U-512 Using the bq2902/3 Rechargeable Alkaline ICs

UNITRODE

Introduction

Choosing the right battery chemistry for a particular application depends on many factors. In some cases, the appropriate choice is rechargeable alkalines, which have advantages over other secondary battery chemistries, such as NiCd or NiMH:

- Much lower self-discharge rate
- Increased capacity
- Increased energy density
- Low cell cost and good availability

For low to moderate power levels (AA or AAA cells at 20–400mA loads), these advantages are exploited in applications which include portable audio, handheld instruments, palmtop computers, calculators, personal communication devices, electronic games, personal care products, and others.

The internal resistance of alkalines, however, is higher than that of the spirally wound NiCd or NiMH systems. As a result, alkaline cells provide lower effective capacity at higher discharge currents.

The bq2902 and bq2903 ICs manage rechargeable alkalines such as the Renewal® cells from Rayovac®. These ICs monitor the charge and discharge cycles of rechargeable alkalines to extend their cycle life. The bq2902 manages two cells, and the bq2903 manages either three or four cells.

These parts feature the following:

- LED driver output(s) to indicate charge status
- Selectable end-of-discharge voltage (EDV) to prevent overdischarge and to improve cycle life
- Optional external FET drive, allowing higher current loads (bq2903 only)
- Pulsed current taper

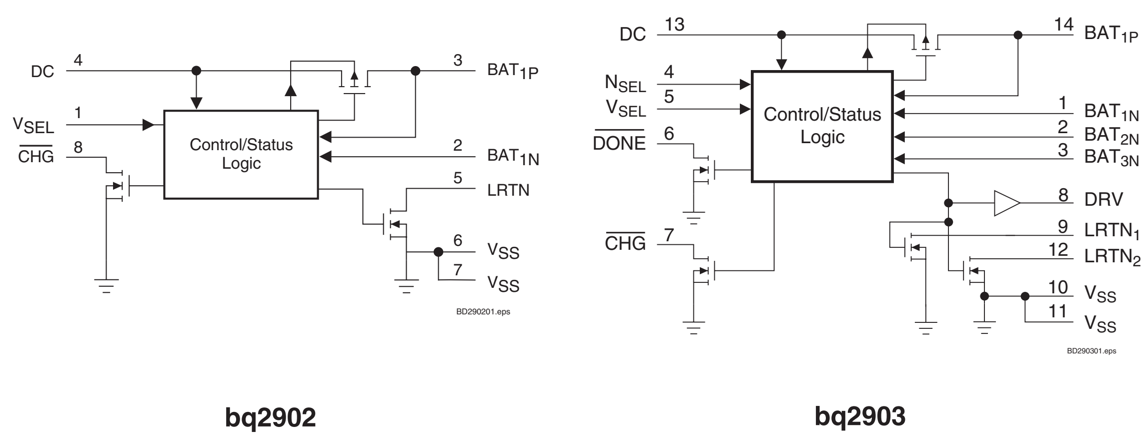

Figure 1. Functional Block Diagrams

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Contents

This application note discusses these key points about the bq2902/3:

- Functional Description
- Charge Control
- Discharge Control
- Practical Considerations

For complete device specification, please refer to the bq2902 or bq2903 data sheet.

Functional Description

The bq2902 and bq2903 function similarly. There are certain differences between the two ICs, however, as indicated in Table 1.

Table 1. bq2902/3 Differences

Feature	bq2902	bq2903
Number of monitored cells	2	3 or 4
V_{OP} (Max)	5.5V	10V
Status outputs	1	2
External FET drive (DRV pin)	No	Yes

The DRV pin on the bq2903 controls an external N-FET for use when discharge currents are in excess of 400mA. (See the functional descriptions in the bq2902 and bq2903 data sheets.) Figure 1 shows the bq2903 functional block diagram; note that the DRV pin is present in that diagram. The bq2902 does not provide a DRV pin for external discharge FET control.

Charging

The bq2902/3 charges cells in series; therefore, it is not recommended for use in stand-alone chargers where anywhere from one to four cells are charged.

A load should not be connected to the battery during charge because the bq2902/3 requires an accurate measurement of the no-load battery voltage (i.e., open-circuit voltage) to terminate charge properly. See the "Powering the Load While Charging" section of this application note. The open-circuit voltage (V_{OCV}) of each cell is monitored during the idle period, as seen in Figure 2.

During the OCV test, if any cell is above 1.63V, then the following charge pulse is skipped. The bq2903 terminates charge when a cell remains above 1.63V long enough for 16 consecutive pulses to be skipped. The effective charging current equals approximately 6% of the fast charge rate. The bq2902 terminates charge when 32 consecutive pulses are skipped. This effective charging current equals approximately 3% of the fast charge rate. These algorithms effectively taper the charging current until termination occurs. Charge termination can be indicated using an LED .

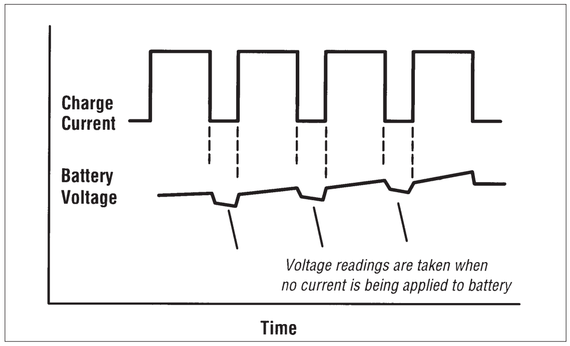


Figure 2. Cell Voltage/Current During Charging

Charging Source

The charging supply must limit the current through the DC pin to less than 300mA to prevent excessive power dissipation in the internal charge switch. The charging supply must provide at least 2.0V*N (where N is number of cells) to charge the battery properly. The bq2902/3 controls charging by periodically connecting the current source to the battery stack through the BAT_{1P} pin. The compliance voltage of the current source should also be limited to prevent the DC pin from exceeding its rated operating voltage (V_{OP} max.) when the charge switch is "off."

