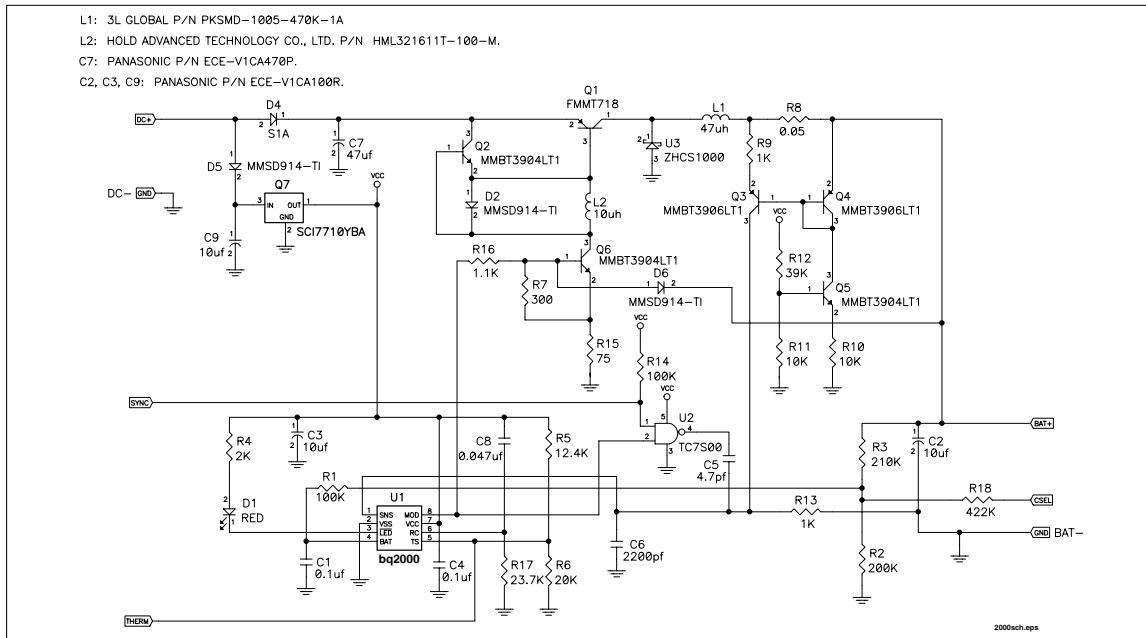


Figure 12. Dual-Chemistry Buck Regulator with High-Side Current Sensing

- Verify that the trickle-pulse rate selected from the graph multiplied by the charge rate determined in step 1, is less than or equal to 1/32 for NiCd or 1/64 for NiMH, and that $R < 500000$.
- Failing any condition imposed in steps 5 and 6, return to step 4 and choose a larger value for C within the limits specified.
- $R = 94.6K\Omega$
- Pulse-trickle = $C/50$ (All parameters within specified limits.) For standard values, choose $R = 95.3K\Omega$ and $C = 0.047\mu F$.

Charge Termination Considerations

Fast charge terminates when any of the following conditions is fulfilled:

Example: NiCd Battery

- $C/2$
- 160 minutes
- $R * C = 4.4459 \cdot 10^{-3}$
- Choose $C = 0.001\mu F$ (1000pF)
- $R = 4.446M\Omega$
- $R > 500K\Omega$ (Selected capacitor is too small.)
- Choose $C = 0.01\mu F$
- $R = 444K\Omega$
- Pulse-trickle = $1/10.7(>1/32)$ (Pulse-trickle exceeds recommended value for NiCd.)
- Choose $C = 0.047\mu F$

- The average voltage at the BAT input to the bq2000/T declines by PVD threshold from its highest previous value (bq2000/T).
- The signal at the TS input declines at a rate of V_{TERM} (bq2000/T).
- Regulation voltage is attained at the BAT input and the current tapers to I_{MIN} threshold.
- The maximum temperature threshold at the TS input is exceeded.
- The timer expires.

Measurement accuracy made in 3 above may depend on the degree to which the battery voltage is filtered. A larger value of capacitance connected across the battery leads to a more accurate termination measurement.

