1A SINGLE-CHIP Li-Ion/Li-Pol CHARGE MANAGEMENT IC WITH THERMAL REGULATION

FEATURES

- **Thermal Regulation Maximizes Charge Rate**
- **Ideal for Low-Dropout Designs for Single-Cell Li-Ion or Li-Pol Packs in Space Limited Applications**
- **Integrated Power FET and Current Sensor for up to 1-A Charge Applications**
- **Reverse Leakage Protection Prevents Battery Drainage**
- **±0.5% Voltage Regulation Accuracy**
- **Charge Termination by Minimum Current and Time**
- **Precharge Conditioning With Safety Timer**
- **Status Outputs for LED or System Interface Indicate Charge, Fault, and Power Good Outputs**
- **Short-Circuit and Thermal Protection**
- **Automatic Sleep Mode for Low Power Consumption**
- **Small 3×3 mm MLP Package**
- **Selectable Battery Insertion and Battery Absent Detection**
- **Input Over-Voltage Protection**

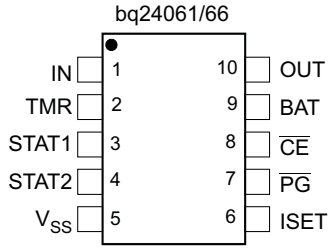
APPLICATIONS

- **PDA, MP3 Players, Digital Cameras**
- **Internet Appliances and Handheld Devices**

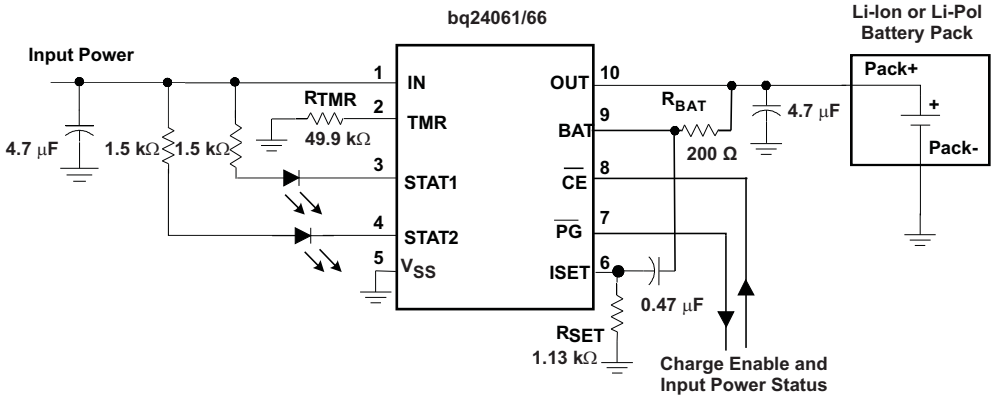
DESCRIPTION

The bq2406x series are highly integrated Li-Ion and Li-Pol linear chargers, targeted at space-limited portable applications. The bq2406x series offers a variety of safety features and functional options, while still implementing a complete charging system in a small package. The battery is charged in three phases: conditioning, constant or thermally regulated current, and constant voltage. Charge is terminated based on minimum current. An internal programmable charge timer provides a backup safety feature for charge termination and is dynamically adjusted during the thermal regulation phase. The bq2406x automatically re-starts the charge if the battery voltage falls below an internal threshold; sleep mode is set when the external input supply is removed. Multiple versions of this device family enable easy design of the bq2406x in cradle chargers or in the end equipment, while using low cost or high-end AC adapters.

PINOUT (TOP VIEW)



TYPICAL APPLICATION CIRCUIT



Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

AVAILABLE OPTIONS

Charge Voltage	Input Over Voltage	Termination Enable	Safety Timer Enable	Power Good Status	IC Enable	Pack Temp	Pack Voltage Detection (Absent)	Devices (1) (2)	Marking
4.2 V	6.5 V	TMR pin	TMR pin	$\overline{PG}$ pin	No	TS pin	With timer enabled	bq24060	BPG
4.2 V	6.5 V	TMR pin	TMR pin	$\overline{PG}$ pin	$\overline{CE}$ pin	No	With timer enabled	bq24061	BPH
4.2 V	6.5 V	$\overline{TE}$ pin	TMR pin	No	$\overline{CE}$ pin	No	With termination enabled	bq24063	Preview
4.2 V	10.5 V	TMR pin	TMR pin	$\overline{PG}$ pin	No	TS pin	With timer enabled	bq24064	BSA

(1) The bq2406x are only available taped and reeled. Add suffix R to the part number for quantities of 3,000 devices per reel (e.g., bq24060BPGR). Add suffix T to the part number for quantities of 250 devices per reel (e.g., bq24060DRCT).
(2) This product is RoHS compatible, including a lead concentration that does not exceed 0.1% of total product weight, and is suitable for use in specified lead-free soldering processes. In addition, this product uses package materials that do not contain halogens, including bromine (Br) or antimony (Sb) above 0.1% of total product weight.

ABSOLUTE MAXIMUM RATINGS (1)

		bq2406x
	Supply voltage (IN with respect to Vss)	–0.3 V to 18 V (2)
	Input voltage on IN, STATx, $\overline{PG}$, TS, $\overline{CE}$, $\overline{TE}$, TMR (all with respect to Vss)	–0.3 V to V(IN)
	Input voltage on OUT, BAT, ISET (all with respect to Vss)	–0.3 V to 7 V
	Output sink current (STATx) + PG	15 mA
	Output current (OUT pins)	1.5 A
T_A	Operating free-air temperature range	–40°C to 125°C
T_{stg}	Storage temperature range	–65°C to 150°C
T_J	Junction temperature range	–40°C to 150°C
	Lead temperature (Soldering, 10 sec)	300°C

(1) Stresses beyond those listed under *absolute maximum ratings* may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under *recommended operating conditions* is not implied. Exposure to absolute–maximum–rated conditions for extended periods may affect device reliability
(2) The bq2406x device can withstand up to 26 V for a maximum of 87 hours.

RECOMMENDED OPERATING CONDITIONS

			MIN	TYP	MAX	UNIT
$V_{(IN)}$	Supply voltage range	Battery absent detection not functional	3.5		16.5	V
$V_{(IN)}$	Supply voltage range	Battery absent detection functional	4.35		16.5	V
T_J	Junction temperature		0		125	°C

DISSIPATION RATINGS (1)

PACKAGE	θ_{JC} (°C/W)	θ_{JA} (°C/W)
10-pin DRC	3.21	46.87

(1) This data is based on using the JEDEC High-K board and the exposed die pad is connected to a Cu pad on the board. This is connected to the ground plane by a 2×3 via matrix.

