Benchmarq Products
from Texas Instruments

bq24400

Programmable NiCd/NiMH Fast-Charge Management Device

Features

- Safe management of fast charge for NiCd and NiMH 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 voltahge (PVD), 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 post-charge maintenance
- Built-in battery removal and insertion detection
- Sleep mode for low power consumption

General Description

The bq24400 is a programmable, monolithic IC for fast-charge management of nickel cadmium (NiCd) and nickel metal-hydride (NiMH) batteries.

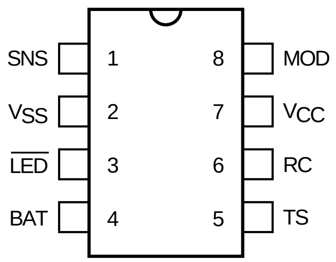
The bq24400 provides a number of charge termination criteria:

- Peak voltage, PVD (for NiCd and NiMH)
- Maximum temperature
- Maximum charge time

For safety, the bq24400 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 bq24400 uses trickle-charge to condition the battery. For NiMH batteries, the bq24400 provides an optional top-off charge to maximize the battery capacity.

The integrated high-frequency comparator allows the bq24400 to be the basis for a complete, high-efficiency power-conversion circuit.

Pin Connections



8-Pin DIP or Narrow SOIC or TSSOP

PN-2000.eps

Pin Names

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

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Pin Descriptions

SNS **Current-sense input**

Enables the bq24400 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**

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

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

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**

RC input used to program the maximum charge-time, hold-off period, and trickle rate during the charge cycle, and to disable or enable top-off charge.

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

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 bq24400 is a versatile, NiCd, NiMH battery- charge control device. See Figure 1 for a functional block diagram and Figure 2 for the state diagram.

