Benchmarq Products
from Texas Instruments

Lead-Acid Fast-Charge IC

Features

- Conforms to battery manufacturers' charge recommendations for cyclic and float charge
- Pin-selectable charge algorithms
  - Two-Step Voltage with temperature-compensated constant-voltage maintenance
  - Two-Step Current with constant-rate pulsed current maintenance
  - Pulsed Current: hysteretic, on-demand pulsed current
- Pin-selectable charge termination by maximum voltage, Δ^2V, minimum current, and maximum time
- Pre-charge qualification detects shorted, opened, or damaged cells and conditions battery
- Charging continuously qualified by temperature and voltage limits
- Internal temperature-compensated voltage reference
- Pulse-width modulation control
  - Ideal for high-efficiency switch-mode power conversion
  - Configurable for linear or gated current use
- Direct LED control outputs display charge status and fault conditions

General Description

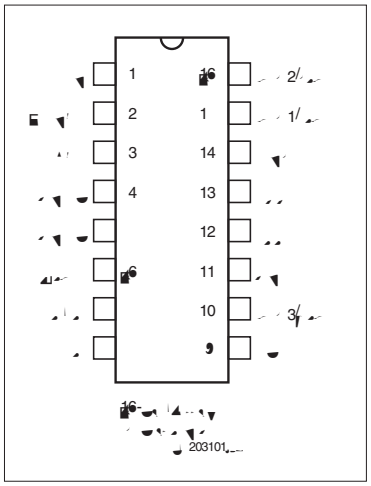
The bq2031 Lead-Acid Fast Charge IC is designed to optimize charging of lead-acid chemistry batteries. A flexible pulse-width modulation regulator allows the bq2031 to control constant-voltage, constant-current, or pulsed-current charging. The regulator frequency is set by an external capacitor for design flexibility. The switch-mode design keeps power dissipation to a minimum for high charge current applications.

A charge cycle begins when power is applied or the battery is replaced. For safety, charging is inhibited until the battery voltage is within configured limits. If the battery voltage is less than the low-voltage threshold, the bq2031 provides trickle-current charging until the voltage rises into the allowed range or an internal timer runs out and places the bq2031 in a Fault condition. This procedure prevents high-current charging of cells that are possibly damaged or reversed. Charging is inhibited anytime the temperature of the battery is outside the configurable, allowed range. All voltage thresholds are temperature-compensated.

The bq2031 terminates fast (bulk) charging based on the following:

- Maximum voltage
- Second difference of cell voltage (Δ^2V)
- Minimum current (in constant-voltage charging)
- Maximum time-out (MTO)

After bulk charging, the bq2031 provides temperature-compensated maintenance (float) charging to maintain battery capacity.



TMTO	Time-out timebase input
FLOAT	State control output
BAT	Battery voltage input
VCOMP	Voltage loop comp input
ICOMP	Current loop comp input
IGSEL	Current gain select input
SNS	Sense resistor input
TS	Temperature sense input
TPWM	Regulator timebase input
LED_3/QSEL	Charge status output 3/ Charge algorithm select input 1
COM	Common LED output
V_{SS}	System ground
V_{CC}	5.0V±10% power
MOD	Modulation control output
LED_1/TSEL	Charge status output 1/ Charge algorithm select input 2
LED_2	

TMTO **Time-out timebase input**

This input sets the maximum charge time. The resistor and capacitor values are determined using equation 6. Figure 9 shows the resistor/capacitor connection.

FLOAT **Float state control output**

This open-drain output uses an external resistor divider network to control the BAT input voltage threshold (V_{FLT}) for the float charge regulation. See Figure 1.

BAT **Battery voltage input**

BAT is the battery voltage sense input. This potential is generally developed using a high-impedance resistor divider network connected between the positive and the negative terminals of the battery. See Figure 6 and equation 2.

VCOMP **Voltage loop compensation input**

This input uses an external C or R-C network for voltage loop stability.

IGSEL **Current gain select input**

This three-state input is used to set I_{MIN} for fast charge termination in the Two-Step Voltage algorithm and for maintenance current regulation in the Two-Step Current algorithm. See Tables 3 and 4.

ICOMP **Current loop compensation input**

This input uses an external C or R-C network for current loop stability.

SNS **Charging current sense input**

Battery current is sensed via the voltage developed on this pin by an external sense resistor, R_{SNS}, connected in series with the low side of the battery. See equation 8.

