Programmable Multi-Chemistry Fast-Charge Management IC

Check for Samples: bq2000

FEATURES

- **Safe Management of Fast Charge for NiCd, NiMH, or Li-Ion Battery Packs**
- **High-Frequency Switching Controller for Efficient and Simple Charger Design**
- **Pre-Charge Qualification for Detecting Shorted, Damaged, or Overheated Cells**
- **Fast-Charge Termination by Peak Voltage (PVD) for Nickel chemistries, Minimum Current for Li-Ion chemistries, Maximum Temperature, and Maximum Charge Time**
- **Selectable Top-Off Mode for Achieving Maximum Capacity in NiMH Batteries**
- **Programmable Trickle-Charge Mode for Reviving Deeply Discharged Batteries and for Postcharge Maintenance**
- **Built-in Battery Removal and Insertion Detection**
- **Sleep Mode for Low Power Consumption**

APPLICATIONS

- **Multi-Chemistry Charger**
- **Nickel Charger**
- **High-Power, Multi-Cell Charger**

GENERAL DESCRIPTION

The bq2000 is a programmable, monolithic IC for fast-charge management of nickel cadmium (NiCd), nickel metal-hydride (NiMH), or lithium-ion (Li-Ion) batteries in single- or multi-chemistry applications. The bq2000 chooses the proper battery chemistry (either nickel or lithium) and proceeds with the optimal charging and termination algorithms. This process eliminates undesirable, undercharged, or overcharged conditions, and allows accurate and safe termination of fast charge

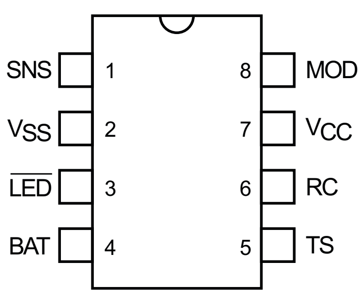
Depending on the chemistry, the bq2000 provides a number of charge termination criteria:

- Peak voltage, PVD (for NiCd and NiMH)
- Minimum charge current (for Li-Ion)
- Maximum temperature
- Maximum charge time

For safety, the bq2000 inhibits fast charge until the battery voltage and temperature are within user-defined limits. If the battery voltage is below the low-voltage threshold, the bq2000 uses trickle-charge to condition the battery. For NiMH batteries, the bq2000 provides an optional top-off charge to maximize the battery capacity.

The integrated high-speed comparator allows the bq2000 to be the basis for a complete, high-efficiency battery charger circuit for both nickel-based and lithium-based chemistries.

8-Pin DIP or Narrow SOIC or TSSOP



Pin Names

SNS	Current-sense input
V_{SS}	System ground
$\overline{LED}$	Charge-status output
BAT	Battery-voltage input
TS	Temperature-sense input
RC	Timer-program input
V_{CC}	Supply-voltage input
MOD	Modulation-control output

These devices have limited built-in ESD protection. The leads should be shorted together or the device placed in conductive foam during storage or handling to prevent electrostatic damage to the MOS gates.

PIN DESCRIPTIONS

SNS **Current-sense input**

Enables the bq2000 to sense the battery current via the voltage developed on this pin by an external sense-resistor connected in series with the battery pack

V_{SS} **System Ground**

Connect to the battery's negative terminal

$\overline{\text{LED}}$ **Charge-status output**

Open-drain output that indicates the charging status by turning on, turning off, or flashing an external LED, driven through a resistor.

BAT **Battery-voltage input**

Battery-voltage sense input. A simple resistive divider, across the battery terminals, generates this input.

TS **Temperature-sense input**

Input for an external battery-temperature monitoring circuit. An external resistive divider network with a negative temperature-coefficient thermistor sets the lower and upper temperature thresholds.

RC **Timer-program input**

Used to program the maximum fast charge-time, maximum top-off charge-time, hold-off period, trickle charge rate, and to disable or enable top-off charge. A capcitor from V_{CC} and a resistor to ground connect to this pin.

V_{CC} **Supply-voltage input**

Recommended bypassing is 10µF + 0.1µF to 0.22µF of decoupling capacitance near the pin.

MOD **Modulation-control output**

Push-pull output that controls the charging current to the battery. MOD switches high to enable charging current to flow and low to inhibit charging-current flow.

FUNCTIONAL DESCRIPTION

The bq2000 is a versatile, multi-chemistry battery charge control device. See Figure 1 for a functional block diagram and Figure 2 for a state diagram.