ELECTRICAL CHARACTERISTICS

over recommended operating, T_J : 0 –125°C range, See the Application Circuits section, typical values at T_J: 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
POWER-ON-RESET							
$V_{(PDWN)}$	Power down threshold	V(IN) = 0 V, increase V(OUT): 0 → 3 V OR V(OUT) = 0 V, increase V(IN): 0 → 3 V, $\overline{CE}$ = LO (1)		1.5		3.0	V
INPUT POWER DETECTION, $\overline{CE}$ = HI or LOW, V(IN) > 3.5 V							
$V_{IN(DT)}$	Input power detection threshold	$V_{(IN)}$ detected at [V(IN) – V(OUT)] > $V_{IN(DT)}$				130	mV
$V_{HYS(INDT)}$	Input power detection hysteresis	Input power not detected at [$V_{(IN)}$– $V_{(OUT)}$] < [$V_{IN(DT)}$– $V_{HYS(INDT)}$]		30			mV
$T_{DGL(INDT1)}$	Deglitch time, input power detected status	$\overline{PG}$:HI → LO, Thermal regulation loop not active, R_{TMR} = 50 KΩ or $V_{(TMR)}$ = OPEN		1.5		3.5	ms
$T_{DGL(NOIN)}$	Delay time, input power not detected status	$\overline{PG}$: LO →HI after $T_{DGL(NOIN)}$				10	µs
$T_{DLY(CHGOFF)}$	Charger off delay	Charger turned off after $T_{DLY(CHGOFF)}$, Measured from $\overline{PG}$: LO → HI; Timer reset after $T_{DLY(CHGOFF)}$		28		32	ms
INPUT OVER-VOLTAGE PROTECTION							
$V_{(OVP)}$	Input over-voltage detection threshold	V(IN) increasing	bq24060/61/63/65/66	6.2	6.5	7.0	V
			bq24064	10.2	10.5	11.7	
$V_{HYS(OVP)}$	Input over-voltage hysteresis	V(IN) decreasing	bq24060/61/63/65/66	0.1		0.2	V
			bq24064	0.3		0.5	
$T_{DGL(OVDET)}$	Input over-voltage detection delay	$\overline{CE}$ = HI or LO, Measured from V(IN) > $V_{(OVP)}$ to $\overline{PG}$: LO → HI; VIN increasing		10		100	µs
$T_{DGL(OVNDET)}$	Input over-voltage not detected delay	$\overline{CE}$ = HI or LO, Measured from V(IN) < $V_{(OVP)}$ to $\overline{PG}$: HI → LO; V(IN) decreasing		10		100	µs
QUIESCENT CURRENT							
$I_{CC(CHGOFF)}$	IN pin quiescent current, charger off	Input power detected, $\overline{CE}$ = HI	$V_{(IN)}$ = 6 V		100	200	µA
			$V_{(IN)}$ = 16.5 V		300		
$I_{CC(CHGON)}$	IN pin quiescent current, charger on	Input power detected, $\overline{CE}$ = LO, V_{BAT} = 4.5 V			4	6	mA
$I_{BAT(DONE)}$	Battery leakage current after termination into IC	Input power detected, charge terminated, $\overline{CE}$ = LO			1	5	µA
$I_{BAT(CHGOFF)}$	Battery leakage current into IC, charger off	Input power detected, $\overline{CE}$ = HI **OR** input power not detected, $\overline{CE}$ = LO			1	5	µA
TS PIN COMPARATOR							
$V_{(TS1)}$	Lower voltage temperature threshold	Hot detected at V(TS) < $V_{(TS1)}$; NTC thermistor		29	30	31	%V(IN)
$V_{(TS2)}$	Upper voltage temperature threshold	Cold detected at V(TS) > $V_{(TS2)}$; NTC thermistor		60	61	62	%V(IN)
$V_{HYS(TS)}$	Hysteresis	Temp OK at V(TS) > [$V_{(TS1)}$ + $V_{HYS(TS)}$] OR $V_{(TS)}$ < [$V_{(TS2)}$– $V_{HYS(TS)}$]			2		%V(IN)
$\overline{CE}$ INPUT							
V_{IL}	Input (low) voltage	V($\overline{CE}$) increasing		0		1	V
V_{IH}	Input (high) voltage	V($\overline{CE}$) decreasing		2.0			V
STAT1, STAT2 AND $\overline{PG}$ OUTPUTS , V(IN) ≥ $V_{O(REG)}$ + $V_{(DO-MAX)}$							
V_{OL}	Output (low) saturation voltage	Ioutput = 5 mA (sink)				0.5	V
THERMAL SHUTDOWN							
$T_{(SHUT)}$	Temperature trip	Junction temperature			155		°C
$T_{(SHUTHYS)}$	Thermal hysteresis	Junction temperature			20		°C

(1) Specified by design, not production tested.

ELECTRICAL CHARACTERISTICS (Continued)

over recommended operating, T_J : 0–125°C range, See the Application Circuits section, typical values at T_J : 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
VOLTAGE REGULATION, V(IN) ≥ $V_{O(REG)}$ + $V_{(DO-MAX)}$, $I_{(TERM)}$ < $I_{(OUT)}$ < $I_{O(OUT)}$, CHARGER ENABLED, NO FAULT CONDITIONS DETECTED							
$V_{O(REG)}$	Output voltage	bq24060/61/62/63/64			4.20		V
		bq24065/66 versions only			4.36		
$V_{O(TOL)}$	Voltage regulation accuracy	T_A = 25°C		–0.5%		0.5%	
				–1%		1%	
$V_{(DO)}$	Dropout voltage, V(IN) – V(OUT)	$I_{(OUT)}$ = 1 A				750	mV
CURRENT REGULATION , V(IN) > V(OUT) > $V_{(DO-MAX)}$, CHARGER ENABLED, NO FAULT CONDITIONS DETECTED							
$I_{O(OUT)}$	Output current range	$V_{(BAT)}$ > $V_{(LOWV)}$, $I_{O(OUT)}$ = $I_{(OUT)}$ = $K_{(SET)}$× $V_{(SET)}/R_{SET}$		100		1000	mA
$V_{(SET)}$	Output current set voltage	V(ISET) = $V_{(SET)}$, $V_{(LOWV)}$ < V(BAT) ≤ $V_{O(REG)}$		2.45	2.50	2.55	V
$K_{(SET)}$	Output current set factor	100 mA ≤ $I_{O(OUT)}$≤ 1000 mA	$\frac{mA \times k\Omega}{Volts}$	315	335	355	
		10 mA ≤ $I_{O(OUT)}$ < 100 mA		315	372	430	
R_{ISET}	External resistor range	Resistor connected to ISET pin		0.7		10	kΩ
VOLTAGE AND CURRENT REGULATION TIMING, V(IN) > V(OUT) + $V_{(DO-MAX)}$, CHARGER ENABLED, NO FAULT CONDITIONS DETECTED, R_{TMR} = 50K or V(TMR) = OPEN; Thermal regulation loop not active							
$T_{PWRUP(CHG)}$	Input power detection to full charge current time delay	Measured from $\overline{PG}$:HI → LO to I(OUT) > 100 mA, $\overline{CE}$ = LO, $I_{O(OUT)}$ = 1 A, V(BAT) = 3.5 V			25	35	ms
$T_{PWRUP(EN)}$	Charge enable to full charge current delay	Measured from $\overline{CE}$:HI → LO to I(OUT) >100 mA, $I_{O(OUT)}$ = 1A, $V_{(BAT)}$= 3.5 V, $V_{(IN)}$ = 4.5 V, Input power detected			25	35	ms
$T_{PWRUP(LDO)}$	Input power detection to voltage regulation delay, LDO mode set, no battery or load connected	Measured from $\overline{PG}$:HI → LO to V(OUT) > 90% of charge voltage regulation; $V_{(TMR)}$ = OPEN, LDO mode set, no battery and no load at OUT pin, $\overline{CE}$ = LO			25	35	ms
PRECHARGE AND OUTPUT SHORT-CIRCUIT CURRENT REGULATION, V(IN)–V(OUT) > V(DO-MAX) , V(IN) ≥ 4.5V, CHARGER ENABLED, NO FAULT CONDITIONS DETECTED, RTMR = 50K or V(TMR)=OPEN; Thermal regulation loop not active							
$V_{(LOWV)}$	Precharge to fast-charge transition threshold	$V_{(BAT)}$ increasing		2.8	2.95	3.15	V
$V_{(SCIND)}$	Short-circuit indication	$V_{(BAT)}$ decreasing		1.2	1.4	1.6	V
$V_{(SC)}$	Precharge to short-circuit transition threshold	$V_{(BAT)}$ decreasing		1.6	1.8	2.0	
$I_{O(PRECHG)}$	Precharge current range	$V_{(SC)}$ < $V_{I(BAT)}$ < $V_{(LOWV)}$, t < $T_{(PRECHG)}$ $I_{O(PRECHG)}$ = $K_{(SET)}$× $V_{(PRECHG)}/R_{(ISET)}$		10		100	mA
$V_{(PRECHG)}$	Precharge set voltage	$V_{(ISET)}$ = $V_{(PRECHG)}$, $V_{(SC)}$ < $V_{I(BAT)}$ < $V_{(LOWV)}$, t < $T_{(PRECHG)}$		225	250	280	mV
$I_{O(SHORT)}$	Output shorted regulation current	$I_{O(SHORT)}$ = $I_{(OUT)}$, $V_{(BAT)}$= VSS	V_{POR} < V_{IN} < 6.0 V	15	22	30	mA
			6.0 V < V_{IN}		25		
TEMPERATURE REGULATION (Thermal regulation™), CHARGER ENABLED, NO FAULT CONDITIONS DETECTED							
$T_{J(REG)}$	Temperature regulation limit	V(IN) = 5.5 V, V(BAT) = 3.2 V, Fast charge current set to 1A		101	112	125	°C
$I_{(MIN\_TJ(REG))}$	Minimum current in thermal regulation	V(LOWV) < V(BAT) < VO(REG), 0.7kΩ < RISET < 3.5kΩ			200	250	mA