TS **Temperature sense input**

This input is for an external battery temperature monitoring thermistor or probe. An external resistor divider network sets the lower and upper temperature thresholds. See Figures 7 and 8 and equations 4 and 5.

TPWM **Regulation timebase input**

This input uses an external timing capacitor to ground the pulse-width modulation (PWM) frequency. See equation 9.

COM **Common LED output**

Common output for $LED_{1–3}$. This output is in a high-impedance state during initialization to read program inputs on TSEL, QSEL, and DSEL.

QSEL **Charge regulation select input**

With TSEL, selects the charge algorithm. See Table 1.

- Fast charge termination
- Maintenance charging
- Charge regulation

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Three charge algorithms are available in the bq2031:

- Two-Step Voltage
- Two-Step Current
- Pulsed Current

The state transitions for these algorithms are described in Table 1 and are shown graphically in Figures 2 through 4. The user selects a charge algorithm by configuring pins QSEL and TSEL.

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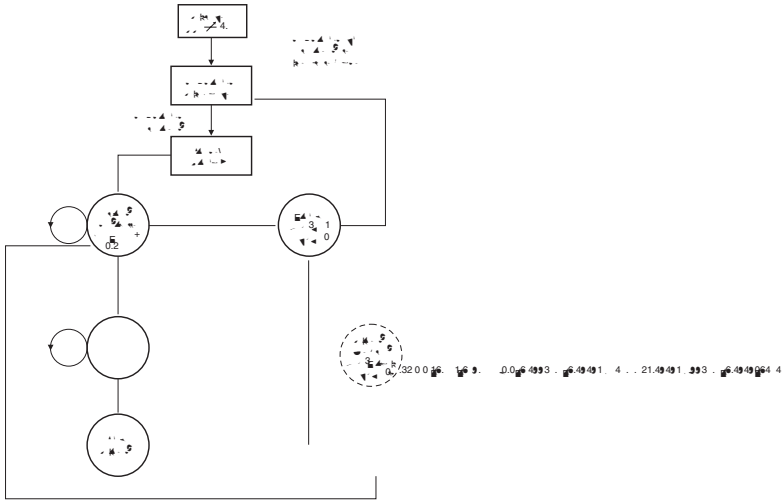
The bq2031 starts a charge cycle when power is applied while a battery is present or when a battery is inserted. Figure 1 shows the state diagram for pre-charge qualification and temperature monitoring. The bq2031 first checks that the battery temperature is within the allowed, user-configurable range. If the temperature is out-of-range (or the thermistor is missing), the bq2031 enters the Charge Pending state and waits until the battery temperature is within the allowed range. Charge Pending is annunciated by LED_3 flashing.