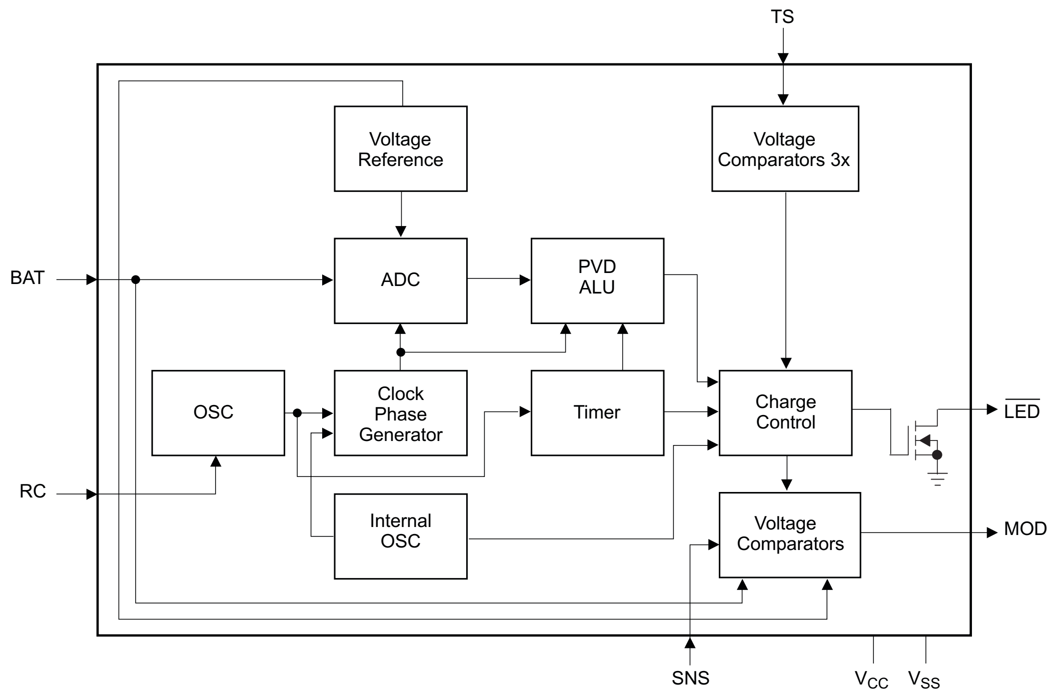
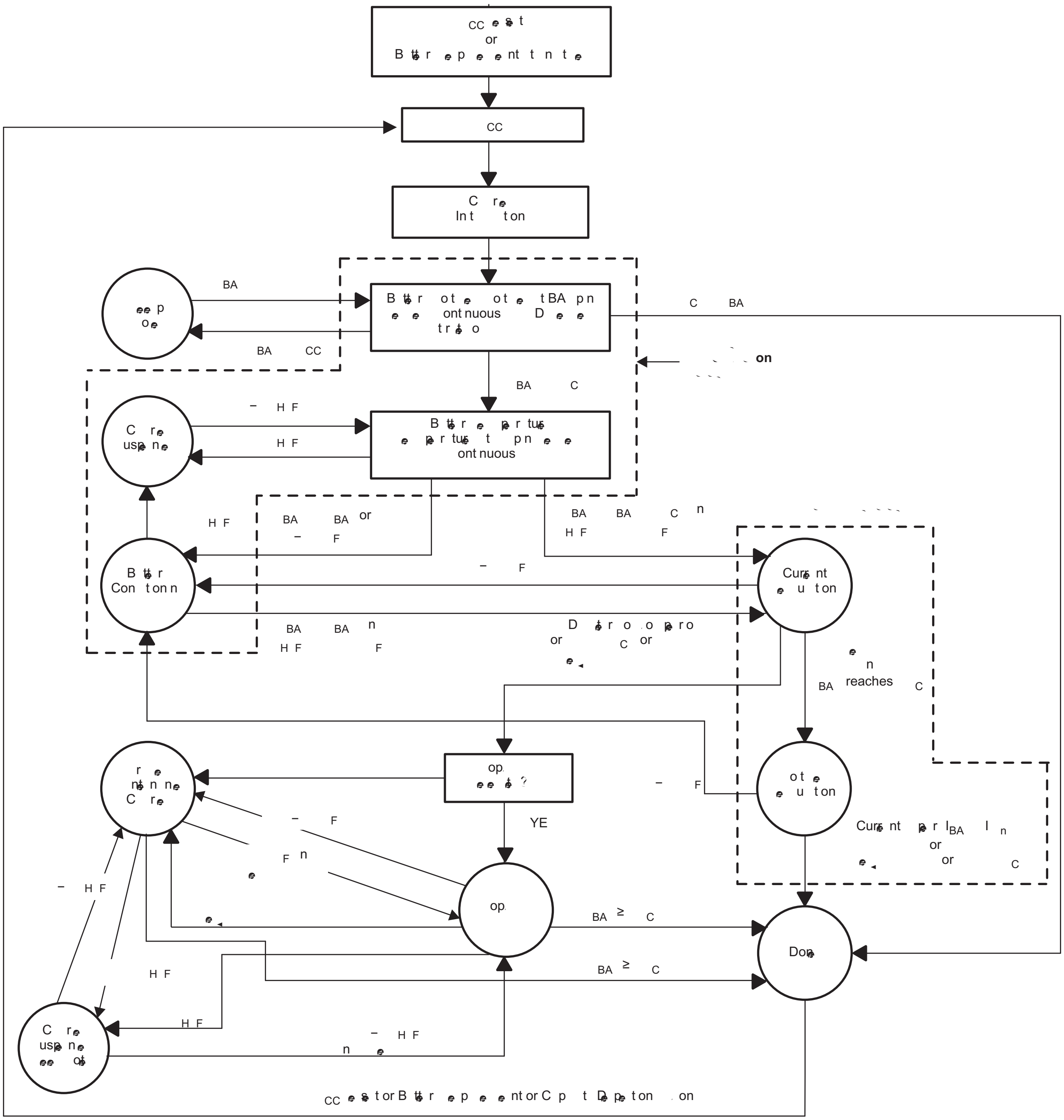


Figure 1. Functional Block Diagram



NOTE: If $V_{TS} < V_{TCO}$ at any time, may only return to Trickle Maintenance Charge state and not to Top-Off.

Figure 2. State Diagram

ABSOLUTE MAXIMUM RATINGS(1)

		VALUE	UNIT
V_{CC}	V_{CC} relative to V_{SS}	–0.3 to 7	V
V_T	DC voltage applied on any pin, relative to V_{SS}	–0.3 to V_{CC}	V
T_{OPR}	Operating ambient temperature	–20 to 70	°C
T_{STG}	Storage temperature	–40 to 125	°C
T_{SOLDER}	Soldering temperature (10 s max.)	260	°C

(1) Permanent device damage may occur if Absolute Maximum Ratings are exceeded. Functional operation should be limited to the Recommended DC Operating Conditions detailed in this data sheet. Exposure to conditions beyond the operational limits for extended periods of t36.19 0 Td (t Td (thctional ET BT 594 Td (periods)Tj 28.63 0 Td (ET BT ve)Tj 20 65Tj 41.ieriocET BT /F2 8 Tf 100 Tz 0 0 0 rg 72 594 Td (peri

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			–evice	

Initiation and Charge Qualification

The bq2000 initiates a charge cycle when it detects

- Application of power to V_{CC}
- Battery replacement
- Exit from sleep mode
- Capacity depletion (Li-Ion only)

Immediately following initiation, the IC enters a charge-qualification mode. The bq2000 charge qualification is based on battery voltage and temperature. If the voltage on the BAT pin is less than the internal threshold, V_{LBAT}, the bq2000 enters the battery conditioning state. This condition indicates the possibility of a defective or shorted battery pack. In an attempt to revive a fully depleted pack, the bq2000 enables the MOD pin to trickle-charge at a rate of once every 1.0s. As explained in the section "Top-Off and Pulse-Trickle Maintenance Charge," the trickle pulse-width is user-selectable and is set by the value of the resistance connected between the RC pin and V_{SS}.

During charge qualification, the $\overline{\text{LED}}$ pin blinks at a 1Hz rate, indicating the pending status of the charger.

Once battery conditioning (trickle charge) has raised the voltage on the BAT pin above V_{LBAT}, the IC enters fast charge, if the battery temperature is within the V_{LTF} to V_{HTF} range. The BQ2000 will stay in the battery conditioning state indefinitely and will not progress to fast charge until the voltage on the BAT pin is above V_{LBAT} and the temperature is within the V_{LTF} and V_{HTF} range. No timer is implemented during battery conditioning.