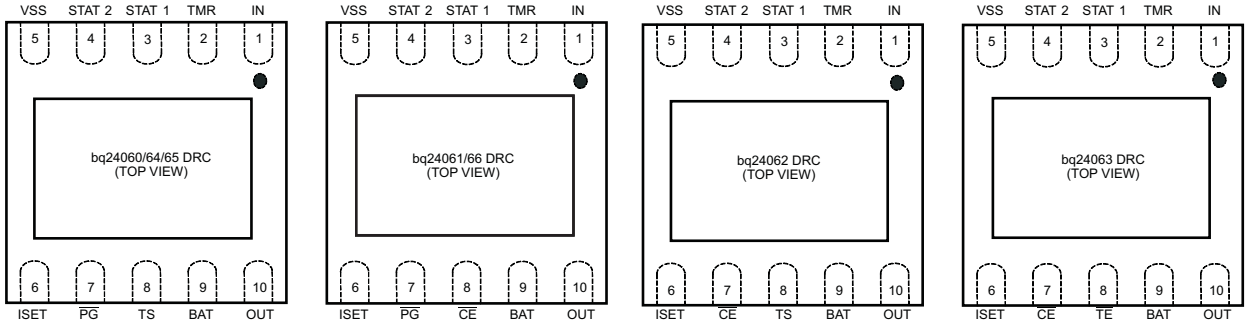
ELECTRICAL CHARACTERISTICS (Continued)

over recommended operating, T_J : 0–125°C range, See the Application Circuits section, typical values at T_J : 25°C (unless otherwise noted)

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
CHARGE TERMINATION DETECTION, $V_{O(REG)}$ = 4.2 V or $V_{O(REG)}$ = 4.36 V, CHARGER ENABLED, NO FAULT CONDITIONS DETECTED, Thermal regulation LOOP NOT ACTIVE, R_{TMR} = 50K or TMR pin OPEN							
$I_{(TERM)}$	Termination detection current range	$V_{(BAT)} > V_{(RCH)}$, $t < T_{TDGL(TERM)}$, $I_{(TERM)} = K_{(SET)} \times V_{(TERM)}/R_{ISET}$		10		100	mA
$V_{(TERM)}$	Charge termination detection set voltage	$V_{(BAT)} > V_{(RCH)}$		225	250	275	mV
$T_{DGL(TERM)}$	Deglitch time, termination detected	$V_{(ISET)}$ decreasing		15	25	35	ms
BATTERY RECHARGE THRESHOLD							
$V_{(RCH)}$	Recharge threshold detection	$[V_{O(REG)} – V(BAT)] > V_{(RCH)}$		75	100	135	mV
$T_{DGL(RCH)}$	Deglitch time, recharge detection	$V_{(BAT)}$ decreasing		15	25	35	ms
TIMERS, $\overline{CE}$ = LO, CHARGER ENABLED, NO FAULT CONDITIONS DETECTED, V(TMR) < 3 V, TIMERS ENABLED							
$T_{(CHG)}$	Charge safety timer range	$T_{(CHG)} = K_{(CHG)} \times R_{TMR}$; thermal loop not active		3		10	hours
$K_{(CHG)}$	Charge safety timer constant	$V_{(BAT)} > V_{(LOWV)}$		0.08	0.1	0.12	hr/kΩ
$T_{(PCHG)}$	Pre-charge safety timer range	$T_{(PCHG)} = K_{(PCHG)} \times T_{(CHG)} \times K_{(CHG)}$; Thermal regulation loop not active		1080		3600	sec
$K_{(PCHG)}$	Pre-charge safety timer constant	$V_{(BAT)} < V_{(LOWV)}$		0.08	0.1	0.12	
$V_{TMR(OFF)}$	Charge timer and termination enable threshold	[Charge timer AND termination disabled] at $V_{(TMR)} > V_{TMR(OFF)}$	bq24060/61/62/64/65/66	2.5	3.0	3.5	V
	Charge timer enable threshold	[Charge timer disabled] at $V_{(TMR)} > V_{TMR(OFF)}$	bq24063				
$I_{TMR(OFF)}$	TMR pin pull-up current	$I_{TMR(OFF)} = I_{(TMR)}$, $V_{(TMR)}$ = 3.5 V, $V_{(IN)}$ = 4.5 V, safety timer off, all other timers set to zero.		1		6	µA
BATTERY DETECTION THRESHOLDS							
$I_{DET(DOWN)}$	Battery detection current (sink)	2 V < $V_{(BAT)}$ < $V_{O(REG)}$		1	2	3.2	mA
$I_{DET(UP)}$	Battery detection current (source)	2 V < $V_{(BAT)}$ < $V_{O(REG)}$			$I_{O(PRECHG)}$		mA
$T_{(DETECT)}$	Battery detection time	2 V < $V_{(BAT)}$ < $V_{O(REG)}$, Thermal regulation loop not active; R_{TMR} = 50 kΩ		85	120	150	ms
TIMER FAULT RECOVERY							
$I_{(FAULT)}$	Fault Current (source)	$V_{(OUT)} < V_{(RCH)}$		–12	–10	–8	mA
CHARGE OVER-CURRENT DETECTION, V(IN) ≥ 4.5 V, CHARGER ENABLED							
$I_{CH(OVC)}$	Charge over-current detection threshold	$V_{(ISET)}$ = VSS			2		A
$T_{DGL(CHOVC)}$	Over current detection delay time	Measured from $V_{(ISET)}$ = VSS to $I_{O(OUT)}$ = 0			100		µs

DEVICE INFORMATION

PIN ASSIGNMENT



TERMINAL FUNCTIONS, REQUIRED COMPONENTS

TERMINAL NO.					I/O	DESCRIPTION AND REQUIRED COMPONENTS
NAME	bq24060/64/65	bq24061/66	bq24062	bq24063		
IN	1	1	1	1	I	Charge Input Voltage and internal supply. Connect a 1- µF (minimum) capacitor from IN to VSS.
TMR	2	2	2	2	I	Safety Timer Program Input, timer disabled if floating. Connect a resistor to VSS pin to program safety timer timeout value
STAT1	3	3	3	3	O	Charge Status Output 1 (open-collector, seeTable 3)
STAT2	4	4	4	4	O	Charge Status Output 2 (open-collector, see Table 3)
VSS	5	5	5	5	I	Ground
ISET	6	6	6	6	O	Charge current set point, resistor connected from ISET to VSS sets charge current value. Connect a 0.47-µF capaciator from BAT to ISET.
$\overline{PG}$	7	7	—	—	O	Power Good status output (open-collector), active low
$\overline{CE}$	—	8	7	7	I	Charge enable Input. $\overline{CE}$ = LO enables charger. $\overline{CE}$ = HI disables charger.
$\overline{TE}$	—	—	—	8	I	Termination enable Input. $\overline{TE}$ = LO enables termination detection and battery absent detection. $\overline{TE}$ = HI disables termination detection and battery absent detection.
TS	8	—	8	—	I	Temperature Sense Input, connect to battery pack thermistor. Connect an external resistive divider to program temperature thresholds.
BAT	9	9	9	9	I	Battery Voltage Sense Input. Connect to the battery positive terminal. Connect a 200-Ω resistor from BAT to OUT.
OUT	10	10	10	10	O	Charge current output. Connect to the battery positive terminal. Connect a 1- µF (minimum) capacitor from OUT to VSS.
Exposed Thermal Pad	Pad	Pad	Pad	Pad		There is an internal electrical connection between the exposed thermal pad and Vss pin of the IC. The exposed thermal pad must be connected to the same potential as the Vss pin on the printed circuit board. Do not use the thermal pad as the primary ground input for the IC. Vss pin must be connected to ground at all times.