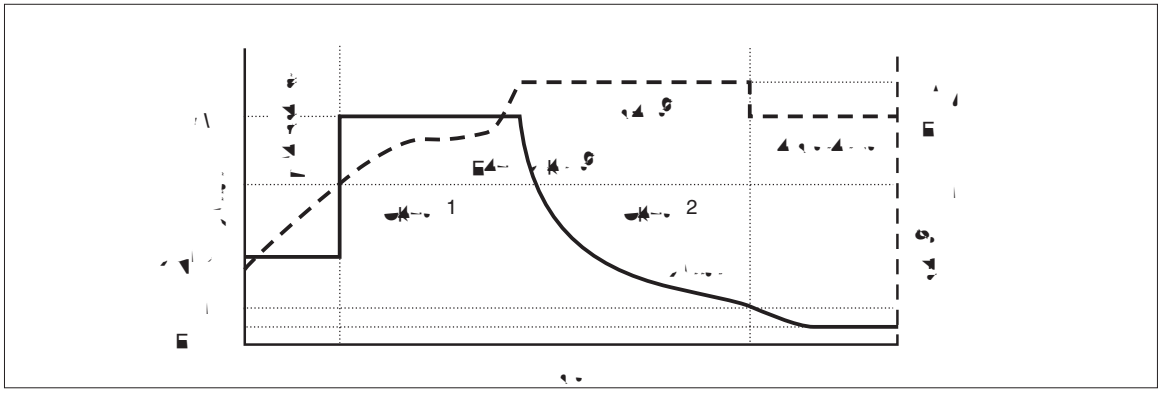


1. 2031 C A

A /	Q EL	EL	C	MOD O
Two-Step Voltage	L	H/L[Note 1]	-	-
Fast charge, phase 1			while $V_{BAT} < V_{BLK}$, $I_{SNS} = I_{MAX}$	Current regulation
Fast charge, phase 2			while $I_{SNS} > I_{MIN}$, $V_{BAT} = V_{BLK}$	Voltage regulation
Primary termination			$I_{SNS} = I_{MIN}$	
Maintenance			$V_{BAT} = V_{FLT}$	Voltage regulation
Two-Step Current	H	L	-	-
Fast charge			while $V_{BAT} < V_{BLK}$, $I_{SNS} = I_{MAX}$	Current regulation
Primary termination			$V_{BAT} = V_{BLK}$ or $\Delta^2V < -8mV$[Note 2]	
Maintenance			I_{SNS} pulsed to average I_{FLT}	Fixed pulse current
Pulsed Current	H	H	-	-
Fast charge			while $V_{BAT} < V_{BLK}$, $I_{SNS} = I_{MAX}$	Current regulation
Primary termination			$V_{BAT} = V_{BLK}$	
Maintenance			$I_{SNS} = I_{MAX}$ after $V_{BAT} = V_{FLT}$; $I_{SNS} = 0$ after $V_{BAT} = V_{BLK}$	Hysteretic pulsed current

Notes: 1. May be high or low, but do not float.
2. A Unitrode proprietary algorithm for accumulating successive differences between samples of V_{BAT}.

Thermal monitoring continues throughout the charge



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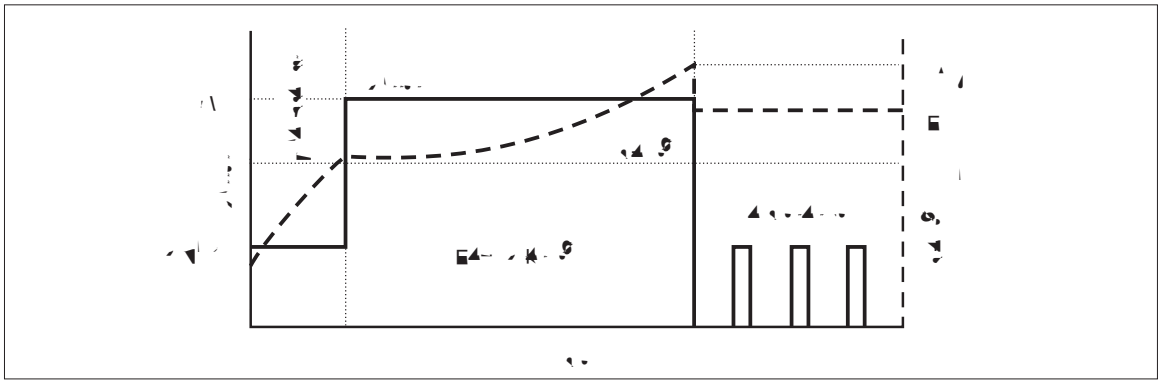

F [illegible] 3. [illegible] C [illegible] A [illegible]

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QSEL/LED
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1. V_{CC} rises to
2. The bq2031
3. The bq2031 c

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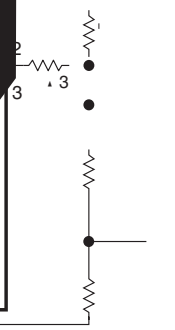

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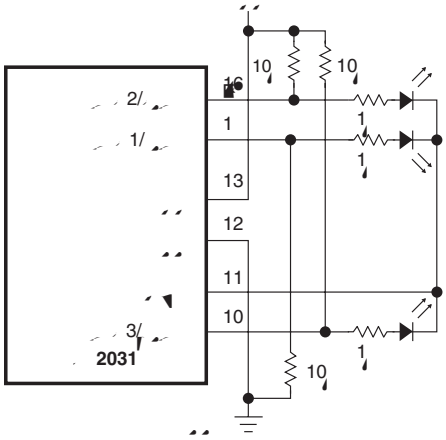
C

The bq2031 monitors batt
pin. A voltage divider betwee
terminals of the battery pack is
battery pack voltage to the BAT pin and an appropriate
value for regulation of float (maintenance) voltage to the
FLOAT pin. The bq2031 also uses the voltage across a
sense resistor (R_{SNS}) between the negative terminal
of the battery pack and ground to monitor current.
See Figure 6 for the configuration of this network.