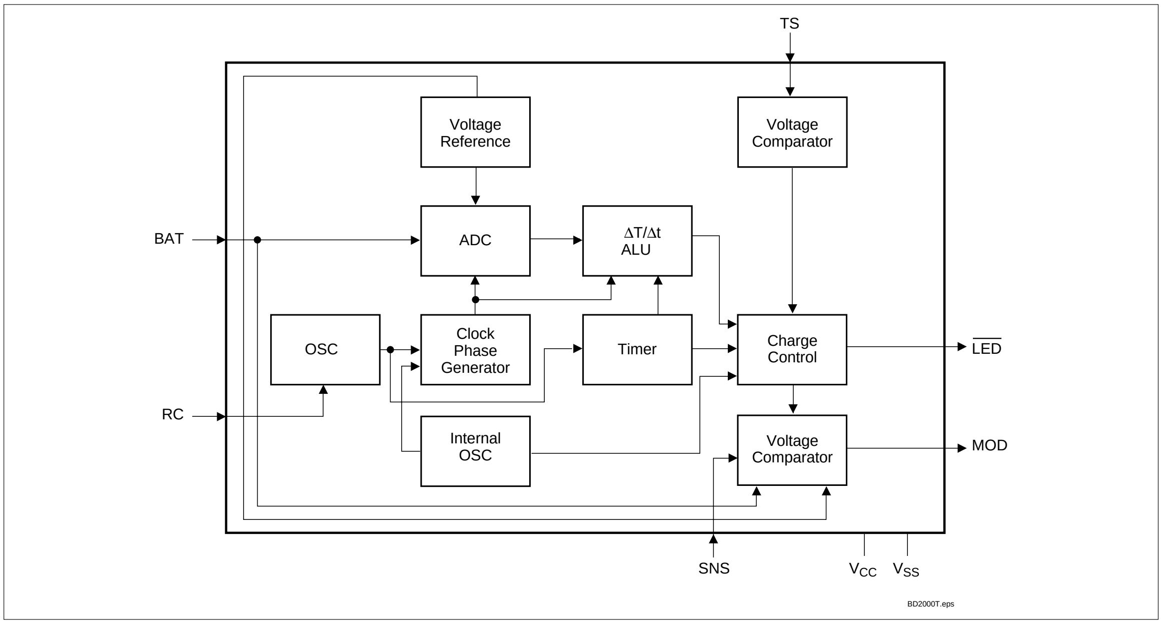

Figure 1. Functional Block Diagram

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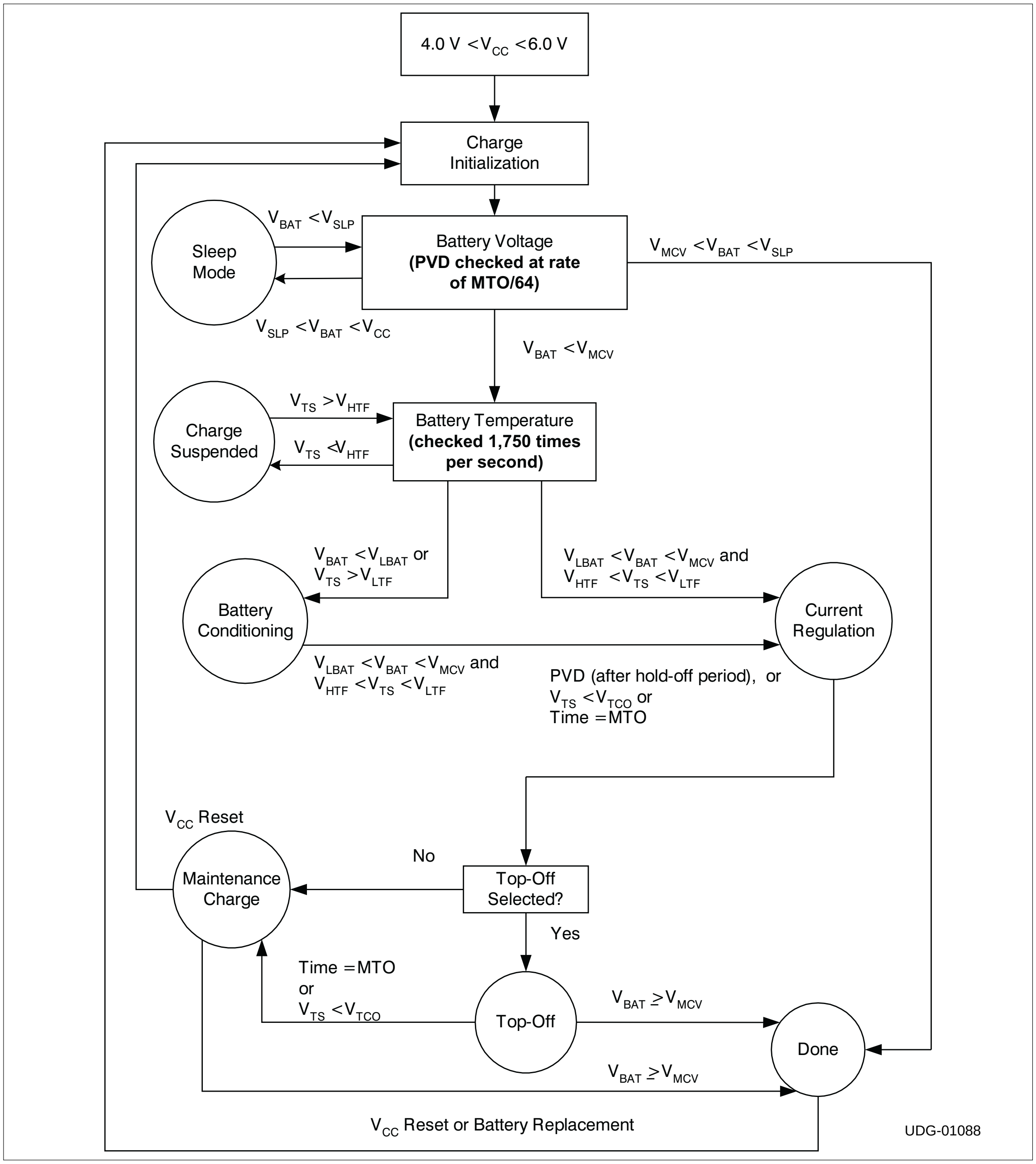

Figure 2. State Diagram

Initiation and Charge Qualification

The bq24400 initiates a charge cycle when it detects

- Application of power to V_{CC}
- Battery replacement
- Exit from sleep mode

Immediately following initiation, the IC enters a charge-qualification mode. The bq24400 charge qualification is based on battery voltage and temperature. If voltage on pin BAT is less than the internal threshold, V_{LBAT}, the bq24400 enters the charge-pending state. This condition indicates the possiblility of a defective or shorted battery pack. In an attempt to revive a fully depleted pack, the bq24400 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 Charge," the trickle pulse-width is user-selectable and is set by the value of the resistance connected to pin RC.

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

Similarly, the bq24400 suspends fast charge if the battery temperature is outside the V_{LTF} to V_{HTF} range. (See Table 4.) For safety reasons, however, it disables the pulse trickle, in the case of a battery over-temperature condition (i.e., $V_{TS} < V_{HTF}$). Fast charge begins when the battery temperature and voltage are valid.

NiCd and NiMH Batteries

Following qualification, the bq24400 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 pin BAT remains below V_{MCV}.

Charge Termination

Maximum Charge Time

The bq24400 sets the maximum charge-time through pin RC. With the proper selection of external resistor and capacitor, various time-out values may be achieved. Figure 3 shows a typical connection.