The charging current can be extended to above 300mA, as discussed in the "Constant-Current Charging: >300mA" section of this application note. At higher charging currents, the cell voltage takes longer to recover, thus skipping more charging pulses and terminating charge earlier. A few percentage points in capacity can be gained by limiting the charging source to below 300mA, but the trade-off is a longer charge time. By testing charge times in your application, you can determine these trade-offs.

Charge Control

Low-Current Charging: ≈ 100mA

A low charge rate of 100mA or less may be acceptable in some applications such as electric toothbrushes, cordless phones, and flashlights. Quasi-constant-current charging can be cost-effective for these applications. (See Figure 3.)

The charge current is limited by an inexpensive resistor, R5, or by the secondary winding resistance of an AC-DC wall-mount adapter. The charge current into the DC pin now varies with the battery's state of charge and input voltage. As the battery charges and the voltage rise, the peak current into the DC pin decreases with the decreasing voltage drop across R5. Low efficiency limits the suitability of this design to low-rate charging.

Design example:

Given: V_{IN} =12V, I_{CHG}(min) ≈ 100mA

Find: R5 for the charger in Figure 3

Solution:

R5 = (12V - 3 cells*2V/cell)/100mA = 60Ω.

Choose a standard resistance value: R5 = 56Ω

Verify that the charge current is under 300mA if the per cell voltage is 0.4V:

I = (12V - 3 cells*0.4V/cell)/56Ω = 193 mA

The maximum power dissipation in R5 is

Pd(R5) = 0.75 ∗ 56Ω ∗ (193mA)2 = 1.56W.

The maximum power dissipation of D4 is

Pd(D4) = (12V - 10V)/56Ω ∗ 10V = 375mW

The charge current varies between 107mA and 193mA, depending on the battery's state of charge.

In most instances, the cell voltage does not go below the minimum EDV cutoff voltage of 0.9V. In these cases, the value of R5 can be increased and its power rating decreased accordingly.

R2, R3, and C1-C3 are for ESD and latch-up protection. Q1 and D3 allow the load to operate from the charging supply or from the battery. The operation of this circuit is discussed in greater depth in "Powering the Load While Charging."

Constant Current Charging: ≤ 300mA

The circuit in Figure 4 can charge up to a 300mA rate. The front end (Q1, Q2, Q3, R2, R3, R4, R8, and R_{SNS}) is a constant-current source with output voltage limiting. The charge current and output voltage limits are set as follows:

Charge current: $I_{CHG} \approx 0.65V/R_{SNS}$

V_{OUT} limit: $R3/R4 \approx (V_O/0.65V-1)$

The output voltage limit is set at 9.1V, providing enough voltage to charge 4 cells. I_{CHG} is set at 295mA.

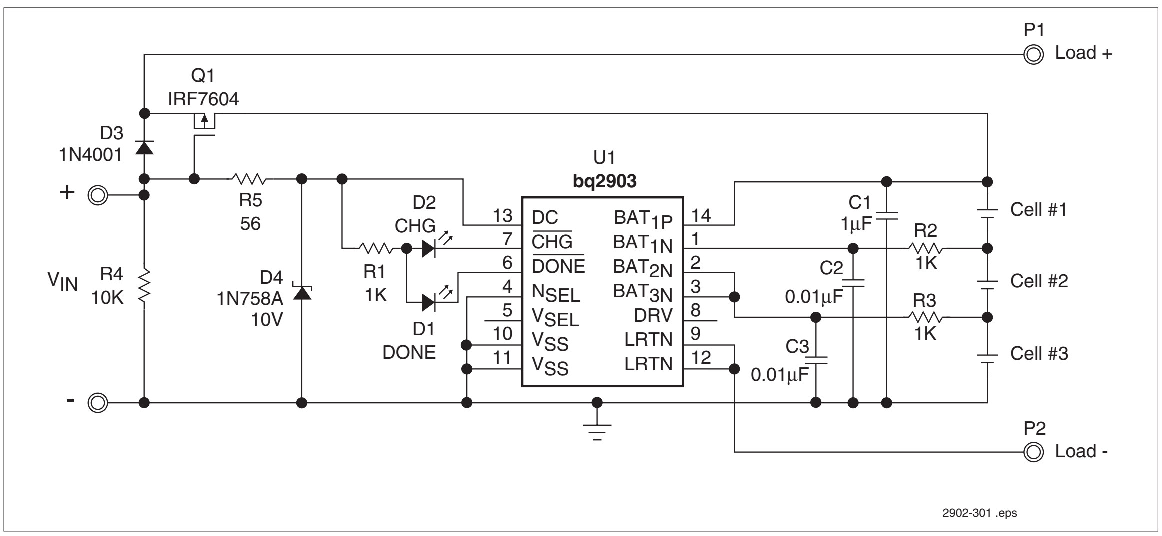


Figure 3. Low-Cost Quasi-Constant-Current Charger

The maximum power dissipated by Q1 is

$$Pd(Q1) = (16V - 0.4V/cell * 4 cells) * 300mA * 75\%$$

or

$$Pd(Q1) = 3.24W$$

This calculation assumes an unregulated power supply with an output voltage of 10V–16V. The power dissipated by Q1 reduces to 1.89W if the power supply is regulated to 10V.