Battery Chemistry

The bq2000 detects the battery chemistry by monitoring the battery-voltage profile during the initial stage of the fast charge. If the voltage on the BAT pin rises to the internal V_{MCV} reference, the IC assumes a Li-Ion battery. Otherwise, the bq2000 assumes a NiCd/NiMH chemistry. While in the fast charge state, the $\overline{\text{LED}}$ pin is pulled low (the $\overline{\text{LED}}$ is on).

As shown in Figure 3, a resistor voltage-divider between the battery pack's positive terminal and V_{SS} scales the battery voltage. A low-pass filter then smooths out this voltage to present a clean signal to the BAT pin. In a mixed-chemistry design, a common voltage-divider is used as long as the maximum charge voltage of the nickel-based pack is below that of the Li-Ion pack. Otherwise, different scaling is required.

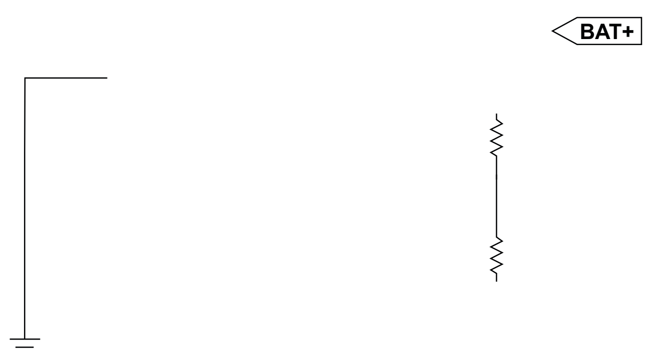

Figure 3. Battery Voltage Divider and Filter

Once the chemistry is determined, the bq2000 completes the fast charge with the appropriate charge algorithm (Table 1). The user can customize the algorithm by programming the device using an external resistor and a capacitor connected to the RC pin, as discussed in later sections.

NiCd and NiMH Batteries

Following charge qualification (which includes trickle charge, if required), the bq2000 fast-charges NiCd or NiMH batteries using a current-limited algorithm. During the fast-charge period, it monitors charge time, temperature, and voltage for adherence to the termination criteria. This monitoring is further explained in later sections. Following fast charge, the battery is topped off, if top-off is selected. The charging cycle ends with a trickle maintenance-charge that continues as long as the voltage on the BAT pin remains below V_{MCV}.

Lithium-Ion Batteries

The bq2000 uses a two-phase fast-charge algorithm for Li-Ion batteries (Figure 4). In phase one, the bq2000 regulates constant current until V_{BAT} rises to V_{MCV}. Once V_{BAT} = V_{MCV}, the device identifies the cell as a Li-ion, and changes the termination method from PVD to minimum current. The bq2000 then moves to phase two, regulates the battery with constant voltage of V_{MCV}, and terminates when the charging current falls below the I_{MIN} threshold or the timer expires (whichever happens first). A new charge cycle is started if the cell voltage falls below the V_{RCH} threshold.

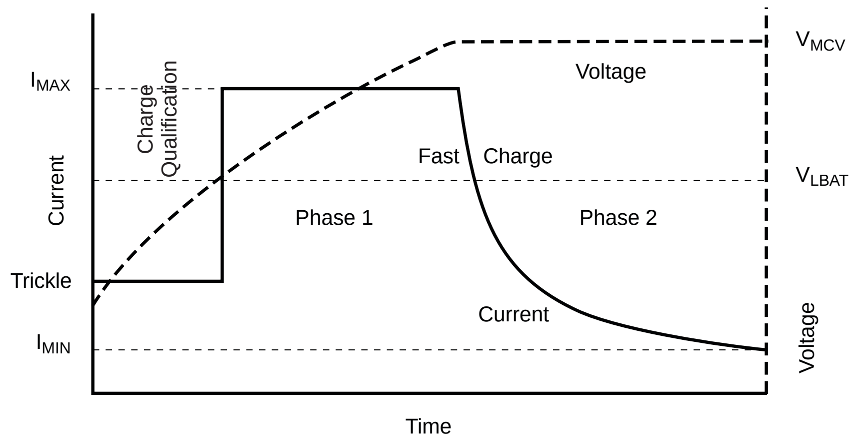

Figure 4. Lithium-Ion Charge Algorithm

During the current-regulation phase, the bq2000 monitors charge time, battery temperature, and battery voltage for adherence to the termination criteria. During the final constant-voltage stage, in addition to the charge time and temperature, it monitors the charge current as a termination criterion. There is no post-charge maintenance mode for Li-Ion batteries.

Table 1 summarizes the charging process for both Nickel and Li-Ion batteries.

Table 1. Charge Algorithm

BATTERY	

$$\text{hold-off period} = \frac{\text{MTO}}{32} \quad (1)$$

Maximum Charge Time (NiCD, NiMH, and Li-Ion)

The bq2000 sets the maximum charge-time through the RC pin. With the proper selection of external resistor and capacitor values, various time-out values may be achieved. If the timer expires while still in constant-current charging, the bq2000 assumes a Nickel chemistry and proceeds to top-off charge (if top-off is enabled) or trickle maintenance charge. Figure 5 shows a typical connection.

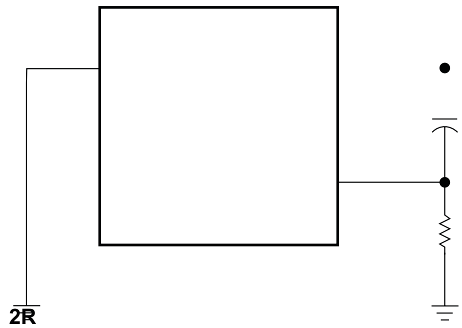

Figure 5. Typical Connection for the RC Input

The following equation shows the relationship between the R_{MTO} and C_{MTO} values and the maximum charge time (MTO) for the bq2000:

$$MTO = R_{MTO} \times C_{MTO} \times 35{,}988 \quad (2)$$

MTO is measured in minutes, R_{MTO} in ohms, and C_{MTO} in farads. (**Note:** R_{MTO} and C_{MTO} values also determine other features of the device. See Table 4 and Table 5 for details.