FUNCTIONAL DESCRIPTION

The charge current is programmable using external components (R_{ISET} resistor). The charge process starts when an external input power is connected to the system, the charger is enabled by $\overline{CE}$ = LO and the battery voltage is below the recharge threshold, V(BAT) < $V_{(RCH)}$. When the charge cycle starts a safety timer is activated, if the safety timer function is enabled. The safety timer timeout value is set by an external resistor connected to TMR pin.

When the charger is enabled two control loops modulate the battery switch drain to source impedance to limit the BAT pin current to the programmed charge current value (charge current loop) or to regulate the BAT pin voltage to the programmed charge voltage value (charge voltage loop). If V(BAT) < V(LOWV) (3.0 V typical) the BAT pin current is internally set to 10% of the programmed charge current value.

A typical charge profile is shown below, for an operation condition that does not cause the IC junction temperature to exceed $T_{J(REG)}$, (112°C typical).

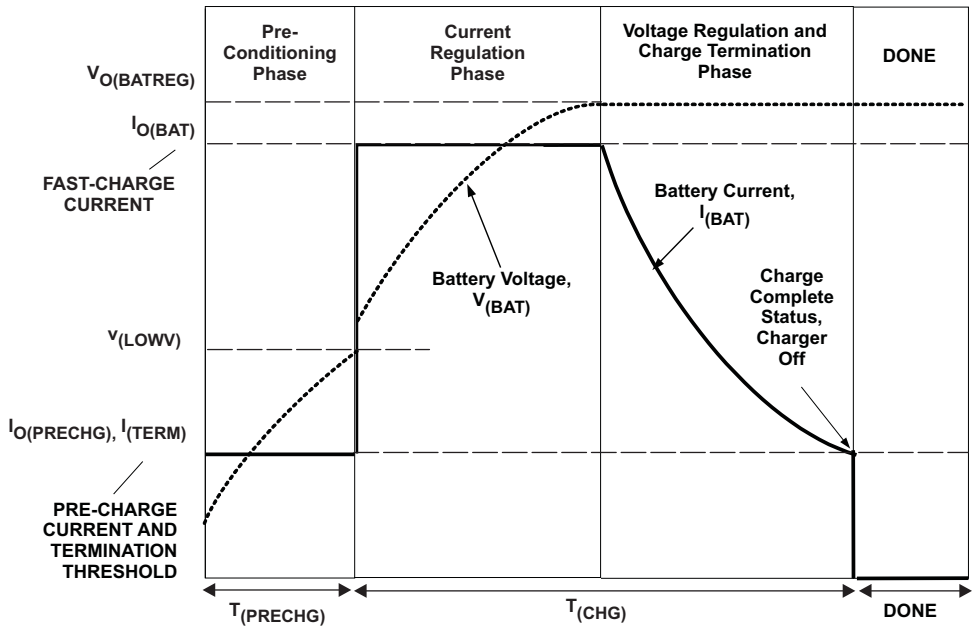


Figure 1. Charging Profile With $T_{J(REG)}$

If the operating conditions cause the IC junction temperature to exceed $T_{J(REG)}$, the charge cycle is modified, with the activation of the integrated thermal control loop. The thermal control loop is activated when an internal voltage reference, which is inversely proportional to the IC junction temperature, is lower than a fixed, temperature stable internal voltage. The thermal loop overrides the other charger control loops and reduces the charge current until the IC junction temperature returns to $T_{J(REG)}$, effectively regulating the IC junction temperature.

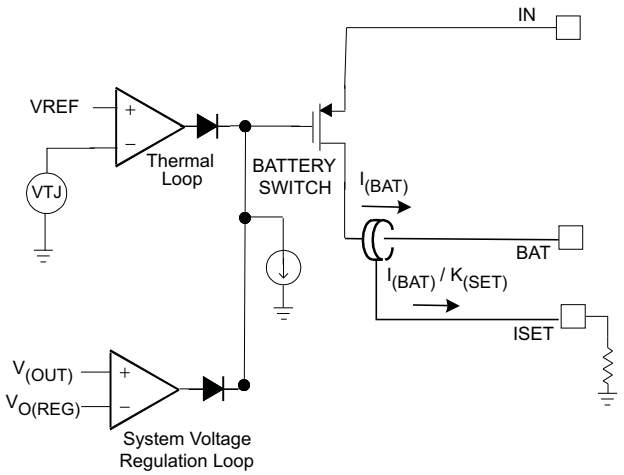


Figure 2. Thermal Regulation Circuit

A modified charge cycle, with the thermal loop active, is shown in Figure 3.