D4 ensures that the bq2902/3 can change from the charge to discharge mode if the charging supply is turned off. This mode change is triggered by the DC pin falling 155mV below the voltage at BAT_{1P}. If the capacitance at the current source input is too large and D4 is absent (i.e., replaced with a short), the bq2902/3 gets stuck in the charge mode. A large capacitance can appear at the current source input if the charger is connected to an adapter that is unplugged from the outlet. A typical adapter has a large filter capacitor across its output (e.g., 1000µF). To understand how the bq2902/3 can get stuck in the charge mode, consider the sequence of events that occur after the charging supply is turned off. Remember, the bq2902/3 is initially in the charge mode, so its internal charge switch is pulsing at a 75% duty cycle.

The sequence of events is as follows:

1. Turn off the charging supply.
2. The voltage at the DC pin falls until it is equal to the voltage at BAT_{1P}.
3. The charge switch is closed. The voltage at the DC pin is forced to the voltage at BAT_{1P}.
4. The charge switch is open. The voltage at the DC pin falls below the voltage at BAT_{1P}. The rate of decay is determined by the capacitance at the current source input
5. If the capacitance is large, the voltage at the DC pin does not fall 155mV below the voltage at BAT_{1P} while the switch is opened. The bq2902/3 remains in the charge mode and the charge switch closes again.
6. The charge switch is closed. The capacitor is connected across the battery through Q1 (Q1 turns on because of its non-zero reverse β). The capacitor is charged to the voltage at BAT_{1P}.
7. The cycle repeats at step 4.

In summary, D4 behaves as a one-way valve. It allows the input capacitor to discharge, but prevents it from being charged by the battery. The capacitor voltage eventually decays and the bq2902/3 exits the charge mode. D4 can be omitted if the capacitor across the current source is small enough to allow the charger to function properly.

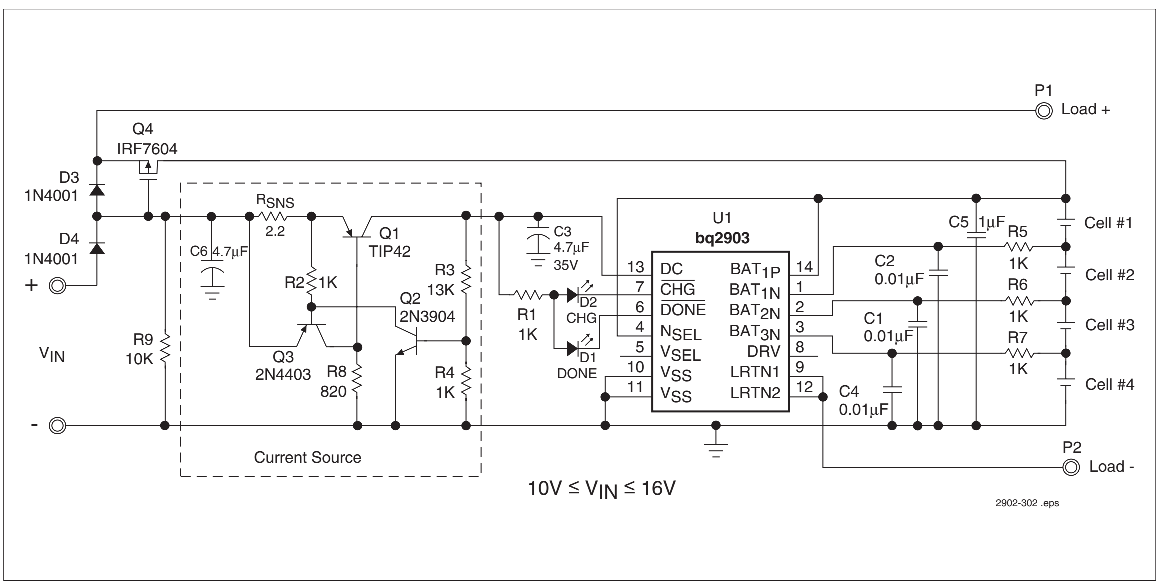


Figure 4. 300mA Linear Charger

Constant-Current Charging: >300mA

There are times when charging at greater than 300mA is desirable—for example, when charging either C or D size cells. The bq2902/3 can carry a maximum charge current of 300mA; however, the bq2902/3 can be used to control rather than carry the charge current. This charge method is used in Figures 5 and 6.

As a point of reference, the table below outlines the maximum recommended pulse charge current for Renewal cells.

Table 2. Maximum Pulse Current for Renewal Cells

Cell	Peak Current (mA)
AAA	300
AA	700
C	1500
D	1500

The circuit in Figure 5 can fast charge C or D cells. The current source (Q1, Q2, Q4, Q6, R_{SNS}, R3, R6, R8, and R9) turns on when the bq2903 gates current into the battery. Less than 1% of the charge current flows through the bq2903. The bulk of the charge current flows directly from the current source to the battery.

D5 prevents the DC pin from exceeding its maximum rated voltage. D4 prevents the battery from being discharged by the current source. Q3 is in parallel with the internal discharge FET to reduce the effective resistance of the discharge path.

A self-oscillating switch-mode current source can be used instead of a linear current source to reduce power dissipation, as shown in Figure 6. Power conversion efficiency is typically 75% for the former and 40% for the latter. In Figure 6, the loop area formed by C5, R_{SNS}, Q2, D4, and D6 should be small to minimize RF emissions.