If, during fast charge, $V_{TS} > V_{LTF}$, then the timer is paused and the IC enters battery conditioning charge until $V_{TS} < V_{LTF}$. Since the IC is in the battery conditioning state, the $\overline{\text{LED}}$ flashes at the 1 Hz rate. Once $V_{TS} < V_{LTF}$, fast charge restarts and the timer resumes from where it left off with no change in total fast charge time.

For Li-Ion cells, when the battery reaches the constant-voltage phase of fast charge, the bq2000 adds an additional MTO of tirleft 0 24 0tTd(meTj 41.34 0 Td (fro0 rg Td (left)Tj)Tj 19. /Fvom)Tj 40 0 0 rg 54 3364 0 Td (fro0 rg was 35.

pin, additional MTO

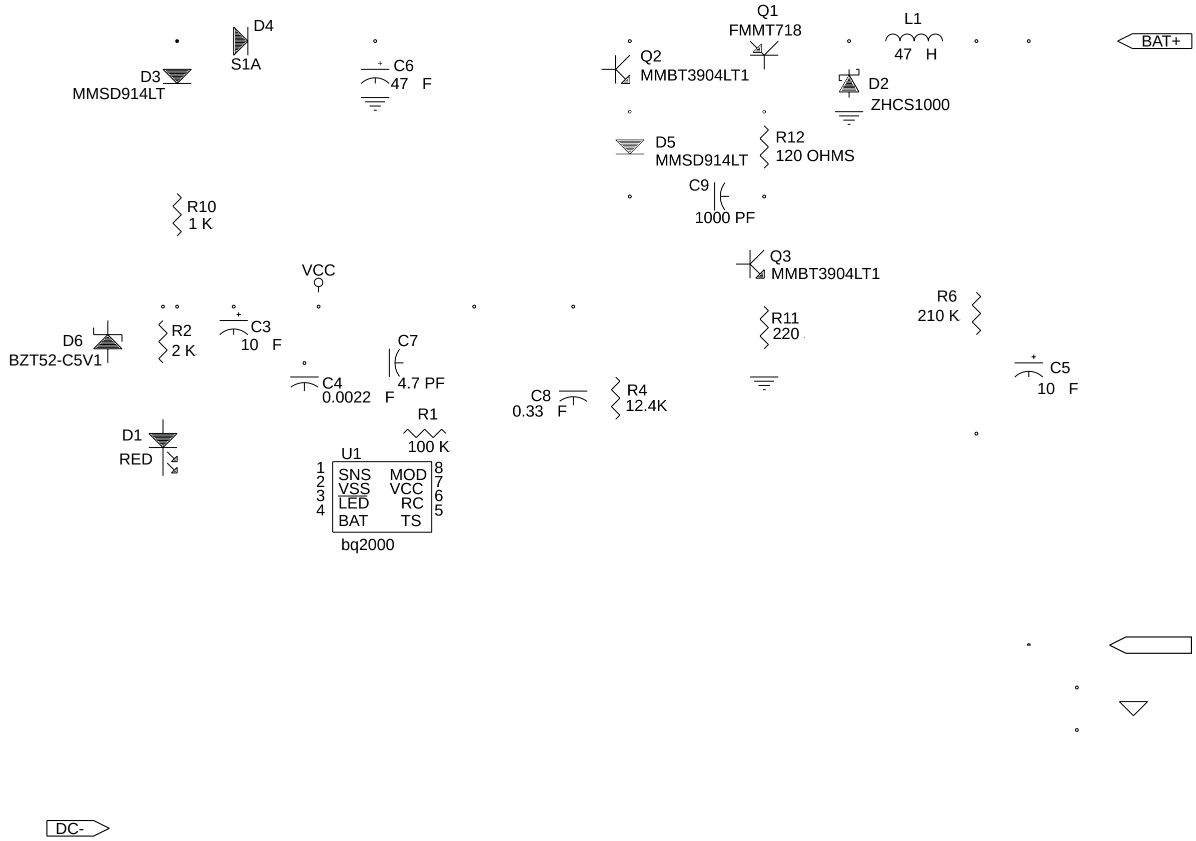

Figure 7. Single-Cell Li-Ion, 3-Cell NiCd/NiMH 1A Charger

Minimum Current (Li-Ion Only)

The bq2000 monitors the charging current during the voltage-regulation phase of Li-Ion batteries. Fast charge is terminated when the current is tapered off to 14% of the maximum charging current.

Once constant-current fast charge has ended, the bq2000 either measures the value of the C_{MTO} capacitor (in the case of Nickel batteries) and then proceeds to either top-off or trickle maintenance charge or simply completes the constant-voltage stage of fast charge (in the case of a Li-Ion cell).

Top-Off and Pulse-Trickle Maintenance Charge

An optional top-off charge is available for NiCd or NiMH batteries. Top-off may be desirable on batteries that have a tendency to terminate charge before reaching full capacity. To enable this option, the capacitance value of C_{MTO} connected between the RC pin and V_{CC} (Figure 5) should be greater than 0.13µF, and the value of the resistor connected to this pin should be less than 250kΩ. To disable top-off, the capacitance value should be less than 0.07µF. The tolerance of the capacitor needs to be taken into account in component selection.

Once top-off is started, the timer is reset and top-off proceeds until the timer expires, V_{MCV} is reached, or there is a temperature fault. During top-off, current is delivered to the battery in pulses that occur each second. The fixed pulse width allows an average current of 1/16 of the fast charge current to be delivered to the battery every second. The LED is always off during top-off and trickle maintenance charge.

During top-off, there are three different temperature faults that can occur. If $V_{TS} > V_{LTF}$, top-off is suspended, the timer is paused, and trickle charge is started. When V_{TS} falls below V_{LTF}, top-off is resumed. If $V_{TS} < V_{HTF}$, all charging stops, but the timer keeps counting. When $V_{TS} > V_{HTF}$, top-off is resumed, if there is still time remaining on the timer. If there is not time left, trickle maintenance charge is entered. If $V_{TS} < V_{TCO}$, all charging stops. Only trickle maintenance charge may resume after $V_{TS} > V_{HTF}$.

Following top-off, the bq2000 trickle-charges the battery by enabling the MOD pin to charge at a rate of once every 1.0 second. The trickle pulse-width is user-selectable and is set by the value of the resistor R_{MTO}, connected between the RC pin and V_{SS}. Figure 8 shows the relationship between the trickle pulse-width and the value of R_{MTO}. The typical tolerance of the pulsewidth below 150kΩ is ±10%.