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F 5. C C A D M

The resistor values are calculated from the following:

Equation 1

$$\frac{RB1}{RB2} = \frac{(N * V_{FLT})}{2.2V} - 1$$

Equation 2

$$\frac{RB1}{RB2} + \frac{RB1}{RB3} = (\frac{N * V_{BLK}}{2.2}) - 1$$

Equation 3

$$I_{MAX} = \frac{0.250V}{R_{SNS}}$$

where:

- N = Number of cells
- V_{FLT} = Desired float voltage
- V_{BLK} = Desired bulk charging voltage
- I_{MAX} = Desired maximum charge current

These parameters are typically specified by the battery manufacturer. The total resistance presented across the battery pack by RB1 + RB2 should be between 150kΩ and 1MΩ. The minimum value ensures that the divider network does not drain the battery excessively when the power source is disconnected. Exceeding the maximum value increases the noise susceptibility of the BAT pin.

An empirical procedure for setting the values in the resistor network is as follows:

1. Set RB2 to 49.9 kΩ. (for 3 to 18 series cells)
2. Determine RB1 from equation 1 given V_{FLT}
3. Determine RB3 from equation 2 given V_{BLK}
4. Calculate R_{SNS} from equation 3 given I_{MAX}

B [illegible] R [illegible]

The bq2031 uses V_{BAT} to detect the presence or absence of a battery. The bq2031 determines that a battery is present when V_{BAT} is between the High-Voltage Cutoff (V_{HCO} = 0.6 * V_{CC}

Second Difference (Δ^2)

Second difference is a Unitrode proprietary algorithm that accumulates the difference between successive samples of V_{BAT}. The bq2031 takes a sample and makes a termination decision at a frequency equal to 0.008 * t_{MTO}. Fast charge terminates when the accumulated difference is ≤ -8mV. Second difference is used only in the Two-Step Current algorithm, and is subject to a hold-off period (see below).

Maximum Voltage

Fast charge terminates when $V_{CELL} \geq V_{BLK}$. V_{BLK} is set per equation 2. Maximum voltage is used for fast charge termination in the Two-Step Current and Pulsed Current algorithms, and for transition from phase 1 to phase 2 in the Two-Step Voltage algorithm. This criterion is subject to a hold-off period.

Hold-off Period

Maximum V and Δ^2V termination criteria are subject to a hold-off period at the start of fast charge equal to 0.15 * t_{MTO}. During this time, these termination criteria are ignored.

Maximum Time-Out

Fast charge terminates if the programmed MTO time is reached without some other termination shutting off fast charge. MTO is programmed from 1 to 24 hours by an R-C network on TMTO (see Figure 9) per the equation:

Equation 6

$$t_{MTO} = 0.5 * R * C$$

where R is in kΩ, C is in µF, and t_{MTO} is in hours. Typically, the maximum value for C of 0.1µF is used.

Fast-charge termination by MTO is a Fault only in the Pulsed Current algorithm; the bq2031 enters the Fault state and waits for a new battery insertion, at which time it begins a new charge cycle. In the Two-Step Voltage and Two-Step Current algorithms, the bq2031 transitions to the maintenance phase on MTO time-out.

The MTO timer starts at the beginning of fast charge. In the Two-Step Voltage algorithm, it is cleared and restarted when the bq2031 transitions from phase 1 (current regulation) to phase 2 (voltage regulation). The MTO timer is suspended (but not reset) during the out-of-range temperature (Charge Pending) state.

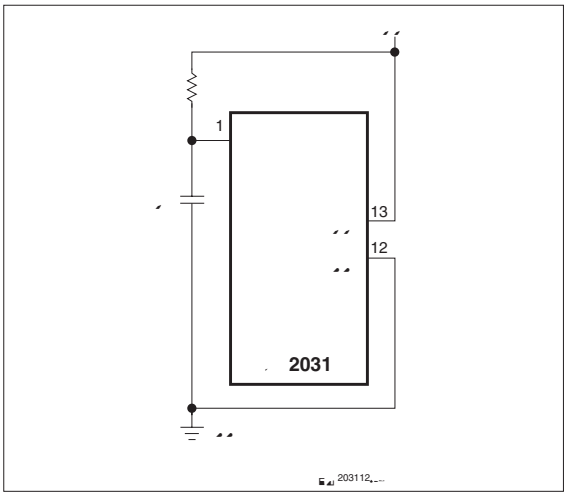


Figure 9. R-C Network for MTO

Maintenance Charging

Three algorithms are used in maintenance charging:

- Two-Step Voltage algorithm
- Two-Step Current algorithm
- Pulsed Current algorithm

Two-Step Voltage Algorithm

In the Two-Step Voltage algorithm, the bq2031 provides charge maintenance by regulating charging voltage to V_{FLT}. Charge current during maintenance is limited to I_{COND}.