The peak charge current for the linear or switch-mode current source is set by R_{SNS}:

$$I_{CHG} \approx 0.65/R_{SNS}$$

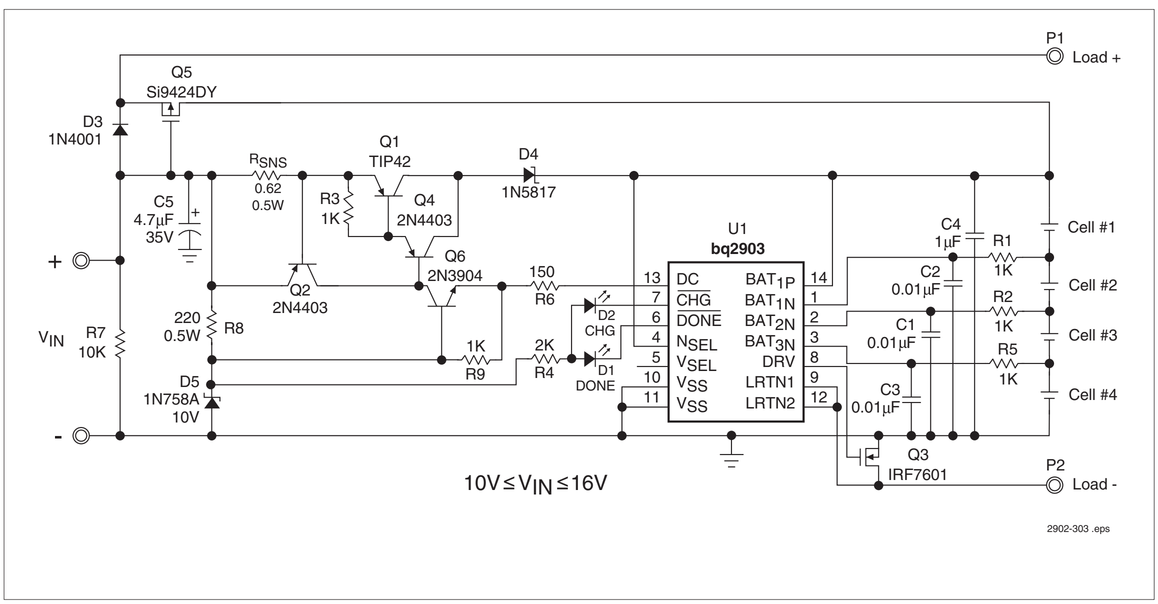


Figure 5. One-Amp Linear Charger

Discharge Control

EDV Selection

The most important causes of capacity fade are over-discharge and the number of discharge cycles. The depth of discharge (DOD) is determined by the rate of discharge and the end-of-discharge voltage (EDV).

The DOD to a given EDV is affected by the internal resistance of rechargeable alkalines. (See Figure 8.) Internal resistance increases with storage time and use. At low discharge rates, the voltage drop across this resistance is low, allowing for a greater DOD than at higher rates. This DOD causes a higher degree of capacity fade at low discharge currents. High discharge rates create a higher voltage drop across the battery's internal resistance, thus allowing a lower EDV with less effect on cycle life.

The bq2902/3 uses a low-side switch connected between LRTN and V_{SS}, as seen in Figure 1, to disconnect the load from the battery when a cell falls below the user selected EDV. EDV can be configured to be 1.1V, 1.0V, or 0.9V, as shown in Table 3.

Table 3. Configuring for Selectable End-of-Discharge Voltage (V_{EDV})

V_{SEL}	V_{EDV}
BAT_{1P}	1.1V
Floating	1.0V
V_{SS}	0.9V

The EDV cutoff function is active only if the bq2902/3 is in the discharge mode ($V_{DC} < V_{BAT1P}$). If the bq2902/3 is in the charge mode ($V_{DC} > V_{BAT1P}$), the EDV cutoff function is disabled, and the discharge switch stays "on."

Again, the discharge current, the battery's internal resistance, and the end-of-discharge voltage together determine the depth of discharge. Table 4 suggests some EDV values for various cell sizes and rates of discharge to help maximize cumulative discharge capacity.