The following equation shows the relationship between the R_{MTO} and C_{MTO} values and the maximum charge time (MTO) for the bq24400:

$$MTO = R_{MTO} * C_{MTO} * 35{,}988$$

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 Tables 2 and 3 for details.)

Maximum Temperature

A negative-coefficient thermistor, referenced to V_{SS} and placed in thermal contact with the battery, may be used as a temperature-sensing device. Figure 4 shows a typical temperature-sensing circuit.

During fast charge, the bq24400 compares the battery temperature to an internal high-temperature cutoff threshold, V_{TCO}. As shown in Table 4, high-temperature termination occurs when voltage at pin TS is less than this threshold.

Peak Voltage

The bq24400 uses a peak-voltage detection (PVD) scheme to terminate fast charge for NiCd and NiMH batteries. The bq24400 continuously samples the voltage on the BAT pin, representing the battery voltage, and triggers the peak detection feature if this value falls below the maximum sampled value by as much as 3.8 mV (PVD). As shown in figure 5, a resistor voltage-divider between the battery pack's positive terminal and V_{SS} scales the battery voltage measured at pin BAT.

The resistor values R_{B1} And R_{B2} are calculated by the following equation:

Table 1. Charge Algorithm

Battery Chemistry	Charge Algorithm
NiCd or NiMH	1. Charge qualification 2. Trickle charge, if required 3. Fast charge (constant current) 4. Charge termination ($\Delta T/\Delta t$, time) 5. Top-off (optional) 6. Trickle charge