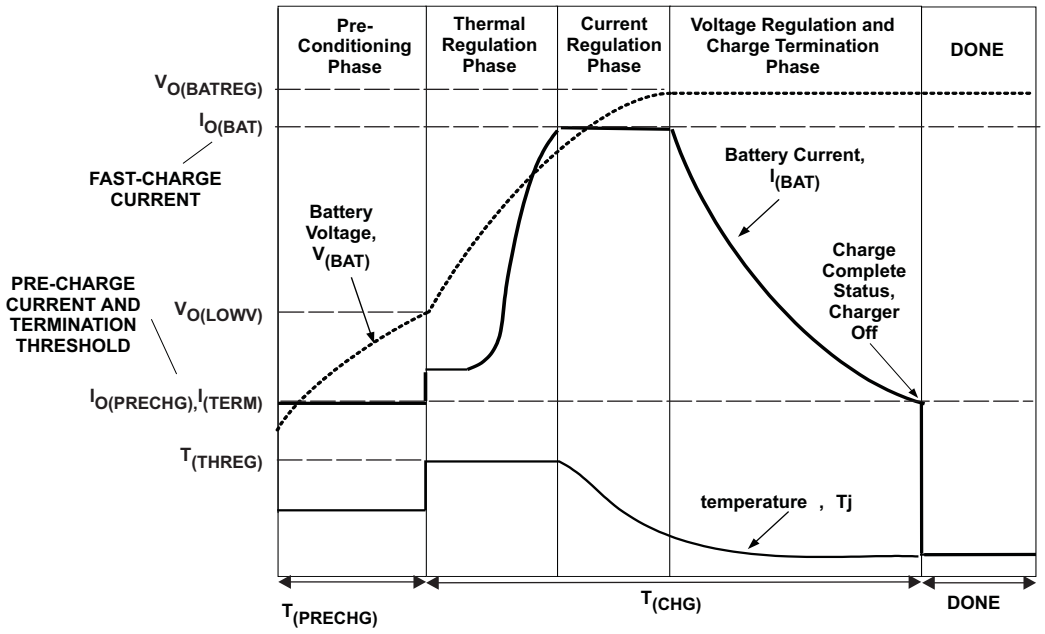
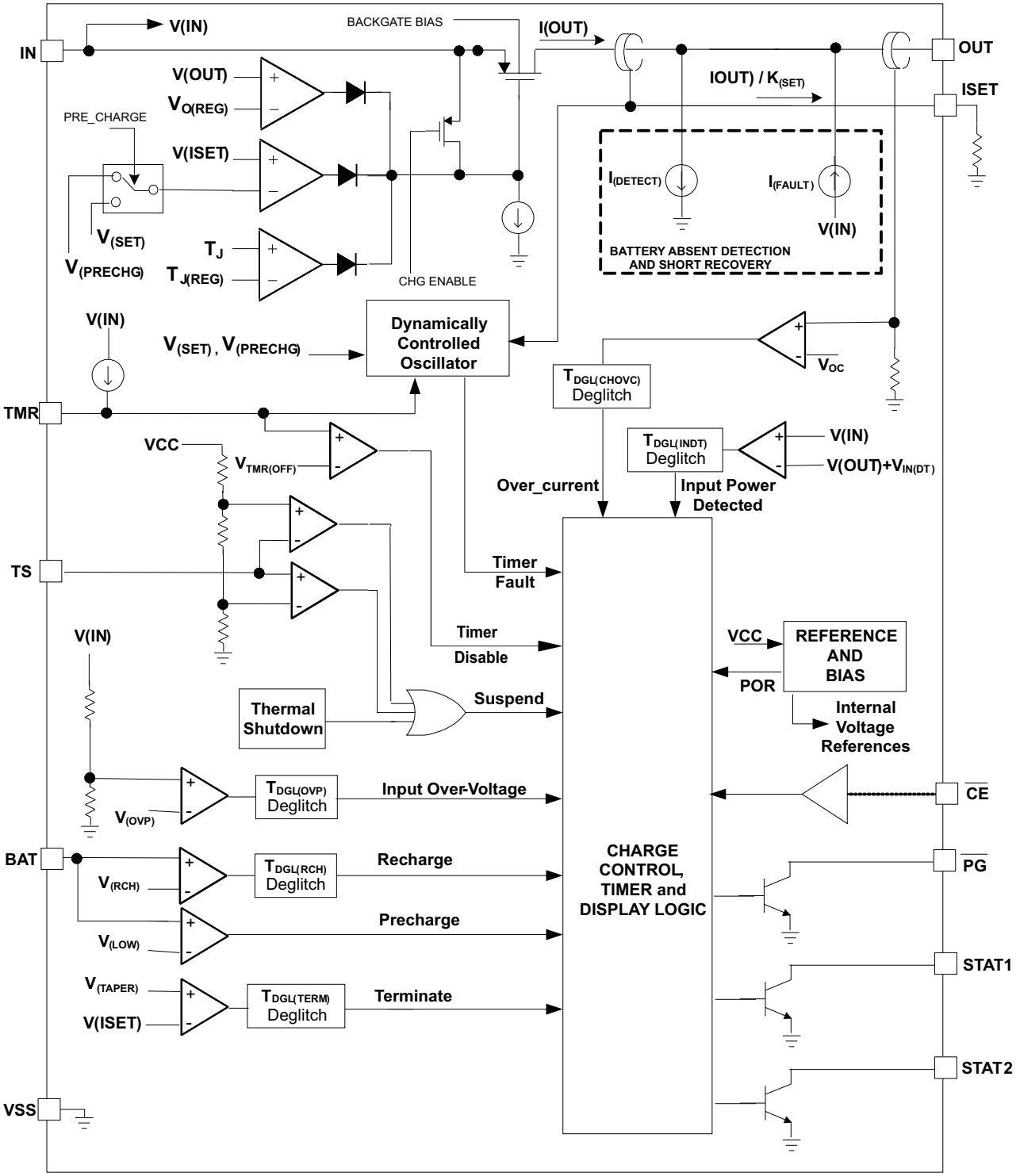


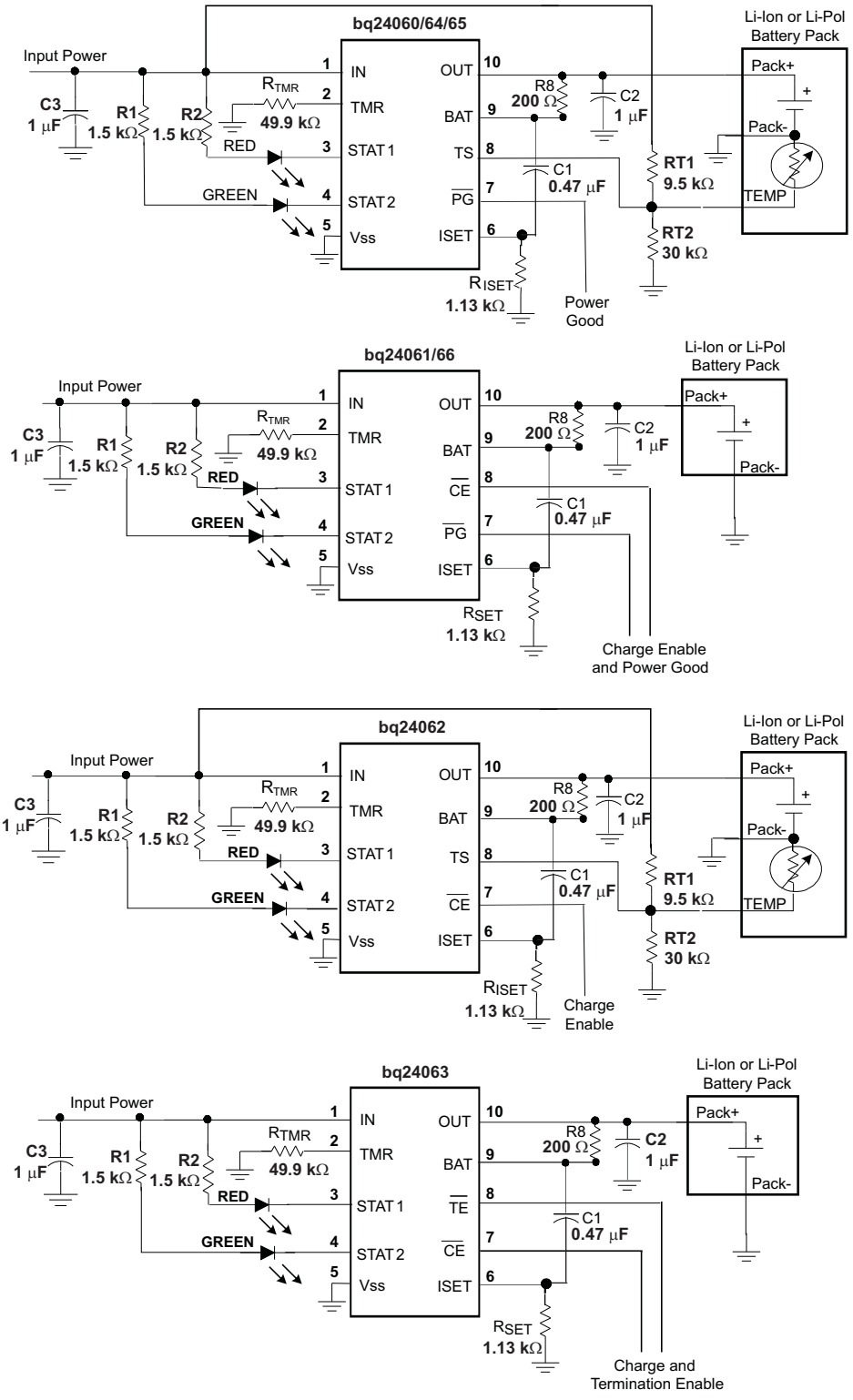
Figure 3. Charge Profile, Thermal Loop Active

FUNCTIONAL BLOCK DIAGRAM



APPLICATION CIRCUITS

The typical application diagrams shown here are configured for 750 mA fast charge current, 75 mA pre-charge current, 5 hour safety timer and 30 min pre-charge timer.


bq24060/64/65
Input Power
C3
1 µF
R1
1.5 kΩ
R2
1.5 kΩ
RTMR
49.9 kΩ
RED
GREEN
IN
TMR
STAT 1
STAT 2
Vss
OUT
BAT
TS
PG
ISET
R8
200 Ω
C2
1 µF
C1
0.47 µF
RT1
9.5 kΩ
RT2
30 kΩ
RISET
1.13 kΩ
Power Good
Li-Ion or Li-Pol Battery Pack
Pack+
Pack-
TEMP
bq24061/66
CE
RSET
Charge Enable and Power Good
bq24062
Charge Enable
bq24063
TE
Charge and Termination Enable

OPERATING MODES

Power Down

The bq2406x family remains in a power-down mode when the input power voltage (IN) is below the power-down threshold $V_{(PDWN)}$. During the power down mode all IC functions are off, and the host commands at the control pins are not interpreted. The integrated power mosfet connected between IN and OUT pins is off, the status output pins STAT1 and STAT2 are set to high impedance mode and $\overline{PG}$ output is set to the high impedance state.