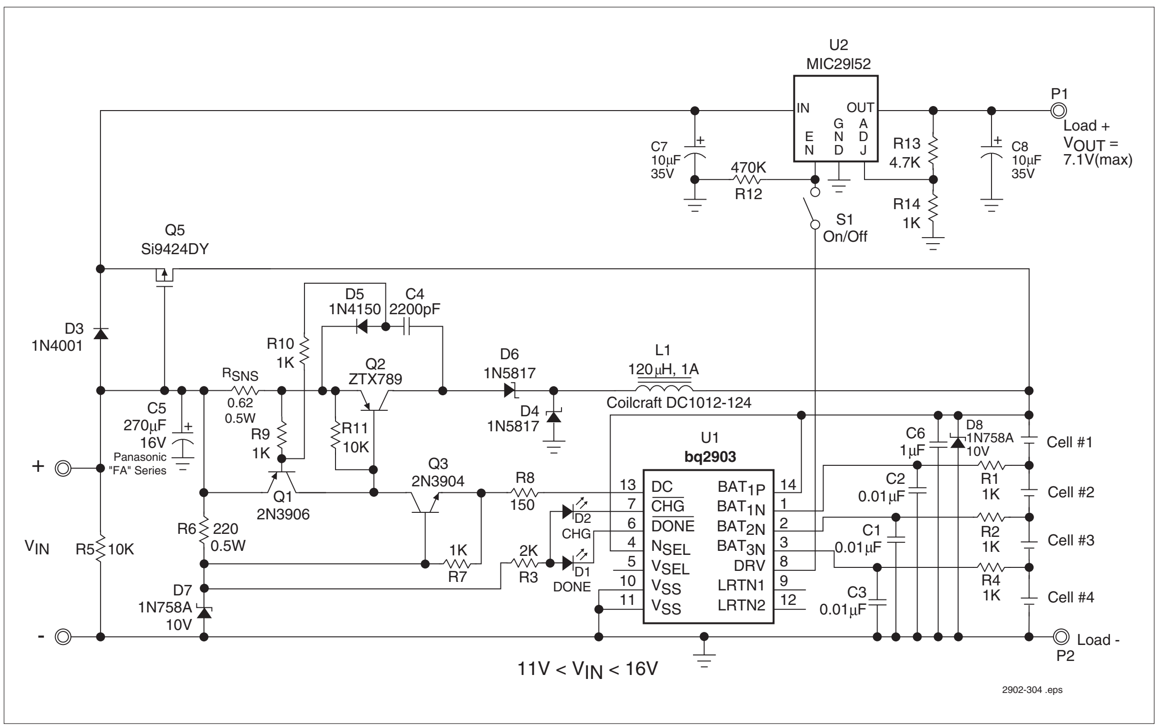


Figure 6. One-Amp Switch-Mode Charger Using an LDO for a Voltage Clamp and High-Side Load Switch

Table 4. Suggested EDV for Various Discharge Rates

V_{EDV}	AAA	AA	C	D
1.1V	20mA	50mA	100mA	100mA
1.0V	50mA	100mA	200mA	200mA
0.9V	>100mA	>200mA	>300mA	>300mA

These voltages may differ depending on the use of the cells in the actual application.

Low-Side Switch

Either the bq2902 or bq2903 can sink 400mA of load current with its internal FET. Current handling can be augmented by paralleling the internal FET with an external FET (Q3) as shown in Figure 5. Only the bq2903, however, has the DRV pin available to drive the gate of the external FET.

High-Side Switch

A high-side load switch can be used if the load and battery must share the same return. The switch is implemented with a P-channel MOSFET (Q5) as illustrated in Figure 7. The current through the LRTN pull-up resistor should be comparable to the battery's leakage current to minimize battery drain during in-system storage.

The leakage current is determined from the self discharge rate of a rechargeable alkaline which is typically 0.01% per day. For example, the leakage current of a 1.4Ahr capacity AA-cell is

$$I = 0.01\% * (1.4Ahr/24hr) = 5.8\mu A$$

Discharge Switch Selection

The external discharge FET must have enough threshold voltage to stay "on" throughout discharge. The number of cells and the EDV setting determine the maximum threshold voltage. For example, an application using 3 cells and an EDV of 0.9V (±5%) requires a FET with a threshold of less than 2.57V.

Table 5 lists FETs that work equally well in 3- or 4-cell applications.

In addition to the threshold voltage constraint, the external discharge FET's on-resistance, or R_{DS} (on), should be low relative to the battery pack's internal resistance. Typical cell resistances at room temperature are 0.3Ω for a AAA-cell, 0.2Ω for a AA-cell, 0.15Ω for a C-cell, and 0.1Ω for a D-cell. Stacking cells in series increases the pack resistance while paralleling cells decreases the pack resistance.

Figure 8 shows a graph of a typical cell's resistance for AA- and D-cell size versus temperature.

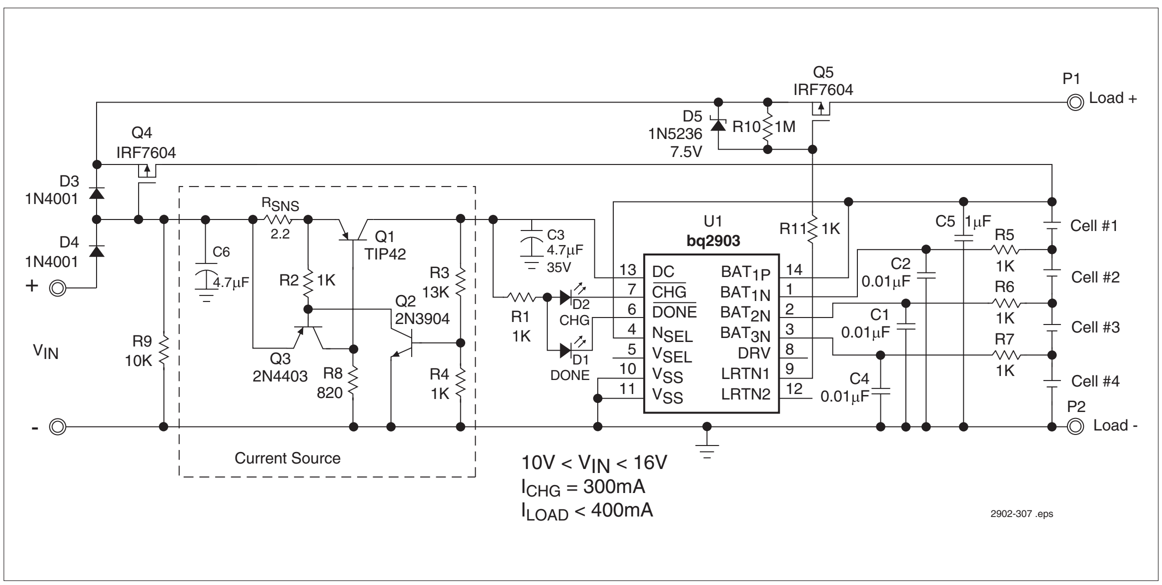


Figure 7. Discharge Control With High-Side Load Switch

Table 5. Switches for 3- and 4-cell Applications

External FET	Maximum $R_{DS\ (on)}$	Package	Manufacturer
Low-Side Switch (N-FETs)			
TN0200T	0.5Ω	SOT-23	Siliconix
IRLML2402	0.35Ω	SOT23	IR
Si6946DQ	0.11Ω	TSSOP-8	Siliconix
IRF7601	0.05Ω	Micro-8	IR
Si6426DQ	0.040	TSSOP-8	Siliconix
IRF7401	0.03Ω	SO-8	IR
Si9426DY	0.016Ω	SO-8	Siliconix
High-Side Switch (P-FETs)			
IRLML6302	0.9Ω	Micro-3	IR
TP0101T	0.85Ω	SOT-23	Siliconix
Si6943DQ	0.18Ω	TSSOP-8	Siliconix
Si6433DQ	0.09Ω	TSSOP-8	Siliconix
Si9434DY	0.060	SO-8	Siliconix
IRF7404	0.06Ω	SO-8	IR
Si9424DY	0.033Ω	SO-8	Siliconix
IRF7604	0.013	Micro-8	IR