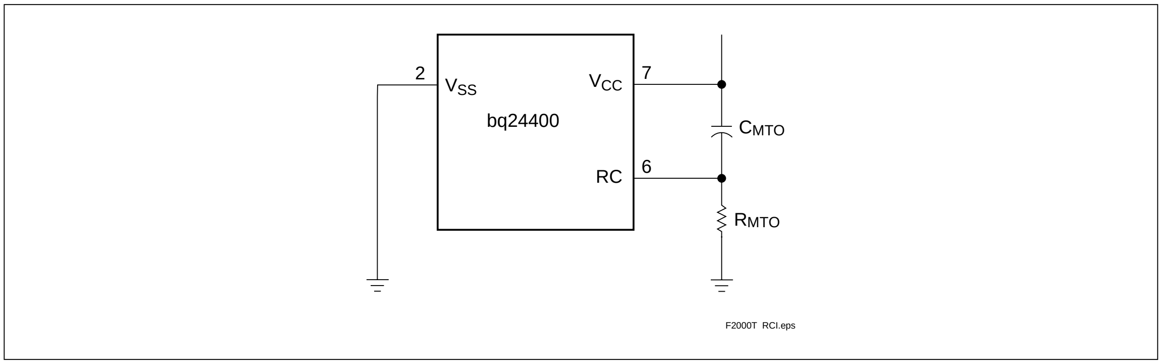

Figure 3. Typical Connection for the RC Input

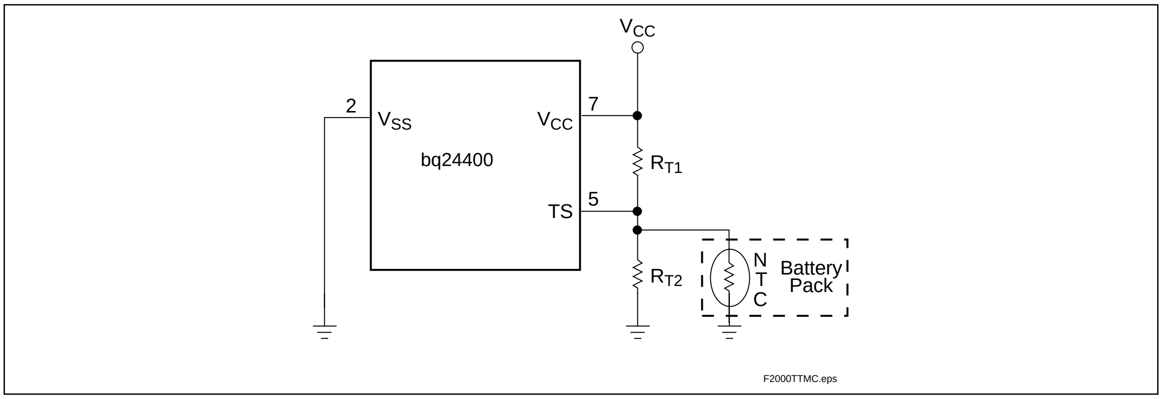

Figure 4. Temperature Monitoring Configuration

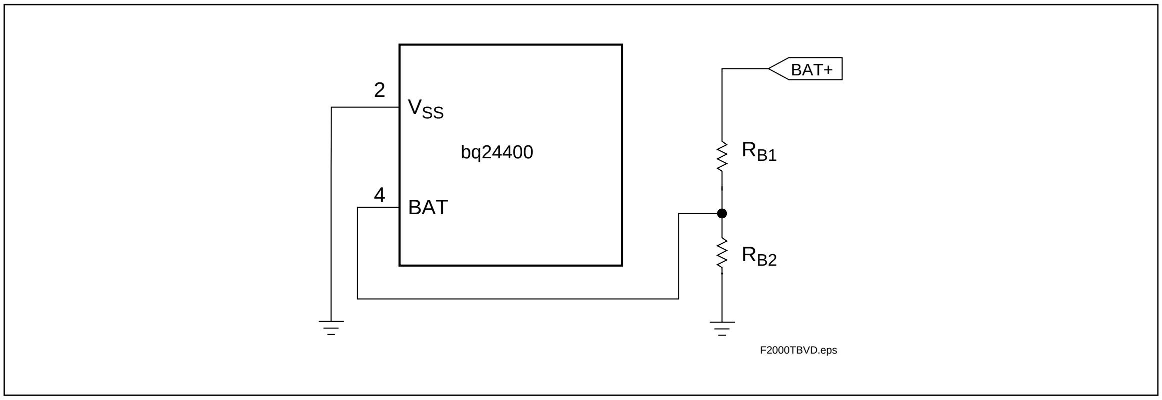

Figure 5. Battery Voltage Divider

Table 2. Summary of NiCd or NiMH Charging Characteristics

Parameter	Value
Maximum cell voltage (V_{MCV})	2V
Minimum pre-charge qualification voltage (V_{LBAT})	950mV
High-temperature cutoff voltage (V_{TCO})	$0.225 * V_{CC}$
High-temperature fault voltage (V_{HTF})	$0.25 * V_{CC}$
Low-temperature fault voltage (V_{LTF})	$0.5 * V_{CC}$
bq24400 fast-charge maximum time out (MTO)	$R_{MTO} * C_{MTO} * 35,988$
Fast-charge charging current (I_{MAX})	$0.05/R_{SNS}$
Hold-off period	MTO/32
Top-off charging current (optional)	$I_{MAX}/16$
Top-off period (optional)	MTO
Trickle-charge frequency	1Hz

Table 3. Temperature-Monitoring Conditions

Temperature	Condition	Action
$V_{TS} > V_{LTF}$	Cold battery—checked at all times	Suspends fast charge or top-off and timer Allows trickle charge—LED flashes at 1Hz rate during pre-charge qualification and fast charge
$V_{HTF} < V_{TS} < V_{LTF}$	Optimal operating range	Allows charging
$V_{TS} < V_{HTF}$	Hot battery—checked during charge qualification and top-off and trickle-charge	Suspends fast-charge initiation, does not allow trickle charge—LED flashes at 1Hz rate during pre-charge qualification
$V_{TS} < V_{TCO}$	Battery exceeding maximum allowable temperature—checked at all times	Terminates fast charge or top-off

$$\frac{R_{B1}}{R_{B2}} = N - 1$$

where N is the number of cells in series.

The end-to-end input impedance of this resistive divider network should be at least 200kΩ and no more than 1MΩ.

Initial Hold-Off Period

The values of the external resistor and capacitor connected to pin RC set the initial hold-off period. During this period, the bq24400 avoids early termination by disabling the ΔT/Δt feature. This period is fixed at the programmed value of the maximum charge time divided by 32.

$$\text{hold-off period} = \frac{\text{maximum time - out}}{32}$$

Table 4. Charge Status Display

Charge Action State	$\overline{\text{LED}}$ Status
Battery absent	High impedance
Pre-charge qualification	1Hz flash
Trickle charge (before fast charge)	1Hz flash
Fast charging	Low
Top-off or trickle	High impedance
Charge complete	High impedance
Sleep mode	High impedance
Charge suspended ($V_{TS} > V_{LTF}$)	1Hz flash

Top-Off and Pulse-Trickle Charge

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 to pin RC (Figure 3) should be greater than 0.13µF, and the value of the resistor connected to this pin should be less than 15kΩ. 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 enabled, the top-off is performed over a period equal to the maximum charge time at a rate of $1/16$ that of fast charge.

Following top-off, the bq24400 trickle-charges the battery by enabling the MOD 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}, which is on pin RC. Figure 6 shows the relationship between the trickle pulse-width and the value of R_{MTO}. The typical tolerance of the pulsewidth below 150kΩ is ±10%.

During top-off and trickle-charge, the bq24400 monitors battery voltage and temperature. These functions are suspended if the battery voltage rises above the maximum cell voltage (V_{MCV}) or if the temperature exceeds the high-temperature fault threshold (V_{HTF}).