Figure 8. Relationship Between Trickle Pulse-Width and Value of R_{MTO}

Note that with an R_{MTO} value around 150 kΩ, the trickle charge pulse width is nearly identical to the top-off pulse width of 62.5 ms (1/16 of a second). With R_{MTO} values near 150 kΩ, it can be difficult to tell which state the IC is in (top-off or trickle charge). The best way to tell if the bq2000 is in top-off or trickle charge is to look at the RC pin when the temperature is between the LTF and HTF. In top-off, the RC pin will be counting and will have a sawtooth waveform on it. In trickle charge, there is no timer and the RC pin will be at a DC value.

The RC pin contains valuable information in determining what state the bq2000 is in, since it always operates in one of three modes. If the RC pin is low (around V_{SS} potential), the IC is in sleep mode. (If the RC pin is low for brief instants during fast charge, the bq2000 is sampling the BAT pin for PVD). If the RC pin is at some DC value (usually around 1-2V), then the IC has paused the timer or the timer is inactive. If the RC pin is a sawtooth waveform (similar to Figure 15), then the timer is running and the RC pin is considered “active.” Lastly, the RC pin can be loaded by too large of a C or too small of an R. This will sometimes make the usual sawtooth waveform look like a triangle waveform on an oscilloscope (the rise time is lengthened), or the RC signal could have the appearance of being clipped (flat top or bottom). The timer [the ±appeara 4 the sampling] [trickle]

$$I_{MAX} = \frac{0.05}{R_{SNS}}$$

$$\text{Hysteresis (V)} = V_{CC} \times \frac{C_{HYS}}{(C_{HYS} + C_f)}$$

voltage and/or inductor value or decreasing C_{HYS} and/or the $R_f \times C_f$ filter corner frequency will increase the switching frequency. Figure 10 and Figure 11 show empirical data on the variation in switching frequency based on adjusting R_f and C_f. This data was taken with an input voltage of 12V, inductor value of 220 µH, R_{SNS} value of 50 mΩ, and C_{HYS} value of 4.7 pF. Typical switching frequencies for the bq2000 are between 100 and 200 kHz, though it is possible to achieve switching frequencies in excess of 300kHz.

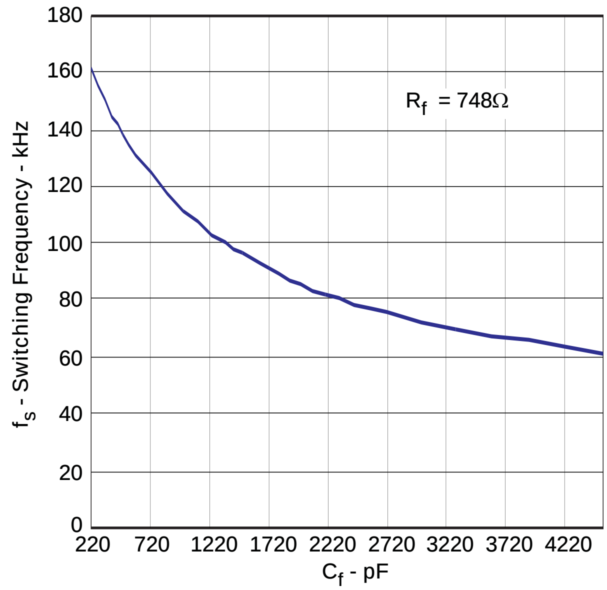

Figure 10. Switching Frequency vs Capacitance

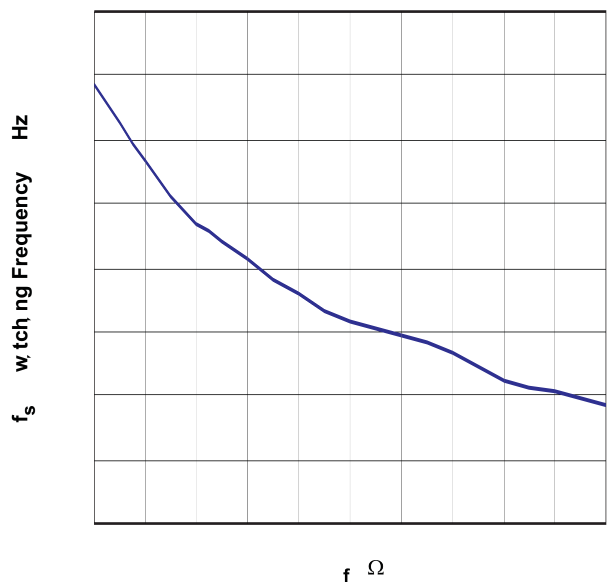

Figure 11. Switching Frequency vs Resistance

TEMPERATURE MONITORING

The bq2000 measures the temperature by the voltage at the TS pin. This voltage is typically generated by a negative-temperature-coefficient thermistor. The bq2000 compares this voltage against its internal threshold voltages to determine if charging is safe. These thresholds are the following:

- High-temperature cutoff voltage: $V_{TCO} = 0.225 \times V_{CC}$ 8 0 d (The

Table 5. Summary of Li-Ion Charging Characteristics

PARAMETER	VALUE[1]
Maximum cell voltage (V_{MCV})	2 V
Minimum pre-charge qualification voltage (V_{LBAT})	950 mV
High-temperature cutoff voltage (V_{TCO})	$0.225 \times V_{CC}$
High-temperature fault voltage (V_{HTF})	$0.25 \times V_{CC}$
Low-temperature	