Powering the Load While Charging

The bq2902/3 requires that the load be disconnected from the battery while the cells are charging to

- Prevent the battery from discharging to 0V if the load current exceeds the effective charge current (the discharge switch stays "on" when the bq2902/3 is in the charge mode)
- Allow the bq2902/3 to accurately measure a cell's open circuit voltage for proper charge termination
- Ensure the battery is at full capacity when the "charge complete" LED is "on"
- Maximize battery life by reducing the number of charge/discharge cycles (the battery cycles between charge and discharge if the battery is lightly loaded)
- Prevent the battery's ripple voltage from interfering with operation of the load

What if the load must operate while the battery is charging? Such operation may be desirable or even necessary for certain applications such as tape recorders, radios, electronic organs, portable computers, and cordless phones. In this case, the charger's power supply

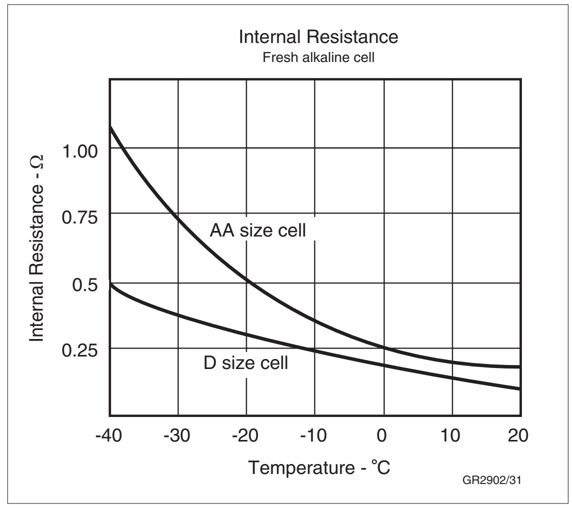


Figure 8. Typical Cells Resistance vs. Temperature

powers the load when the battery is charging; the battery powers the load when the battery is not charging.

A crude way to enable the load to be powered by either the battery or the charger is to wire-OR the power supply and battery to the load with rectifiers. This solution may be simple, but it is inefficient because the rectifiers' voltage drop reduces the available operating time.

To improve efficiency, the rectifier between the battery and the load is replaced with a P-channel MOSFET, Q4, as shown in Figure 4. When the charger's power supply is on, D3 conducts, turning off Q4. The load disconnects from the battery and connects to the charger's power supply. When the power supply output is off, the battery initially powers the load through the body diode of Q4. The voltage drop across the body diode is rather high ($V_f \approx 1V$). As C6 discharges, the gate of Q4 is pulled to ground turning on Q4. Q4 shorts out the body diode, reducing the voltage drop between the battery and the load.

In some cases, the power supply's output voltage can be significantly higher than the battery voltage. In Figure 4, the power supply voltage can be as high as 16V and the battery voltage can be as low as 4V. Many loads cannot tolerate this voltage swing. These loads may require either a voltage regulator or a voltage clamp to limit the excursion. A low drop-out regulator (LDO), U2 in Figure 6, limits the load voltage to 7.1V. The LDO operates in the linear region when the power supply is on and can dissipate significant power at moderate load currents. Efficiency is of little consequence when operating from external power because run-time is not affected, as it is when operating from a battery.

When the power supply is off, the LDO saturates, becoming a switch, since the battery voltage is less than the regulation voltage. The voltage drop across the MIC29l52 LDO is 350mV (typ) at a 1.5A load. The low loss connection between the battery and load maximizes operating time. The bq2903 turns the LDO off when EDV is reached. Here the discharge FET is not used.

Adapting the circuit in Figure 6 to 2 cells (i.e., with the bq2902) is difficult because present LDOs and MOSFETs do not work well with the lower voltage from 2 cells. This situation should change as manufacturers respond to the proliferation of 2-cell applications.

Practical Considerations

Cell Matching

Replace all cells as a set. Battery performance is optimal when cells are matched for capacity and state of charge. Cells with different charge and discharge histories suffer from different degrees of capacity fade.

Battery Interchangeability

In some cases, the use of both rechargeable and primary alkalines in an application may be desirable. If so, it is especially important not to allow the primary alkalines to be charged, because charging could cause the primary battery to leak or explode.

Rayovac has developed a special charger contact for AA and AAA Renewal cells that can be used to detect if a Renewal cell is placed into a holder. (See Figure 9.)

Renewal cells have a unique exposed anode shoulder with which the contact can make a connection. For primary alkalines, the insulating outer layer covers up the shoulder, not allowing a connection to be made to the contact. This recharge contact allows primary alkalines to be used in place of rechargeable alkalines. A schematic showing how to implement a circuit using this contact is shown in Figure 10.

If a primary alkaline cell is placed into the holder, it cannot be recharged because the current source is disabled; the current source is enabled only if the special recharge contact is in electrical contact with the battery's anode. Thus the bq2902/3 is prevented from charging, but it still disconnects the load from the battery when EDV is reached.