Charge Current Control

The bq24400 controls the charge current through the MOD output pin. The current-control circuit supports a switching-current regulator with frequencies up to 500kHz. The bq24400 monitors charge current at the SNS input by the voltage drop across a sense-resistor, R_{SNS}, in series with the battery pack. See Figure 8 for a typical current-sensing circuit. R_{SNS} is sized to provide the desired fast-charge current (I_{MAX}):

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

If the voltage at the SNS pin is greater than V_{SNSLO} or less than V_{SNSHI}, the bq24400 switches the MOD output high to pass charge current to the battery. When the SNS voltage is less than V_{SNSLO} or greater than V_{SNSHI}, the bq24400 switches the MOD output low to shut off charging current to the battery. Figure 7 shows a typical multi-chemistry charge circuit.

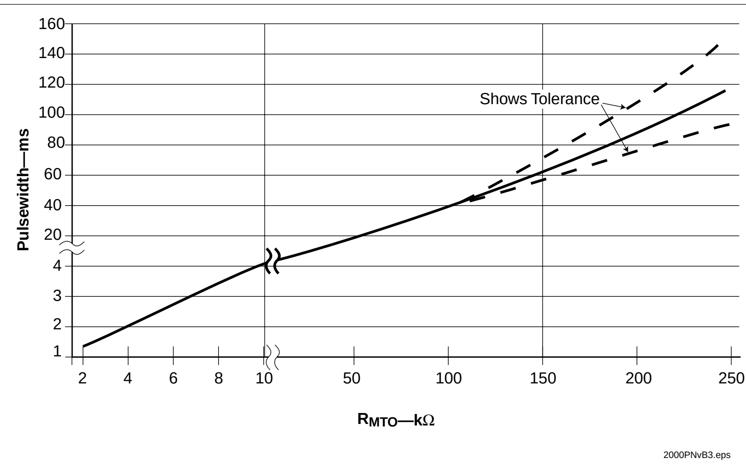

Figure 6. Relationship Between Trickle Pulse-Width and Value of R_{MTO}

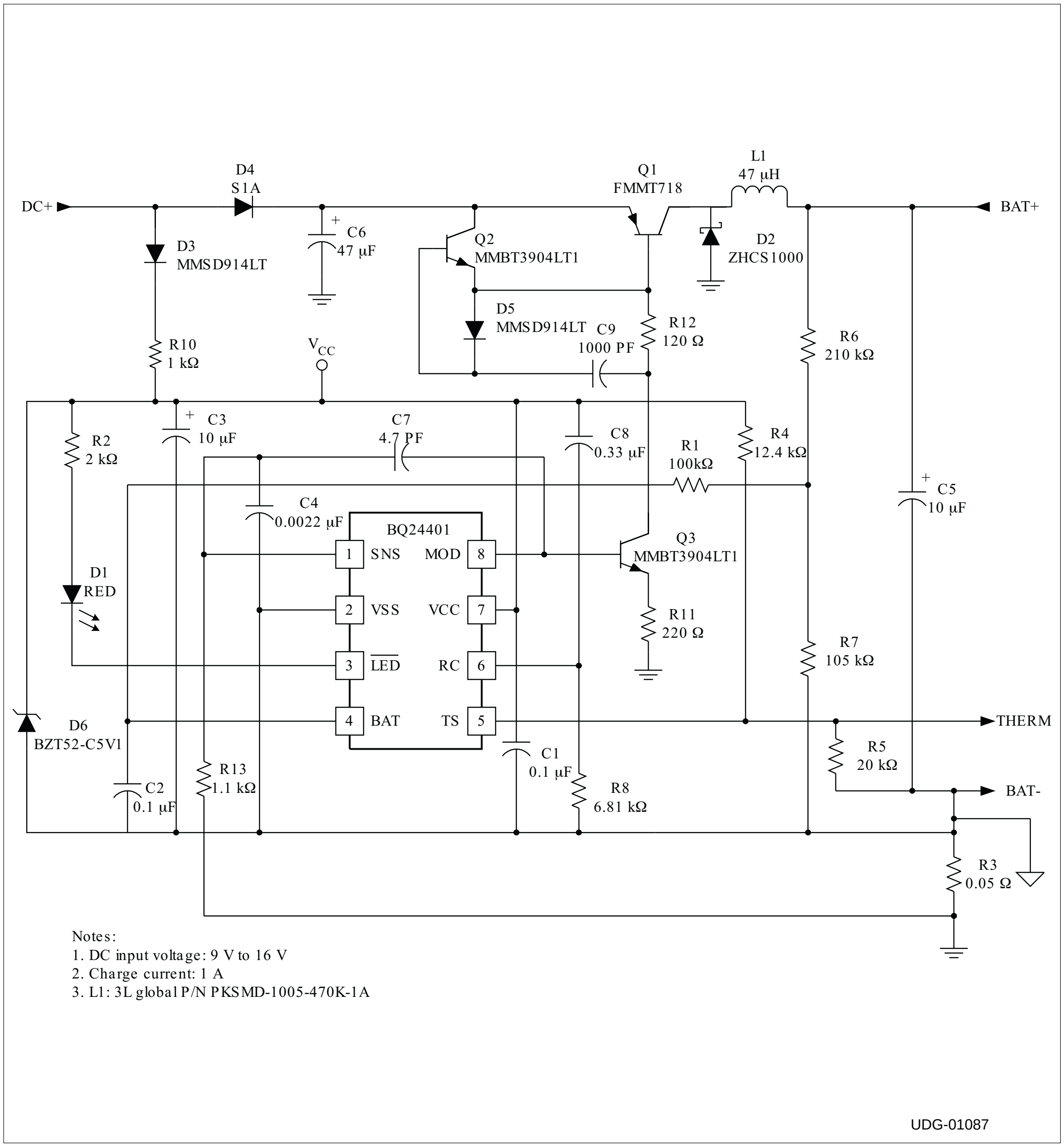

Figure 7. Three-Cell NiCd/NiMH 1A Charger

Temperature Monitoring

The bq24400 measures the temperature by the voltage at the TS pin. This voltage is typically generated by a negative-temperature-coefficient thermistor. The bq24400 compares this voltage against its internal threshold voltages to determine if charging is safe. These thresholds are the following:

- High-temperature cutoff voltage: $V_{TCO} = 0.225 * V_{CC}$ This voltage corresponds to the maximum temperature (TCO) at which fast charging is allowed. The bq24400 terminates fast charge if the voltage on pin TS falls below V_{TCO}.
- High-temperature fault voltage: $V_{HTF} = 0.25 * V_{CC}$ This voltage corresponds to the temperature (HTF) at which fast charging is allowed to begin.
- Low-temperature fault voltage: $V_{LTF} = 0.5 * V_{CC}$ This voltage corresponds to the minimum temperature (LTF) at which fast charging or top-off is allowed. If the voltage on pin TS rises above V_{LTF}, the bq24400 suspends fast charge or top-off but does not terminate charge. When the voltage falls back below V_{LTF}, fast charge or top-off resumes from the point where suspended. Trickle-charge is allowed during this condition.