Using the bq2000/T to Control Fast Charge

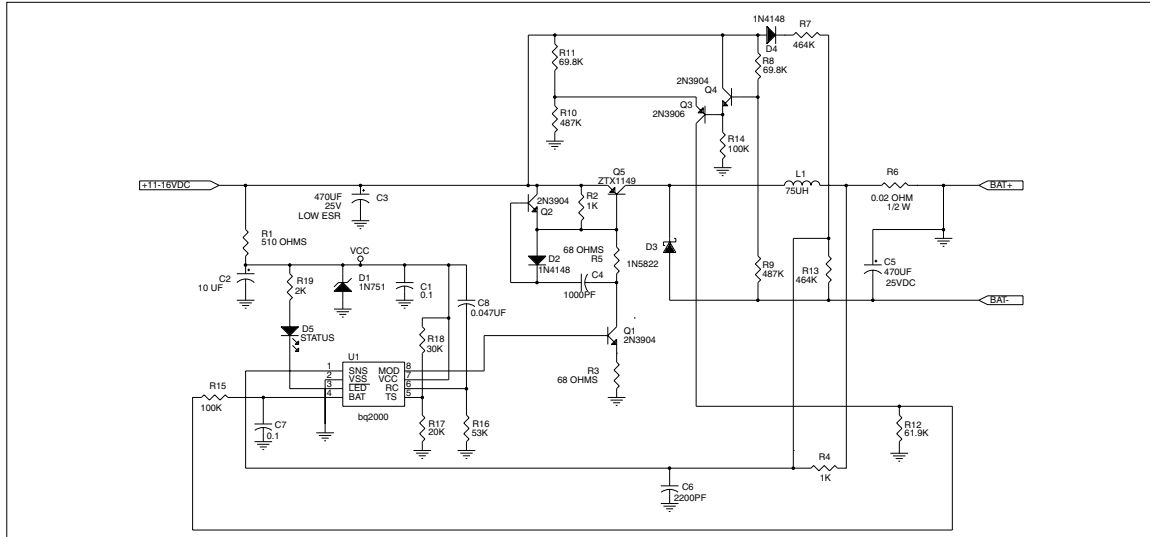


Figure 13. Simple Buck-Boost Design

Configuring the LED Output

The LED output is an open-drain MOSFET capable of sinking up to 10mA of DC current. Unlike the CMOS inputs to the bq2000/T, the LED output is protected from overvoltage by a punch-through ESD structure. Thus the LED output can tolerate voltages within the recommended operating range, independent of the bias on the VCC pin.

Layout Considerations

The bq2000/T makes its voltage and temperature measurements with the switching regulator and timing oscillator turned off. This prevents layout considerations from affecting termination decisions. Layout is very important, however, for predicting the performance of the switching regulation function. One rule applies for high or low-side regulation:

Minimize the size of all input pin nodes. Locate all bypass, feedback, and filtering components adjacent to their connected input pins, or power pins in the case of bypass. Ground connections associated with any power or input pin to the bq2000/T must be kept separate from all other grounds and brought directly to the correct side of the sense resistor. The resistor associated with the SNS input filter must connect separately and alone to the opposite side of the sense resistor.

Application Example: Simple Dual-Chemistry Buck Regulator

To safely accommodate two distinct battery chemistries in the same charger, voltage regulation must supercede completeness of charge. This requirement implies that, for simplicity of charger design, the user must sacrifice similarity of discharge voltage, but for similarity of pack voltage under discharge, the user must default under conditions of contact failure to voltage regulation for safety reasons. A fixed cell-ratio usually applies for applications requiring similar discharge voltage—for example, 3 NiCd/NiMH to 1 Li-Ion. The safest design approach for these packs is to include an additional negative battery contact on the nickel chemistry packs that will adjust the battery divider in the charger to accommodate the higher charge voltage requirement. See Figure 12.

If packs of dissimilar voltage can be allowed, the user may select a pack of higher output voltage for the voltage regulated chemistry while the nickel chemistry pack has a higher amp-hour rating. These pack cell ratios should be 2 Li-Ion to 5 or fewer nickel cells or 2 lead acid to 3 or fewer nickel cells. Care must be taken here to limit the charge current to the nickel cells so they do not achieve voltage regulation. If they do, they will not terminate for $-\Delta V$. The safest approach to cell counts that risk this situation is to use the bq2000T.

Using the bq2000/T to Control Fast Charge

Buck-Boost Design

This section illustrates a commonly encountered application, one in which a user wishes to design an automotive charger for a number of cells whose voltage at end of charge would exceed the supply. A nickel cell count of 8 would fit the requirement of a buck-boost implementation if charged from a cigarette lighter. This circuit maintains a constant current to the battery by compensating the current regulation in the inductor for the difference between the input and output voltages from the supply. The voltage inversion allows the inductor to remain a single winding. See Figure 13.