Two-Step Current Algorithm

Maintenance charging in the Two-Step Current Algorithm is implemented by varying the period (T_P) of a fixed current (I_{COND} = I_{MAX}/5) and duration (0.2 seconds) pulse to achieve the configured average maintenance current value. See Figure 10.

Maintenance current can be calculated by:

Equation 7

$$\text{Maintenance current} = \frac{((0.2) * I_{COND})}{T_P} = \frac{((0.04) * I_{MAX})}{T_P}$$

where T_P is the period of the waveform in seconds.

Table 4 gives the values of P programmed by IGSEL.

Pulsed Current Algorithm

In the Pulsed Current algorithm, charging current is turned off after the initial fast charge termination until V_{CELL} falls to V_{FLT}. Full fast charge current (I_{MAX}) is

A . \ t _ M \ t R \ .

\	P _ _	M \ \ t	M \ t	\ \	N \ _ .
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	Commercial
T_{STG}	Storage temperature	-55	+125	°C	
T_{SOLDER}	Soldering temperature	-	+260	°C	10 s. max.
T_{BIAS}	Temperature under bias	-40	+85	°C	

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 _ . \ . (A = OPR; CC = 5 ±10%)

\	P _ _	R \	\ \	\ _ \ : _	N \ _ .
V_{REF}	Internal reference voltage	2.20	V	1%	T_A = 25°C
	Temperature coefficient	-3.9	mV/°C	10%	
V_{LTF}	TS maximum threshold	0.6 ∗ V_{CC}	V	±0.03V	Low-temperature fault
V_{HTF}	TS hysteresis threshold	0.44 ∗ V_{CC}	V	±0.03V	High-temperature fault
V_T	∗ V	C	V	±0	
V					

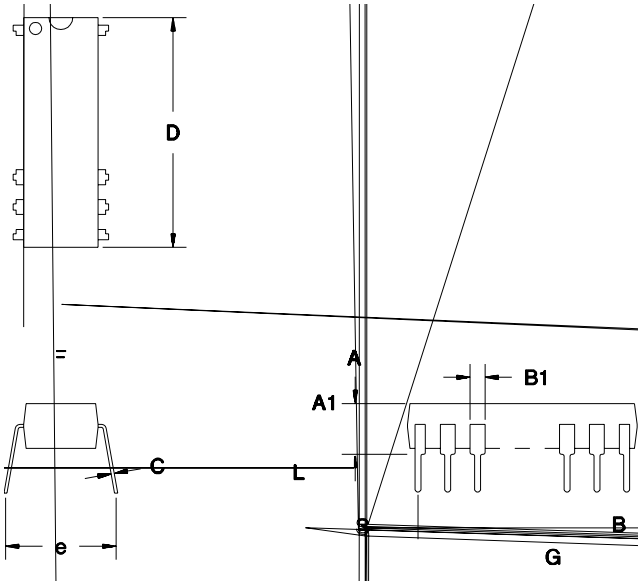
R DC O C (A = OPR)