Table 3 summarizes these various conditions.

Charge Status Display

The charge status is indicated by open-drain output LED. Table 4 summarizes the display output of the bq24400.

Sleep Mode

The bq24400 features a sleep mode for low power consumption. This mode is enabled when the voltage at pin BAT is above the low-power-mode threshold, V_{SLP}. During sleep mode, the bq24400 shuts down all internal circuits, drives the LED output to high-impedance state, and drives pin MOD to low. Restoring BAT below the V_{MCV} threshold initiates the IC and starts a fast-charge cycle.

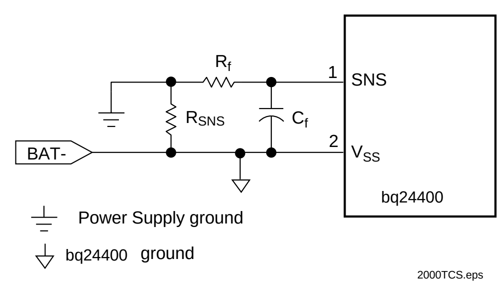

Figure 8. Current-Sensing Circuit

Absolute Maximum Ratings

Symbol	Parameter	Minimum	Maximum	Unit	Notes
V_{CC}	V_{CC} relative to V_{SS}	-0.3	+7.0	V	
V_T	DC voltage applied on any pin, excluding V_{CC} relative to V_{SS}	-0.3	+7.0	V	
T_{OPR}	Operating ambient temperature	-20	+70	°C	
T_{STG}	Storage temperature	-40	+125	°C	
T_{SOLDER}	Soldering temperature	-	+260	°C	10s max.

Note: 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 time may affect device reliability.

DC Thresholds ($T_A = T_{OPR}$; V_{CC} = 5V ±20% unless otherwise specified)

Symbol	Parameter	Rating	Tolerance	Unit	Notes
V_{TCO}	Temperature cutoff	0.225 * V_{CC}	±5%	V	Voltage at pin TS
V_{HTF}	High-temperature fault	0.25 * V_{CC}	±5%	V	Voltage at pin TS
V_{LTF}	Low-temperature fault	0.5 * V_{CC}	±5%	V	Voltage at pin TS
V_{MCV}	Maximum cell voltage	2.00	±2.5%	V	$V_{BAT} > V_{MCV}$ inhibits fast charge
V_{LBAT}	Minimum cell voltage	950	±5%	mV	Voltage at pin BAT
PVD	BAT input change for PVD detection	3.8	±20%	mV	
V_{SNSHI}	High threshold at SNS, resulting in MOD-low	50	±10	mV	Voltage at pin SNS
V_{SNSLO}	Low threshold at SNS, resulting in MOD-high	-50	±10	mV	Voltage at pin SNS
V_{SLP}	Sleep-mode input threshold	V_{CC} - 1	±0.5	V	Applied to pin BAT
V_{RCH}	Recharge threshold	V_{MCV} - 0.1	±0.02	V	At pin BAT