TYPICAL CHARACTERISTICS

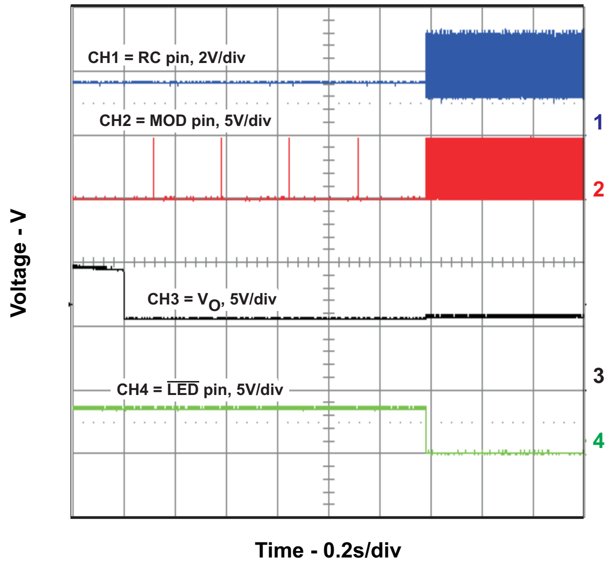

Figure 12. bq2000 Start-up on Battery Insertion

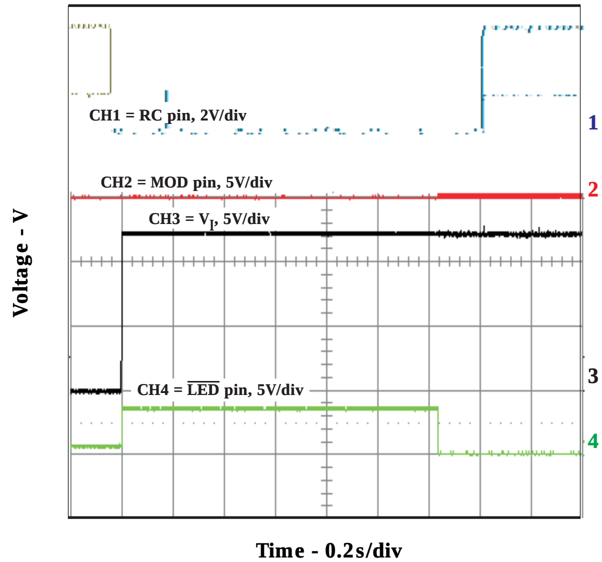

Figure 13. bq2000 Start-up on Vin

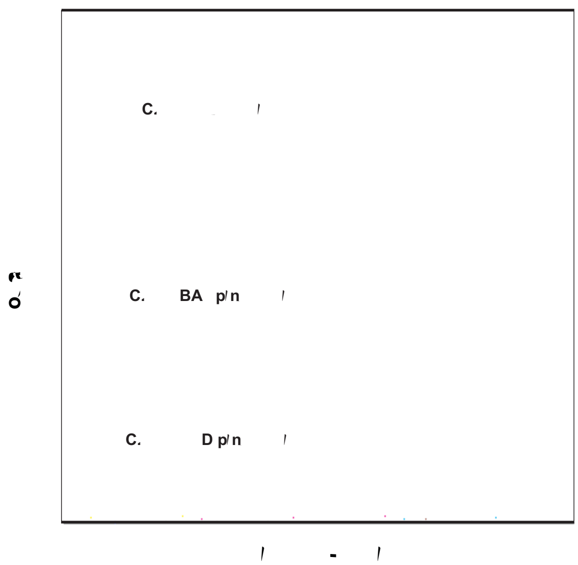

Figure 14. Battery Removal During Fast Charge

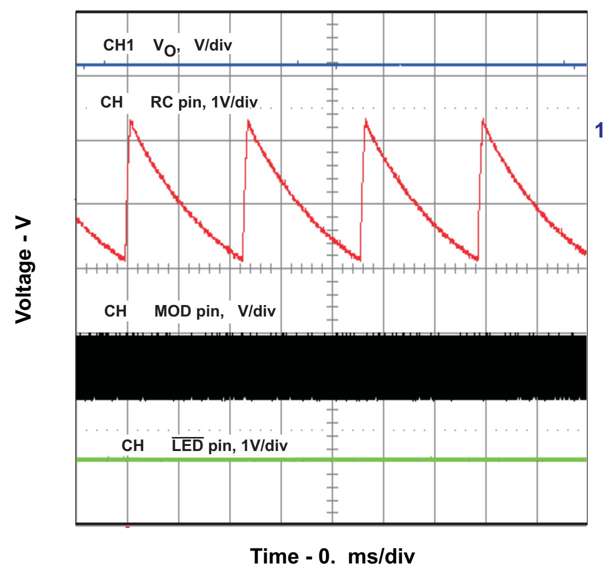

Figure 15. bq2000 in Fast Charge

TYPICAL CHARACTERISTICS (continued)