The contacts in Figure 9 may be obtained from

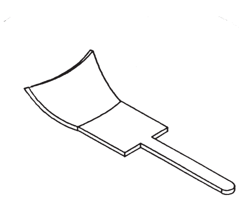
Memory Protection Devices
320 Broadhollow Road
Farmingdale, NY 11735
(516) 293-5891

For C and D size cells, the Renewal cells have a smaller diameter nubbin, allowing the nubbin to pass through a hole only large enough for Renewal cells. For more information on special contact systems for Renewal cells, please contact Rayovac.

Power-up Initialization

Power-on reset begins when BAT1P rises above 1.4V. During reset, the bq2902/3 turns on its discharge FET, checks the cells for EDV, and turns off the discharge FET if EDV is detected. The bq2902/3 must reset after the last cell is installed to initialize properly. ESD protection diodes at BAT_{1N}–BAT_{3N} allow the bq2902/3 to power up with a missing cell, however, causing reset to occur prematurely. The discharge FET initializes off

Contact	Part Number
Negative	SN-T5-1
Recharge	ABG-147
Positive	SN-T5-2



Recharge contact

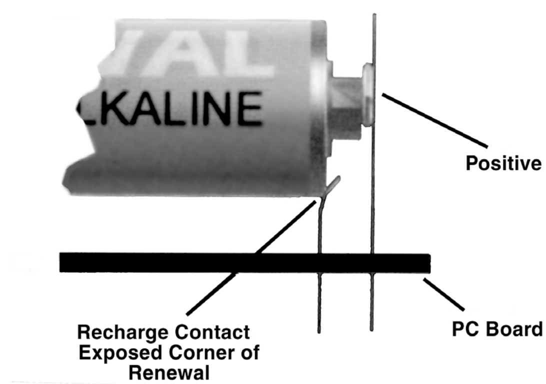


Figure 9. Charging Contacts for AA and AAA Cells

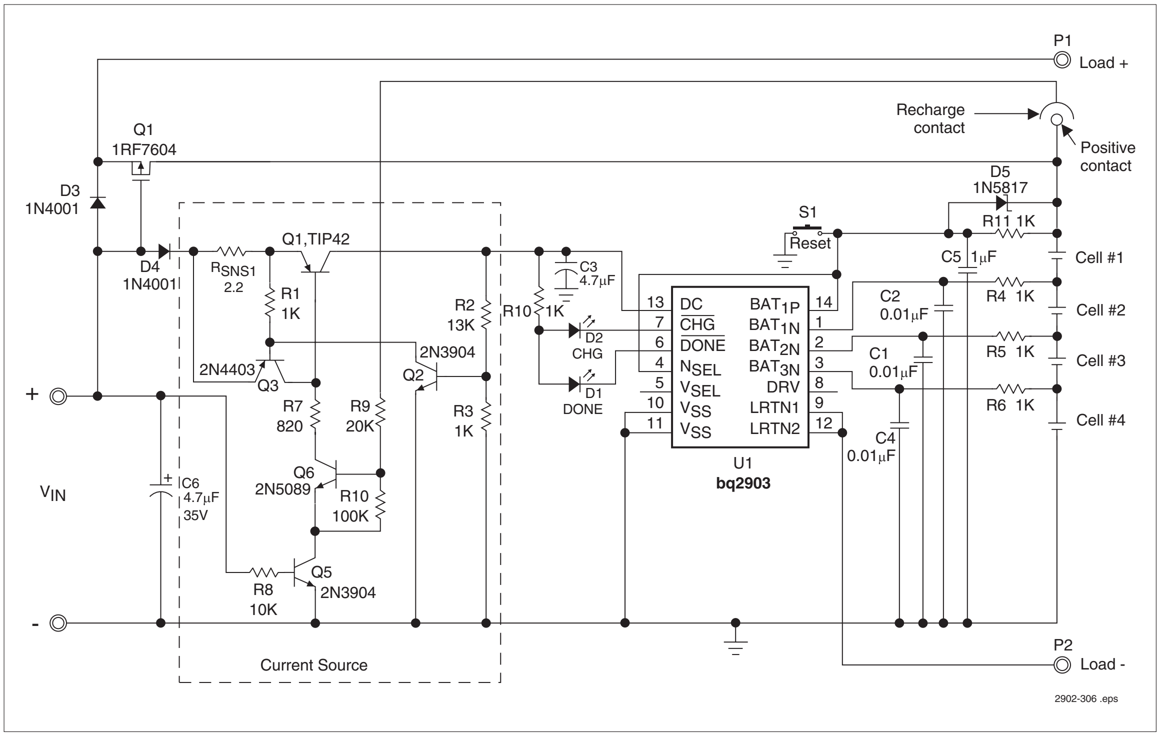


Figure 10. Using Rayovac Contacts to Permit Only Renewal Cells to Charge

(i.e., EDV is detected) by the time the missing cell is inserted. The discharge FET is reset by charging the battery, but if a wall outlet is not available or if primary alkalines are used (i.e., charging is disabled), the FET must be reset in another way.

Manual Reset

S1 in Figure 10 allows manual initialization of the discharge FET. By grounding BAT_{1P} (removing power to the bq2903) and then reapplying power (letting up on switch S1), the bq2903 initializes with the discharge FET on. S1 must be depressed long enough to discharge the capacitors at BAT_{1N}–NAT_{3N}. These capacitors discharge through the bq2902/3's internal ESD protection diodes. D5 allows S1 to be depressed without shorting the battery while maintaining a low-impedance charging path to the battery. The bq2902/3 measures the battery's open-circuit voltage through R11; D5 is off during this interval.