	P	M		M		N
V_{CC}	Supply voltage	4.5	5.0	5.5	V	
V_{TEMP}	TS voltage potential	0	-	V_{CC}	V	V_{TS} - V_{SNS}
V_{CELL}	Battery voltage potential	0	-	V_{CC}	V	V_{BAT} - V_{SNS}
I_{CC}	Supply current	-	2	4	mA	Outputs unloaded
I_{IZ}	DSEL tri-state open detection	-2	-	2	µA	Note 2
	IGSEL tri-state open detection	-2		2	µA	
V_{IH}	Logic input high	V_{CC}-1.0	-	-	V	QSEL,TSEL
		V_{CC}-0.3	-	-	V	DSEL, IGSEL
V_{IL}	Logic input low	-	-	V_{SS}+1.0	V	QSEL,TSEL
		-	-	V_{SS}+0.3	V	DSEL, IGSEL
V_{OH}	LED_1, LED_2, LED_3, output high	V_{CC}-0.8	-	-	V	$I_{OH} \leq 10mA$
	MOD output high	V_{CC}-0.8	-	-	V	$I_{OH} \leq 10mA$
V_{OL}	LED_1, LED_2, LED_3, output low	-	-	V_{SS}+0.8V	V	$I_{OL} \leq 10mA$
	MOD output low	-	-	V_{SS}+0.8V	V	$I_{OL} \leq 10mA$
	FLOAT output low	-	-	V_{SS}+0.8V	V	$I_{OL} \leq 5mA$, Note 3
	COM output low	-	-	V_{SS+}0.5	V	$I_{OL} \leq 30mA$
I_{OH}	LED_1, LED_2, LED_3, source	-10	-	-	mA	$V_{OH} = V_{CC}$-0.5V
	MOD source	-5.0	-	-	mA	$V_{OH} = V_{CC}$-0.5V
I_{OL}	LED_1, LED_2, LED_3, sink	10	-	-	mA	$V_{OL} = V_{SS}$+0.5V
	MOD sink	5	-	-	mA	$V_{OL} = V_{SS}$+0.8V
	FLOAT sink	5	-	-	mA	$V_{OL} = V_{SS}$+0.8V, Note 3
	COM sink	30	-	-	mA	$V_{OL} = V_{SS}$+0.5V
I_{IL}						

I

P M M N

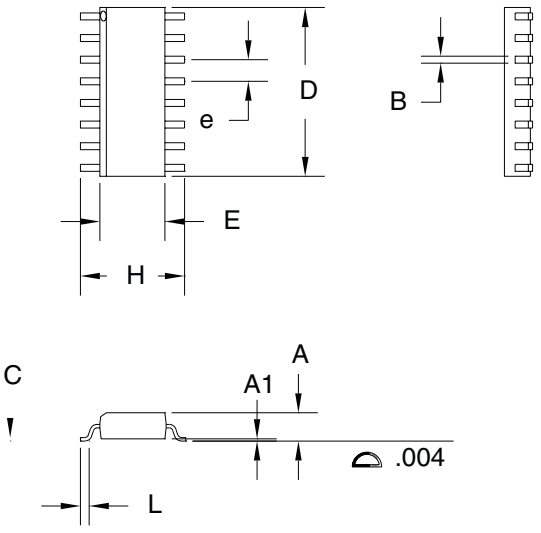
16-Pi DIP Na (PN)



16-Pi PN (0.300" DIP)

Di e i	Inches		Millimeters	
	Min.	Max.	Min.	Max.
A	0.160	0.180	4.06	4.57
A1	0.015	0.040	0.38	1.02
B	0.015	0.022	0.38	0.56
B1	0.055	0.065	1.40	1.65
C	0.008	0.013	0.20	0.33
D	0.740	0.770	18.80	19.56
E	0.300	0.325	7.62	8.26
E1	0.230	0.280	5.84	7.11
e	0.300	0.370	7.62	9.40
G	0.090	0.110	2.29	2.79
L	0.115	0.150	2.92	3.81
S	0.020	0.040	0.51	1.02

16-Pi SOIC Na (SN)



16-Pi SN (0.150" SOIC)

Di e i	Inches		Millimeters	
	Min.	Max.	Min.	Max.
A	0.060	0.070	1.52	1.78
A1	0.004	0.010	0.10	0.25
B	0.013	0.020	0.33	0.51
C	0.007	0.010	0.18	0.25
D	0.385	0.400	9.78	10.16
E	0.150	0.160	3.81	4.06
e	0.045	0.055	1.14	1.40
H	0.225	0.245	5.72	6.22
L	0.015	0.035	0.38	0.89

Data Sheet Revision History

Change No.	Page No.	Description	Nature of Change
1		Descriptions	Clarified and consolidated
1		Renamed	Dual-Level Constant Current Mode to Two-Step Current Mode V_{MCV} to V_{HCO} V_{INT} to V_{LCO} t_{UV1} to t_{QT1} t_{UV2} to t_{QT2}
1		Consolidation	Tables 1 and 2
1		Added figures	Start-up states Temperature sense input voltage thresholds Pulsed maintenance current implementation
1		Updated figures	Figures 1 through 6
1		Added equations	Thermistor divider network configuration equations
1		Raised condition	MOD V_{OL} and V_{OH} parameters from ≤5mA to ≤10µA
1		Corrected Conditions	VSNS rating from V_{MAX} and V_{MIN} to I_{MAX} and I_{MIN}
1		Added table	Capacitance table for C_{MTO} and C_{PWM}
2	6	Changed values in Figure 5	Was 51K; is now 10K
3	7, 10	Changed values in Equations 3 and 8	Was: I_{MAX} = 0.275V/R_{SNS}; is now I_{MAX} = 0.250V/R_{SNS}
3	8	Changed values in Equation 4	Was: (V_{CC} - 0.275); is now (V_{CC} - 0.250V)
3	11	Changed rating value for V_{SNS} in DC Thresholds table	Was 0.275; is now 0.250
4	11	T_{OPR}	Deleted industrial temperature range.