The power down mode is entered from any other state, if the input power V(IN) falls below the voltage threshold $V_{(PDWN)}$.

Sleep Mode

The bq2406x enters the sleep mode when the input power voltage (IN) is above the power down threshold V(PDWN) but still lower than the input power detection threshold, V(IN) < V(OUT) + $V_{IN(DT)}$.

During the sleep mode the charger is off, and the host commands at the control pins are not interpreted. The integrated power mosfet connected between IN and OUT pins is off, the status output pins STAT1 and STAT2 are set to the high impedance state and the $\overline{PG}$ output indicates input power not detected.

The sleep mode is entered from any other state, if the input power (IN) is not detected.

Power-On-Reset Mode

The input power is detected when the input voltage V(IN) > V(OUT) + $V_{IN(DT)}$. When the input power is detected the bq2460x transitions from the sleep mode to the power-on-reset mode. In this mode of operation an internal timer $T_{(POR)}$ is started and internal blocks are reset (power-on-reset). Until the timer expires the STAT1 and STAT2 outputs indicate charger OFF, and the $\overline{PG}$ output indicates the input power status as not detected.

At the end of the power-on-reset delay the internal comparators are enabled, and the STAT1, STAT2 and $\overline{PG}$ pins are active.

Stand-By Mode

In the bq24031/2/3/6 the stand-by mode is started at the end of the power-on-reset phase, if the input power is detected and $\overline{CE}$ = HI. In the stand-by mode selected blocks in the IC are operational, and the control logic monitors system status and control pins to define if the charger will set to on or off mode. The quiescent current required in stand-by mode is 100 μA typical.

The stand-by mode is entered from any other state, if $\overline{CE}$ = HI. If the $\overline{CE}$ pin is not available the bq2406x enters the begin charge mode at the end of the power-on-reset phase.

Begin Charge Mode

All blocks in the IC are powered up, and the bq2406x is ready to start charging the battery pack. A new charge cycle is started when the control logic decides that all conditions required to enable a new charge cycle are met. During the begin charge phase all timers are reset, after that the IC enters the charging mode.

Charging Mode

When the charging mode is active the bq2406x executes the charging algorithm, as described in the state machine diagram, Figure 4.

Suspend Mode

The suspend mode is entered from any other state when the pack temperature is not within the valid temperature range. During the suspend mode the charger is set to off, but the timers are not reset.

The normal charging mode resumes when the pack temperature is within range.

STATE MACHINE DIAGRAM

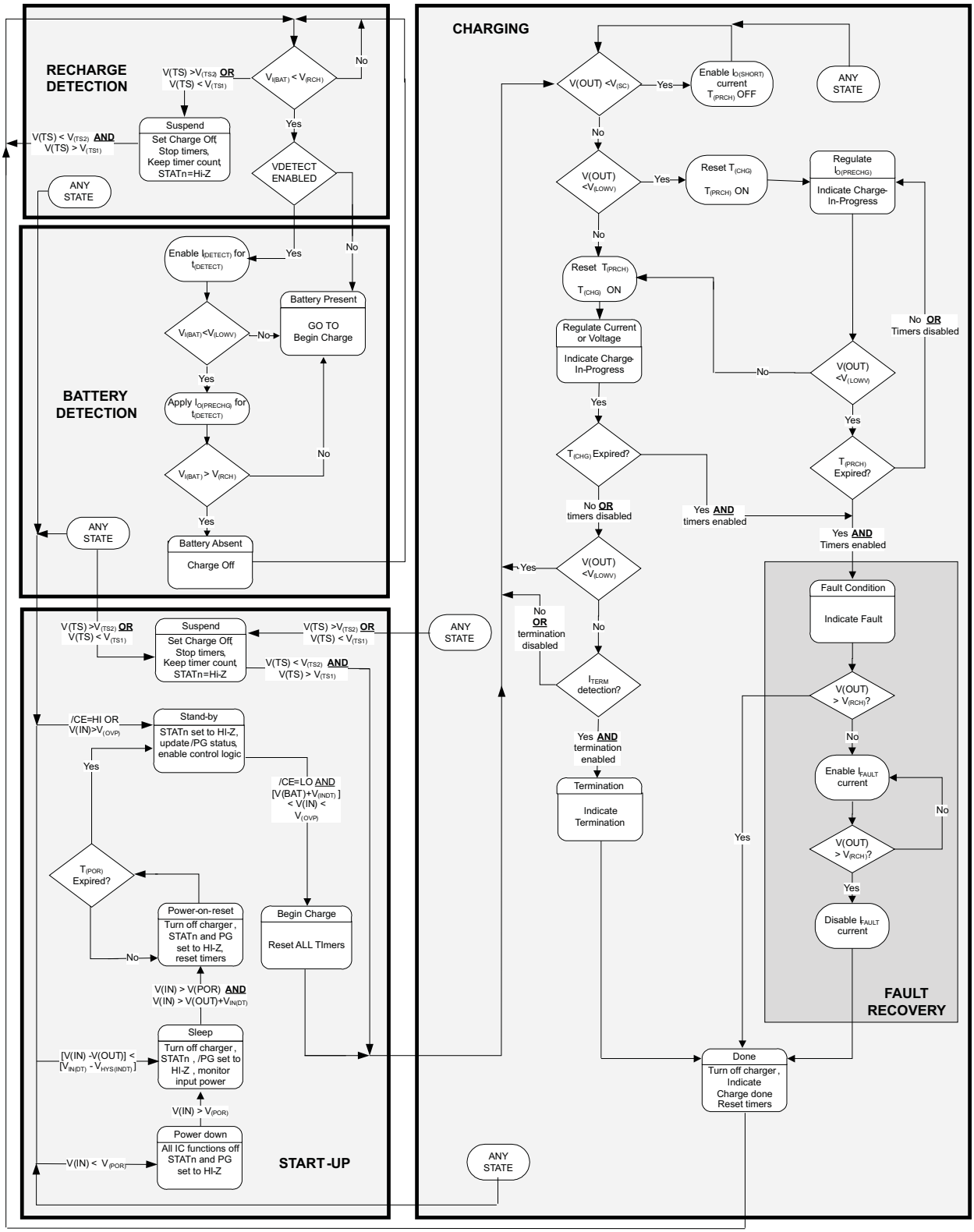


Figure 4. Operational Flow Chart

CONTROL LOGIC OVERVIEW

An external host can enable or disable the charging process using a dedicated control pin, $\overline{CE}$. A low-level signal on this pin enables the charge, and a high-level signal disables the charge. The bq2460x is in stand-by mode with $\overline{CE}$ = HI. When the charger function is enabled ($\overline{CE}$ = LO) a high accuracy reference is activated, to provide the charge voltage and charge current internal references.

The charger power stage is turned on if $\overline{CE}$ = LO and if the bq2406X detects that all conditions for safely charging a battery exist. Table 1 describes the charger control logic operation, in bq2460x versions without the TS pin the pack temp status is internally set to OK.