Automatic Reset

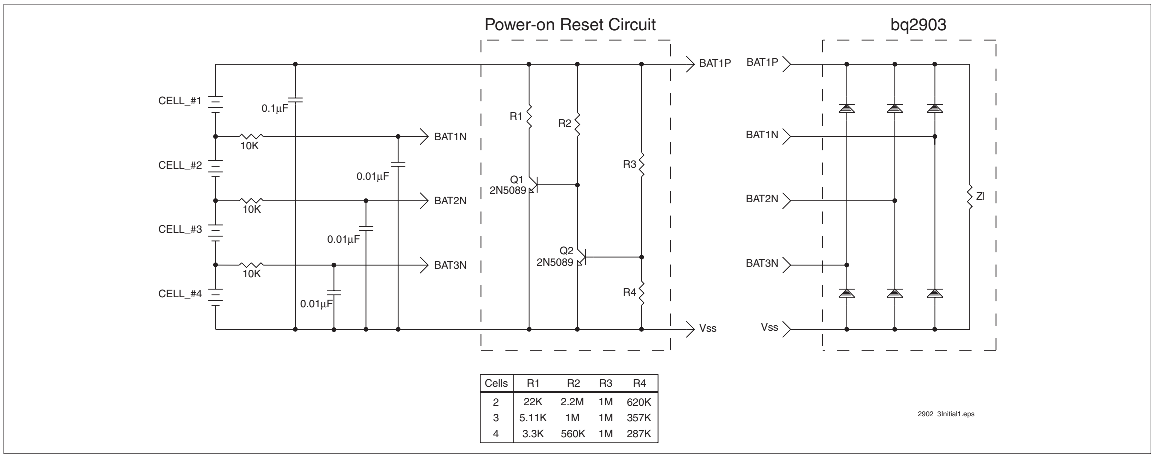
Q1 in Figure 11 holds the voltage at BAT_{1P} below the 1.4V reset threshold until the last cell is inserted. The last cell forces the voltage at BAT_{1P} above 1.4V to initiate the reset cycle. Note that the input current-limiting resistors at BAT_{1N}–BAT_{3N} are 10kΩ.

ESD and Latch-up

The battery contacts are subject to ESD during battery installation. These contacts are connected to the BAT_{1P}, BAT_{1N}, BAT_{2N},and BAT_{3N} pins of the bq2902/3. Bypass capacitors from these pins to V_{SS} are recommended for ESD protection. Latch-up can occur if these contacts are subjected to excessive ESD. Series resistors at these inputs limit the current so that latch-up cannot be sustained.

Reverse Battery Insertion

Excessive current through BAT_{1P} and V_{SS} damages the bq2902/3 if cells are inserted backwards. Figure 12 shows several ways to protect the bq2902/3 from cell reversal. The MOSFET in Figures 12a and 12b turns on only when the cells are correctly inserted.



Cells	R1	R2	R3	R4
2	22K	2.2M	1M	620K
3	5.11K	1M	1M	357K
4	3.3K	560K	1M	287K

Figure 11. Automatic Power-Up Iniatilization

Battery Storage

Cells may be stored in the system (i.e., making connection to the bq2902/3) only if all cells are present. A missing cell can turn on parasitic structures in the IC that can discharge the battery. The discharge rate is limited by external resistors in series with BAT_{1N-3N}.

EMI

Twist **+** and **–** leads of the cell stack to reduce EMI.

References

[1] Upal Sengupta, "Real World Aspects of Smart Battery Management," Proceedings of the Third Annual Portable by Design Conference 1996, pp. 299–305.

[2] Rayovac 1996–1997 OEM Designer's Guide and Technical Data.

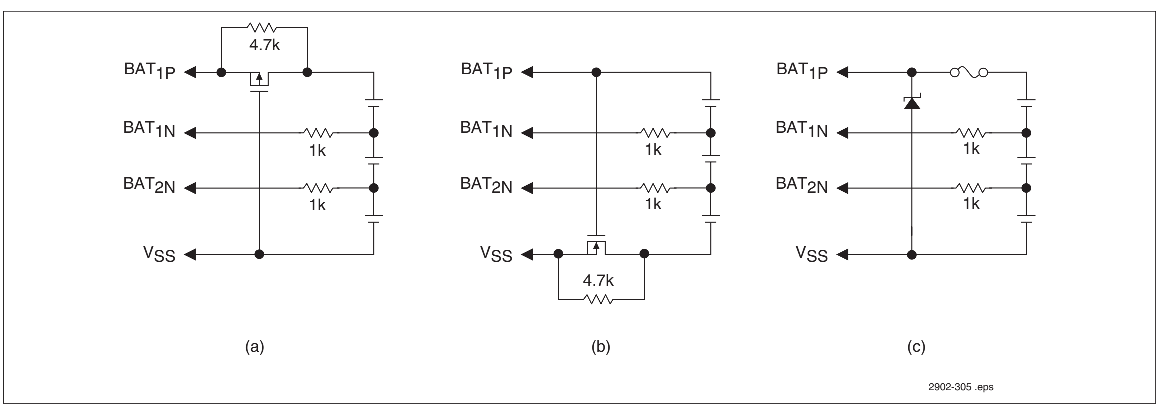


Figure 12. Protecting the bq2902/3 Against Reverse Battery Insertion

Data Sheet Revision History

Change No.	Page No.	Description	Nature of Change
1	2	Table 1	Clarified table
1	3, 4, 5, 6, 7, 10	Schematic	Updated schematic.

Notes: Change 1 = May 1999 B changes from Oct. 1997.

IMPORTANT NOTICE