Charging Lead-Acid Batteries

The bq2000/T charges lead-acid batteries where a pulsed-charge algorithm is acceptable. The charger is designed so that (1) the bulk voltage (nominally 2.45 V/cell) on the BAT input and (2) the float voltage (nominally 2.275V/cell) causes the battery replaced voltage of 1.9V to appear on the BAT input. The SNS input can be configured normally for current limit. For temperature compensation, an NTC thermistor is part of the resistive divider. The design procedure is to solve the following four equations simultaneously for values R_1 , R_2 , R_3 , and R_4 :

$$\left(\frac{V(LO)_{BULK} - 2}{R_1 + \frac{R_{T(LOW)} * R_4}{R_{T(LOW)} + R_4}} + \frac{3}{R_2} \right) * (R_3) = 2$$

$$\left(\frac{V(25)_{BULK} - 2}{R_1 + \frac{R_{T(25)} * R_4}{R_{T(25)} + R_4}} + \frac{3}{R_2} \right) * (R_3) = 2$$

$$\left(\frac{V(25)_{FLOAT} - 2}{R_1 + \frac{R_{T(25)} * R_4}{R_{T(25)} + R_4}} + \frac{3.1}{R_2} \right) * (R_3) = 1.9$$

$$\left(\frac{V(HI)_{BULK} - 2}{R_1 + \frac{R_{T(HI)} * R_4}{R_{T(HI)} + R_4}} + \frac{3}{R_2} \right) * (R_3) = 2$$

where bulk and float voltages and thermistor values are HI for the high-temperature limit, LO for the low-temperature limit, and 25 for the value at 25°C. R_1 is connected from the battery positive terminal to the higher voltage side of the thermistor. R_2 is connected between the lower-voltage side of the thermistor and V_{CC} . R_3 is connected between the lower-voltage side of the thermistor and ground of the IC. R_4 is in parallel with the thermistor. The voltage at the juncture of the thermistor, R_4 , R_3 , and R_2 is applied to the BAT input through a filter. The 3V and 3.1V values on the left side of the above equations assume 5V for V_{CC} . In applications where an alternative voltage for V_{CC} is used, these values would be $(V_{CC} - 2)$ and $(V_{CC} - 1.9)$ respectively. A thermistor value of 100KΩ or greater at 25°C is recommended.

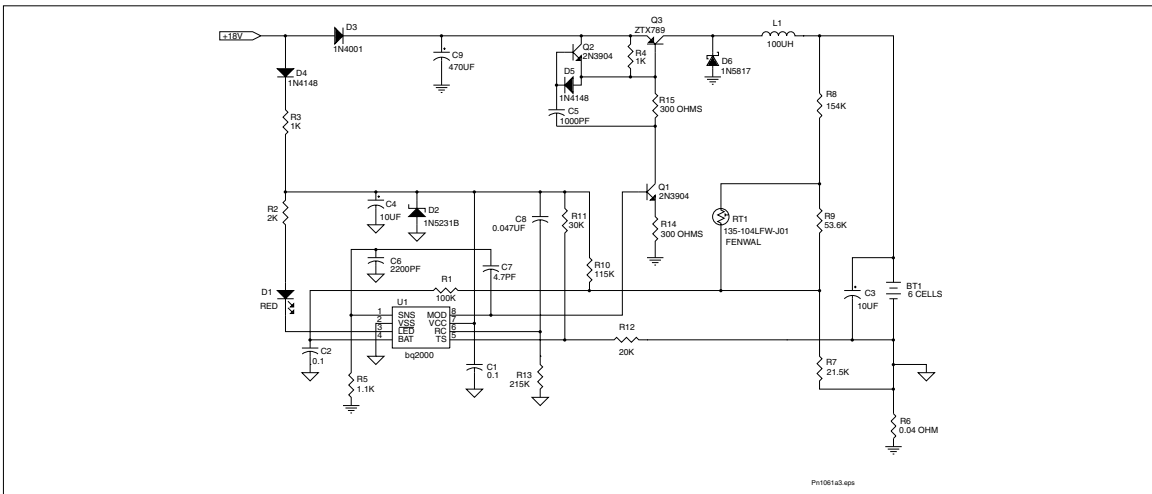


Figure 14. Design Example for Lead-Acid Batteries

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