Notes: Change 1 = Dec. 1995 B changes from June 1995 A.
Change 2 = Sept. 1996 C changes from Dec. 1995 B.
Change 3 = April 1997 D changes from Sept. 1996 C.
Change 4 = June 1999 E changes from April 1997 D.

Ordering Information

bq2031

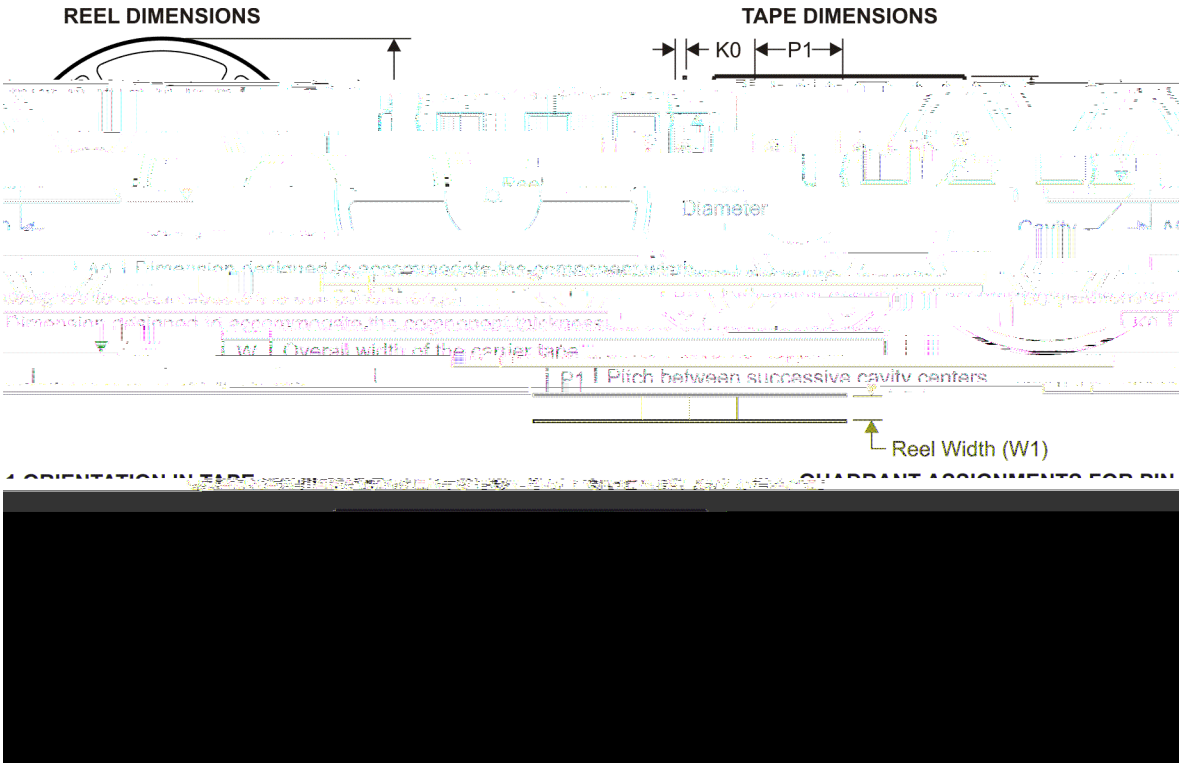
Package Option:
PN = 16-pin plastic DIP
SN = 16-pin narrow SOIC

Device:
bq2031 Lead Acid Charge IC

PACKAGING INFORMATION

Orderable Device	Status

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
BQ2031SN-A5TR	SOIC	D	16	2500	330.0	16.4	6.5	10.3	2.1	8.0	16.0	Q1

TAPE AND REEL BOX DIMENSIONS

*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
BQ2031SN-A5TR	SOIC	D	16	2500	346.0	346.0	33.0

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