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Recommended DC Operating Conditions (T_A = T_{OPR})

Symbol	Condition	Minimum	Typical	Maximum	Unit	Notes
V_{CC}	Supply voltage	4.0	5.0	6.0	V	
I_{CC}	Supply current	-	0.5	1	mA	Exclusive of external loads
I_{CCS}	Sleep current	-	-	5	µA	$V_{BAT} = V_{SLP}$
V_{TS}	Thermistor input	0.5	-	V_{CC}	V	$V_{TS} < 0.5V$ prohibited
V_{OH}	Output high	V_{CC} - 0.2	-	-	V	MOD, I_{OH} = 20mA
V_{OL}	Output low	-	-	0.2	V	MOD, LED, I_{OL} = 20mA
I_{OZ}	High-impedance leakage current	-	-	5	µA	LED
I_{snk}	Sink current	-	-	20	mA	MOD, LED
R_{MTO}	Charge timer resistor	2	-	250	kΩ	
C_{MTO}	Charge timer capacitor	0.001	-	1.0	µF	

Note: All voltages relative to V_{SS} except as noted.

Impedance

Symbol	Parameter	Minimum	Typical	Maximum	Unit
R_{BAT}	Battery input impedance	10	-	-	MΩ
R_{TS}	TS input impedance	10	-	-	MΩ
R_{SNS}	SNS input impedance	10	-	-	MΩ

Timing (T_A = T_{OPR}; V_{CC} = 5V ±20% unless otherwise specified)

Symbol	Parameter	Minimum	Typical	Maximum	Unit
d_{MTO}	MTO time-base variation	-5	-	+5	%
f_{TRKL}	Pulse-trickle frequency	0.9	1.0	1.1	Hz