Table 1. Control Logic Functionality

$\overline{CE}$	INPUT POWER	TIMER FAULT (latched)	OUTPUT SHORT CIRCUIT	TERMINATION (latched)	PACK TEMP	THERMAL SHUTDOWN	POWER DOWN	CHARGER POWER STAGE	bq2460X OPERATION MODE
LO	X	X	X	X	X	X	Yes	***OFF***	***POWER DOWN***
X	Not Detected	X	X	X	X	X	No	***OFF***	***SLEEP***
HI	Detected	X	X	X	X	X	No	***OFF***	***STANDBY***
LO	Detected	X	Yes	X	X	X	No		***SEE STATE DIAGRAM***
LO	Detected	No	No	Yes	X	X	No	***OFF***	
LO	Detected	Yes	No	No	X	X	No	***IFAULT***	
LO	Detected	No	No	Yes	Absent	$T_J < T_{SHUT}$	No	***IDETECT***	
LO	Detected	No	No	No	Hot or Cold	$T_J < T_{SHUT}$	No	***OFF***	
LO	Detected	No	No	No	Ok	$T_J < T_{SHUT}$	No	***OFF***	
LO	Over Voltage	No	No	No	Ok	$T_J < T_{SHUT}$	No	***OFF***	
LO	Detected	No	No	No	Ok	$T_J < T_{SHUT}$	No	***ON***	***CHARGING***

In both STANDBY and SUSPEND modes the charge process is disabled. In the STANDBY mode all timers are reset; in SUSPEND mode the timers are held at the count stored when the suspend mode was set.

The timer fault, termination and output short circuit variables shown in the control logic table are latched in the detection circuits, outside the control logic. Refer to the timers, termination and short circuit protection sections for additional details on how those latched variables are reset.

The following states do not happen simultaneously due to the implementation of state machine flow:

- Termination detected and timer fault detected
- Battery absent function enabled when termination is not detected

TEMPERATURE QUALIFICATION (Applies only to versions with TS pin option)

The bq24060/62/64/65 devices continuously monitor the battery temperature by measuring the voltage between the TS and VSS pins. The IC compares the voltage on the TS pin against the internal $V_{(TS1)}$ and $V_{(TS2)}$ thresholds to determine if charging is allowed. Once a temperature outside the $V_{(TS1)}$ and $V_{(TS2)}$ thresholds is detected the IC immediately suspends the charge. The IC suspends charge by turning off the power FET and holding the timer value (i.e., timers are NOT reset). Charge is resumed when the temperature returns to the normal range.

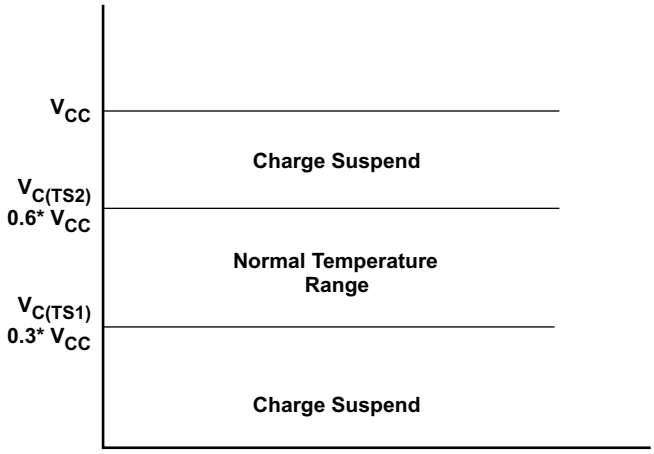


Figure 5. Battery Temperature Qualification With NTC Thermistor

The external resistors R_{T1} and R_{T2} (see application diagram) enable selecting a temperature window. If R_{TC} and R_{TH} are the thermistor impedances for the Cold and Hot thresholds the values for R_{T1} and R_{T2} can be calculated as follows, for a NTC (negative temperature coefficient) thermistor:

$$R_{T1} = \frac{\left(5 \times R_{\times} R_{TC}\right)}{\left(3 \times \left(R_{TC} - R_{TH}\right)\right)} \quad (1)$$

$$R_{T2} = \frac{\left(5 \times R_{\times} R_{TC}\right)}{\left[\left(2 \times R_{TC}\right) - \left(7 \times R_{TH}\right)\right]} \quad (2)$$

Applying a constant voltage between the V(TS1) and V(TS2) thresholds to pin TS disables the temperature sensing feature.

INPUT OVER-VOLTAGE DETECTION, POWER GOOD STATUS OUTPUT

The input power detection status for pin IN is shown at the open collector output pin $\overline{PG}$.

Table 2. Input Power Detection Status

INPUT POWER DETECTION (IN)	$\overline{PG}$ STATE
NOT DETECTED	High impedance
DETECTED, NO OVER-VOLTAGE	LO
DETECTED, OVER-VOLTAGE	High impedance

The bq2406x detects an input over-voltage when V(IN) > $V_{(OVP)}$. When an over-voltage protection is detected the charger function is turned off and the bq2460x is set to standby mode of operation. The OVP detection is not latched, and the IC returns to normal operation when the fault condition is removed.

CHARGE STATUS OUTPUTS

The open-collector STAT1 and STAT2 outputs indicate various charger operations as shown in Table 3. These status pins can be used to drive LEDs or communicate to the host processor. Note that OFF indicates the open-collector transistor is turned off. When termination is disabled the Done state is not available; the status LEDs indicate fast charge or pre-charge even if the charge current is lower than the termination detection threshold.

Table 3. Charge Status

Charge State	STAT1	STAT2
Precharge in progress	ON	ON
Fast charge in progress	ON	OFF
Done (termination enabled only)	OFF	ON
Charge Suspend (temperature)	OFF	OFF
Timer Fault		
Charger off		
Selected Input power over-voltage detected		
Battery absent		
Batteryshort		

BATTERY CHARGING: CONSTANT CURRENT PHASE

The bq2406x family offers on-chip current regulation. The current regulation is defined by the value of the resistor connected to ISET pin.

During a charge cycle the fast charge current $I_{O(OUT)}$ is applied to the battery if the battery voltage is above the $V_{(LOWV)}$ threshold (2.95 V typ):

$$I(OUT) = I_{O(OUT)} = \frac{V_{(SET)} \times K_{SET)}}{R_{ISET}} \quad (3)$$

Where $K_{(SET)}$ is the output current set factor and $V_{(SET)}$ is the output current set voltage.

During a charge cycle if the battery voltage is below the $V_{(LOWV)}$ threshold a pre-charge current $I_{(PRECHG)}$ is applied to the battery. This feature revives deeply discharged cells.

$$I(OUT) = I_{(PRECHG)} = \frac{V_{(PRECHG)} \times K_{SET)}}{R_{ISET}} \sim \frac{I_{O(OUT)}}{10} \quad (4)$$

Where $K_{(SET)}$ is the output current set factor and $V_{(PRECHG)}$ is the precharge set voltage.

CHARGE CURRENT TRANSLATOR

When the charge function is enabled internal circuits generate a current proportional to the charge current at pin ISET, this current, when applied to the external charge current programming resistor R_{ISET} generates an analog voltage that can be used by an external host to measure the charge current:

$$V(ISET) = I(OUT) \times \frac{R_{ISET}}{K_{(SET)}} \quad (5)$$

BATTERY VOLTAGE REGULATION

The battery pack voltage is sensed through the BAT pin, which is tied directly to the positive side of the battery pack. The bq2406x monitors the battery pack voltage between the BAT and VSS pins. When the battery voltage rises to $V_{O(REG)}$ threshold the voltage regulation phase begins and the charging current begins to taper down. The voltage regulation threshold $V_{O(REG)}$ is fixed by an internal IC voltage reference. Two charge regulation voltages are available: 4.2 V (typ., bq24060/61/62/63/64) and 4.36 V (typ., bq24065/66).