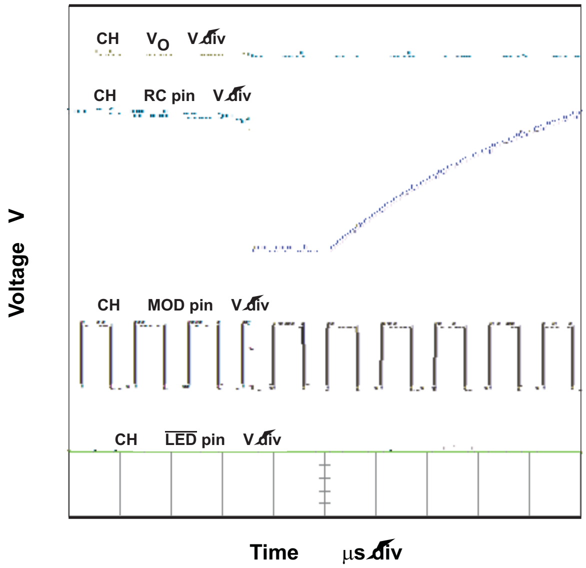

Figure 16. bq2000 in Fast Charge

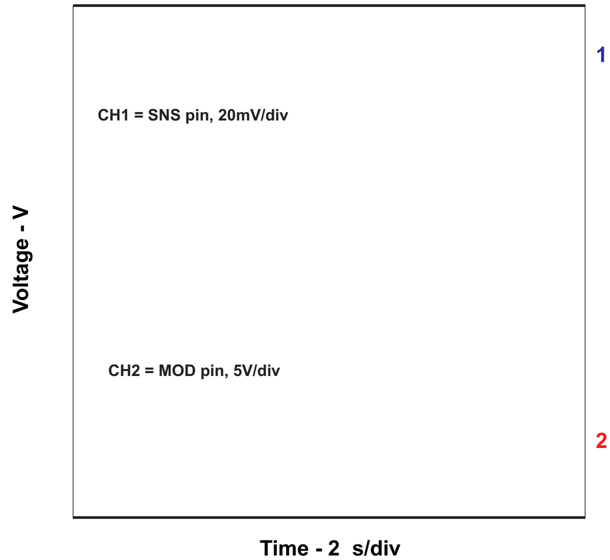

Figure 17. bq2000 Fast Charge SNS and MOD Waveforms

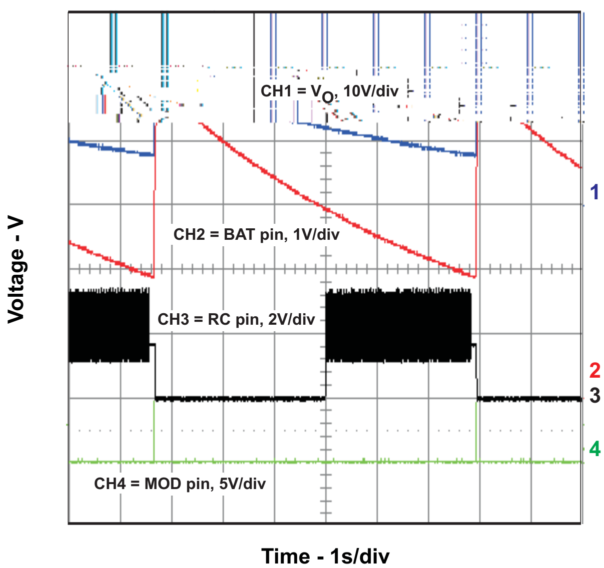

Figure 18. bq2000 in Sleep Mode

REVISION HISTORY

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/ Ball Finish	MSL Peak Temp (3)	Samples (Requires Login)
BQ2000PN-B5	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type	Request Free Samples
BQ2000PW	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	Request Free Samples
BQ2000PWG4	ACTIVE	TSSOP	PW	8	150	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	Request Free Samples
BQ2000PWR	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	Purchase Samples
BQ2000PWRG4	ACTIVE	TSSOP	PW	8	2000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR	Purchase Samples
BQ2000SN-B5	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	Request Free Samples
BQ2000SN-B5G4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	Request Free Samples
BQ2000SN-B5TR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	Purchase Samples
BQ2000SN-B5TRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-1-260C-UNLIM	Purchase Samples

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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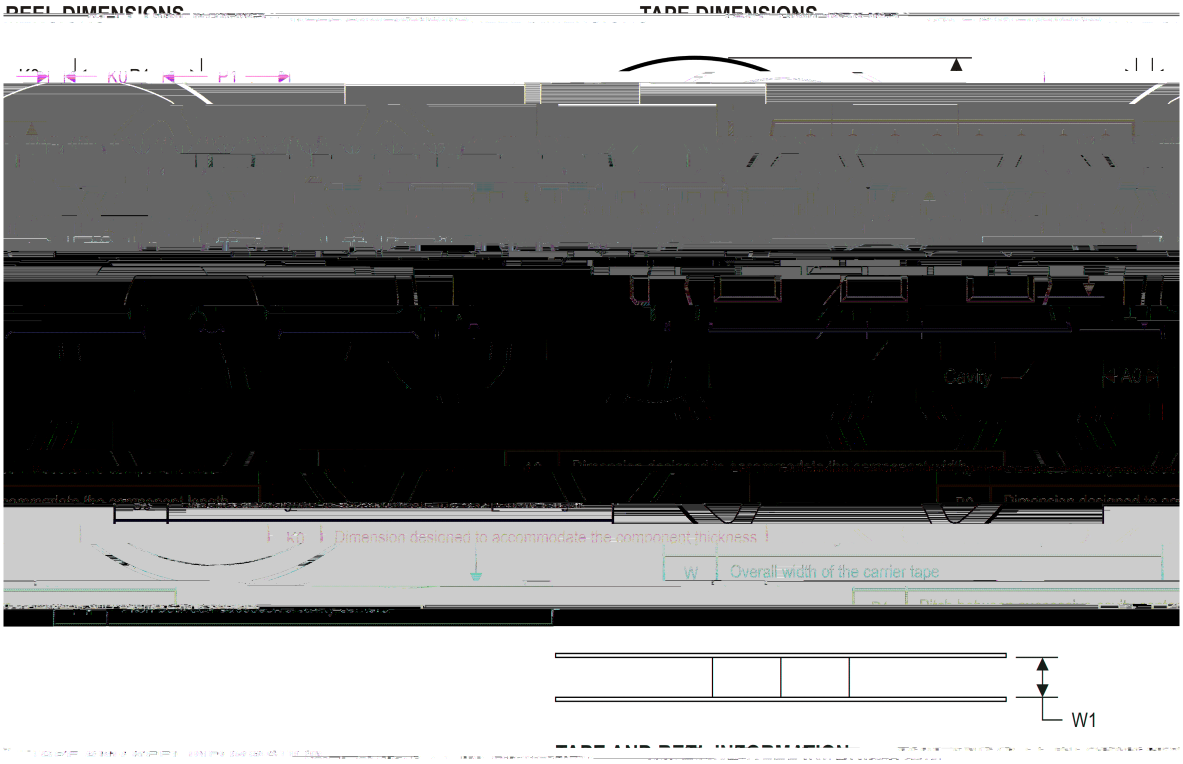
TAPE AND REEL INFORMATION