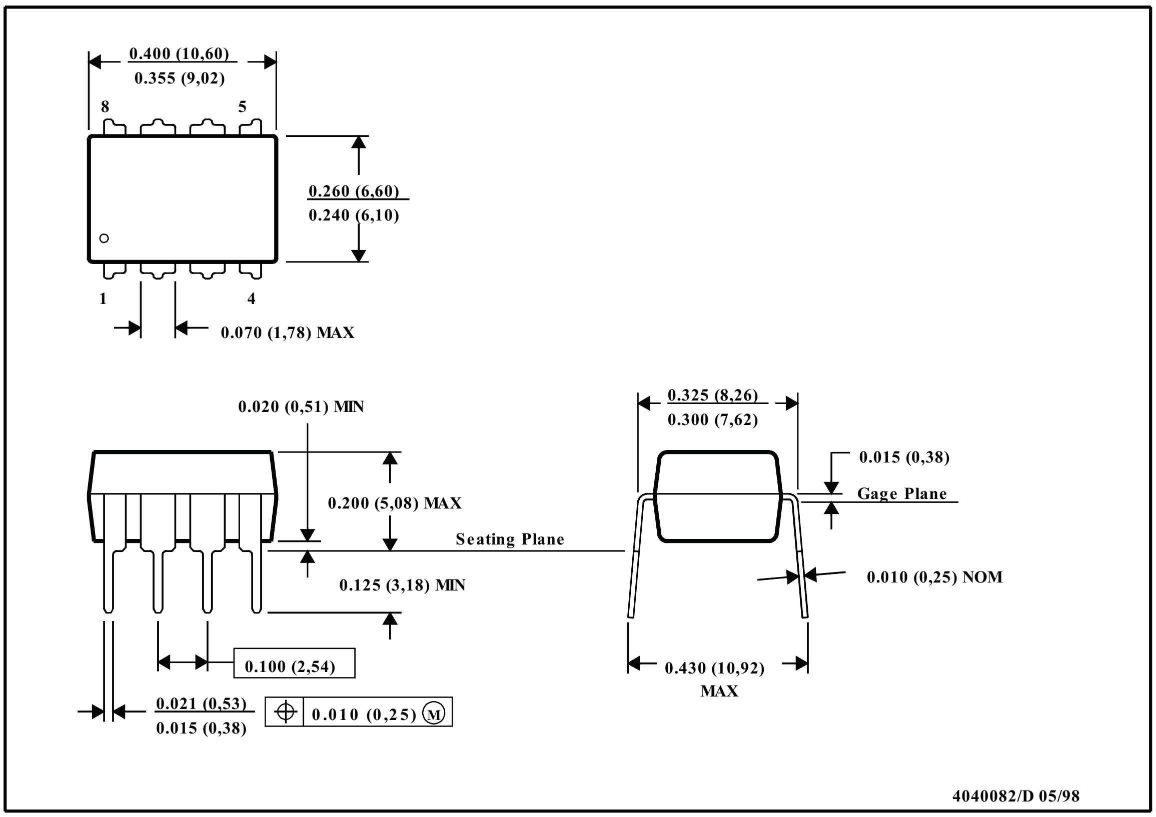
Ordering Information

bq24400 _

Package Option:
P = 8-pin narrow plastic DIP
D = 8-pin narrow SOIC
PW = 8-pin TSSOP

Device:
bq24400 NiCd/NiMH Fast-Charge IC with ΔT/Δt Detection

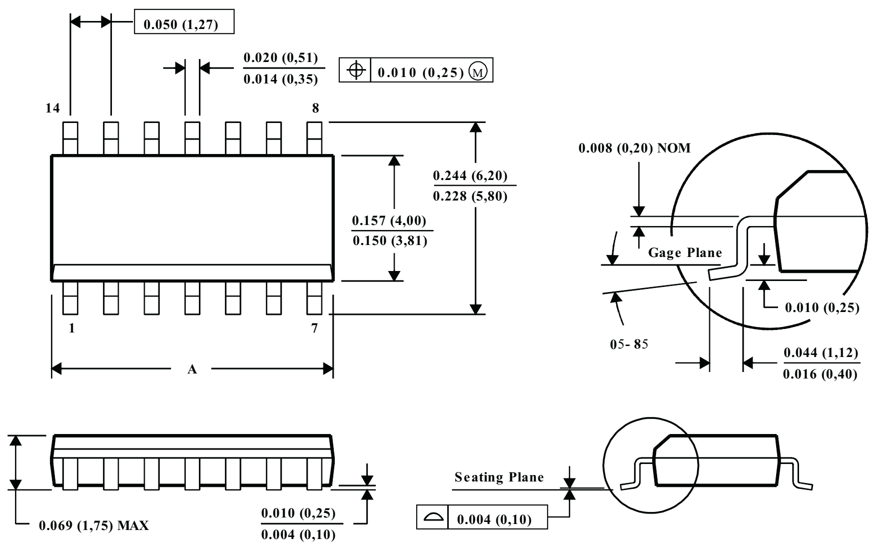
8-Pin DIP (P)



NOTES:
A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS-001

8-Pin SOIC Narrow (D)

14 PINS SHOWN



DIM \ PINS **	8	14	16
A MAX	0.197 (5,00)	0.344 (8,75)	0.394 (10,00)
A MIN	0.189 (4,80)	0.337 (8,55)	0.386 (9,80)

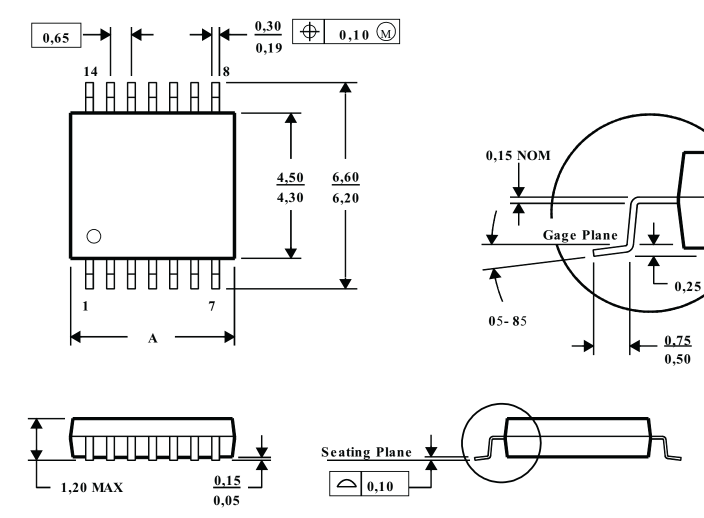
4040047 / D 10/96

NOTES:

A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion, not to exceed 0.006 (0,15).
D. Falls within JEDEC MS-012

8-Pin TSSOP ~ PW Package Suffix

14 PINS SHOWN



DIM \ PINS **	8	14	16	20	24	28
A MAX	3,10	5,10	5,10	6,60	7,90	9,80
A MIN	2,90	4,90	4,90	6,40	7,70	9,60

4040064/F 01/97

NOTES:

A. All linear dimensions are in millimeters.
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C. Body dimensions do not include mold flash or protrusion not to exceed 0,15.
D. Falls within JEDEC MO-153

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