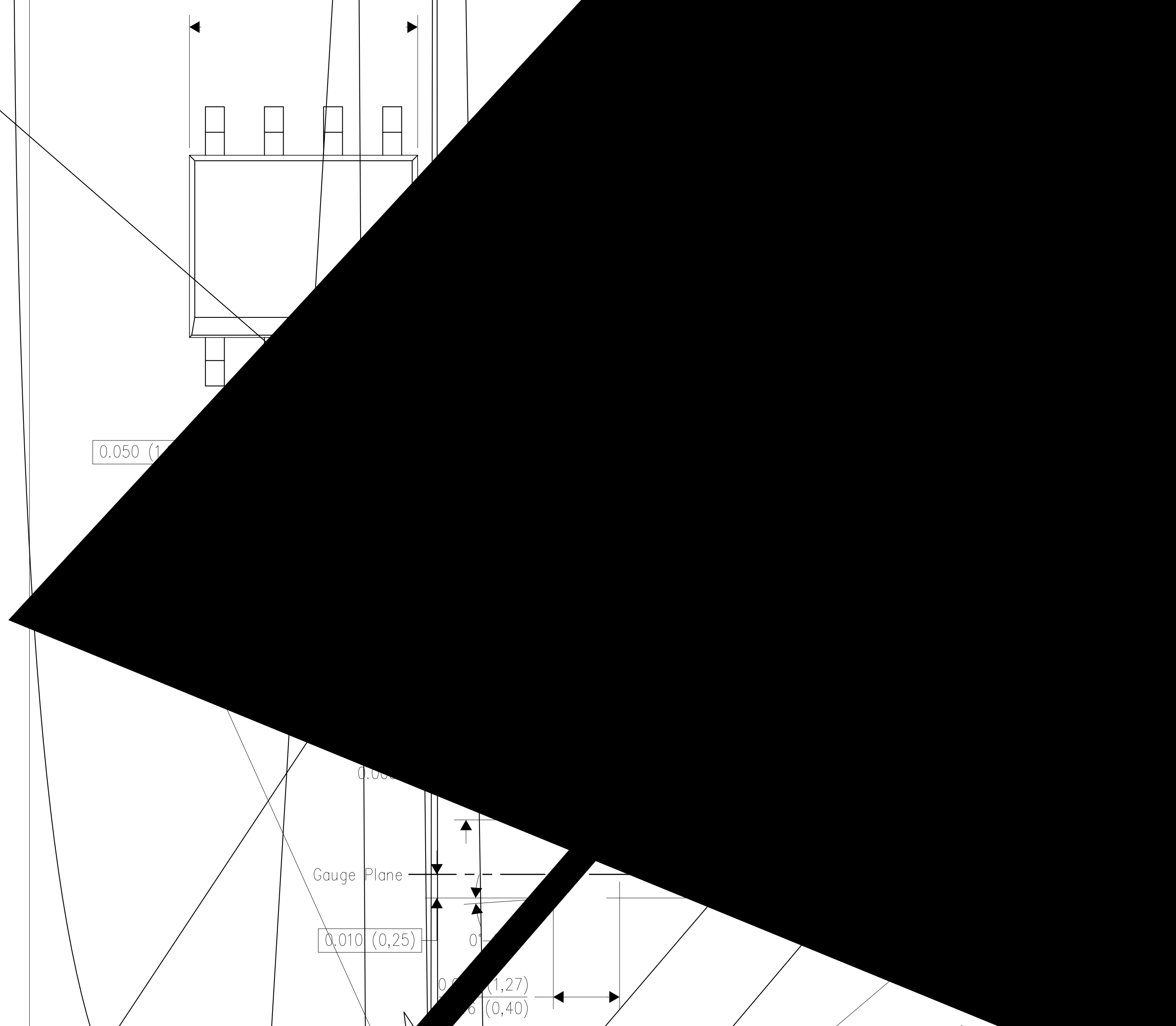
*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
BQ2000PWR	TSSOP	PW	8	2000	330.0	12.4	7.0	3.6	1.6	8.0	12.0	Q1
BQ2000SN-B5TR	SOIC	D	8	2500	330.0	12.4	6.4	5.2	2.1	8.0	12.0	Q1

TAPE AND REEL BOX DIMENSIONS

*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
BQ2000PWR	TSSOP	PW	8	2000	367.0	367.0	35.0
BQ2000SN-B5TR	SOIC	D	8	2500	367.0	367.0	35.0



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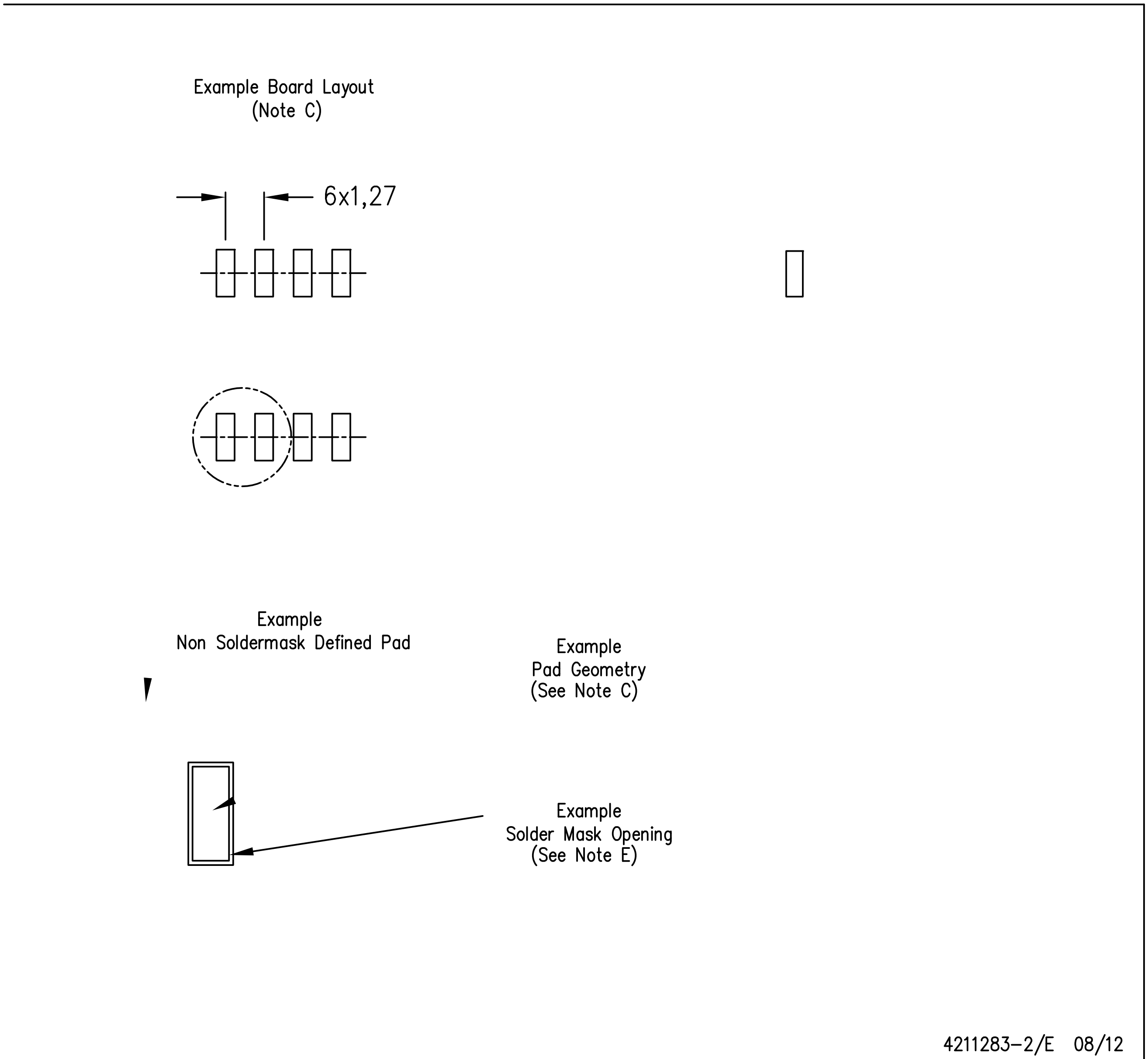

D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers shoul l contact their board assembly site for stencil design recommendations. Refer to IPC-7525 for other stencil recommendations.

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A. All linear dimensions

D. Body width does not include inte... exceed 0,25 each side.

IMPORTANT NOTICE

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