PRE-CHARGE TIMER

The bq2406x family activates an internal safety timer during the battery pre-conditioning phase. If the TMR pin is left open (floating) the pre-charge timer is disabled. The charge safety timer time-out value is set by the external resistor connected to TMR pin, R_{TMR} and the timeout constants $K_{(PCHG)}$ and $T_{(CHG)}$:

$T_{(PCHG)} = K_{(PCHG)} \times T_{(CHG)}$

The pre-charge timer operation is detailed in Table 4.

Table 4. Pre-Charge Timer Operational Modes

bq2460X MODE	V(OUT) > $V_{(LOWV)}$	PRE-CHARGE TIMER MODE
STANDBY	X	***RESET***
CHARGING	Yes	***RESET***
SUSPEND	Yes	***RESET***
SUSPEND	No	***SUSPEND***
CHARGING, TMR PIN NOT OPEN	No	***COUNTING, EXTERNAL PROGRAMMED RATE***
CHARGING, TMR PIN OPEN	X	***RESET***

In SUSPEND mode the pre-charge timer is put on hold (i.e., pre-charge timer is not reset), normal operation resumes when the timer returns to the normal operating mode (COUNTING). If V(BAT) does not reach the internal voltage threshold $V_{(LOWV)}$ within the pre-charge timer period a fault condition is detected, the charger is turned off and the pre-charge safety timer fault condition is latched.

When the pre-charge timer fault latch is set the charger is turned off. Under those conditions a small current I_{FAULT} is applied to the OUT pin, as long as input power (IN) is detected **AND** V(OUT) < $V_{(LOWV)}$, as part of a timer fault recovery protocol. This current allows the output voltage to rise above the pre-charge threshold $V_{(LOWV)}$, resetting the pre-charge timer fault latch when the pack is removed. Table 5 further details the pre-charge timer fault latch operation.

Table 5. Pre-Charge Timer Latch Functionality

PRE-CHARGE TIMER FAULT LATCHED WHEN	PRE-CHARGE TIMER FAULT LATCH RESET AT
Pre-charge timer timeout **AND** V(OUT) > $V_{(PRECH)}$	$\overline{CE}$ rising edge or OVP detected
	Input power removed (not detected)
	New charging cycle started; see state diagram
	Timer function disabled

THERMAL PROTECTION LOOP

An internal control loop monitors the bq2406x junction termperature (T_J) to ensure safe operation under input voltage transients, or unexpected printed circuit board temperature increase. This loop monitors the bq2406x junction temperature and reduces the charge current when the IC junction temperature exceeds an internally set reference temperature, $T_{J(REG)}$, (112°C, typical). The bq2406x has a minimum charge current, I(MIN_TJ(REG)), in thermal regulation (200 mA, typical). If the input voltage is set too high, the junction temperature exceeds the regulation point and approaches thermal shutdown.

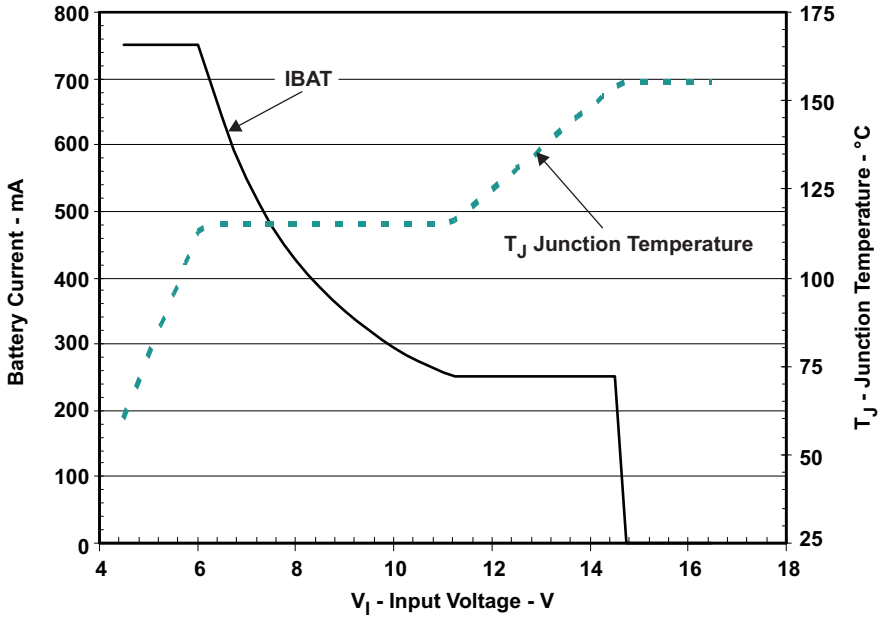


Figure 6. Thermal Regulation Loop Performance

DYNAMIC TIMER FUNCTION

The charge and pre-charge safety timers are programmed by the user to detect a fault condition if the charge cycle duration exceeds the total time expected under normal conditions. The expected charge time is usually calculated based on the fast charge current rate.

When the thermal loop is activated the charge current is reduced, and a false safety timer fault can be observed if the thermal loop is active for a long period of time. To avoid this undesirable fault condition the bq2406x activates the dynamic timer control, an internal circuit that slows down the safety timer's clock. The dynamic timer control circuit effectively adds an extra time to the programmed timeout value. The dynamic timer control circuit is enabled under the following conditions:

1. If battery voltage is below the pre-charge threshold: the pre-charge timer value is modified while the Thermal regulation loop is active
2. If the battery voltage is above the pre-charge threshold: the safety timer value is modified if the Thermal regulation loop is active.

The bq2406x dynamic timer control (DTC) monitors the voltage at pin ISET during pre-charge and fast charge, and increases the safety timers effective timeout value when the charge current is out of regulation and the thermal loop is active. Under normal current regulation operation, the voltage at pin ISET is set by the control loops to either $V_{(SET)}$ or $V_{(PRECHG)}$. If the thermal loop is active, the voltage at pin ISET is lower than the regulation voltage, and the DTC circuit changes the safety timers clock period based on the $V_{(SET)}/V_{(ISET)}$ ratio (fast charge) or $V_{(PRECHG)}/V(SET)$ ratio (pre-charge). Typical safety timer multiplier values relative to the $V_{(SET)}/V_{(ISET)}$ ratio is shown in the following graph.

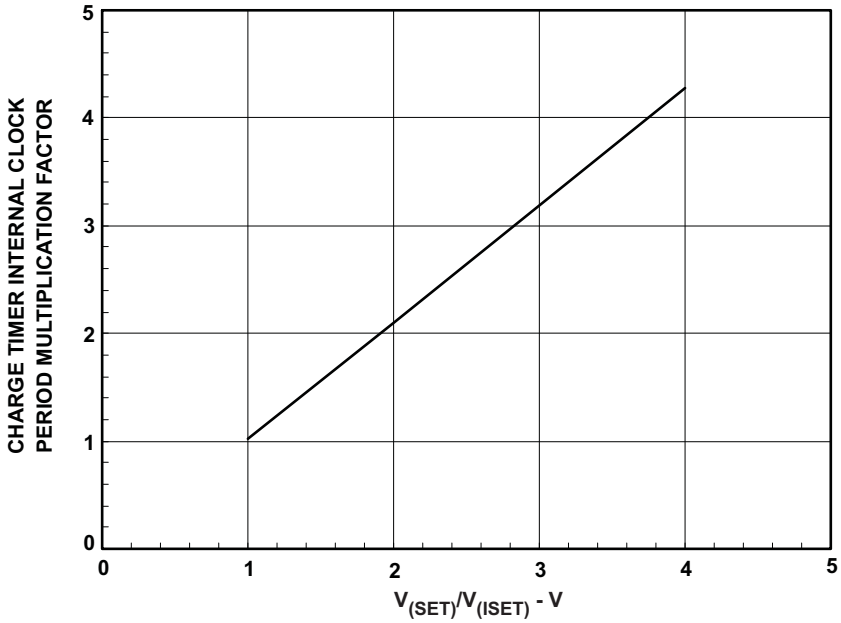


Figure 7. Safety Timer Linearity Internal Clock Period Multiplication Factor

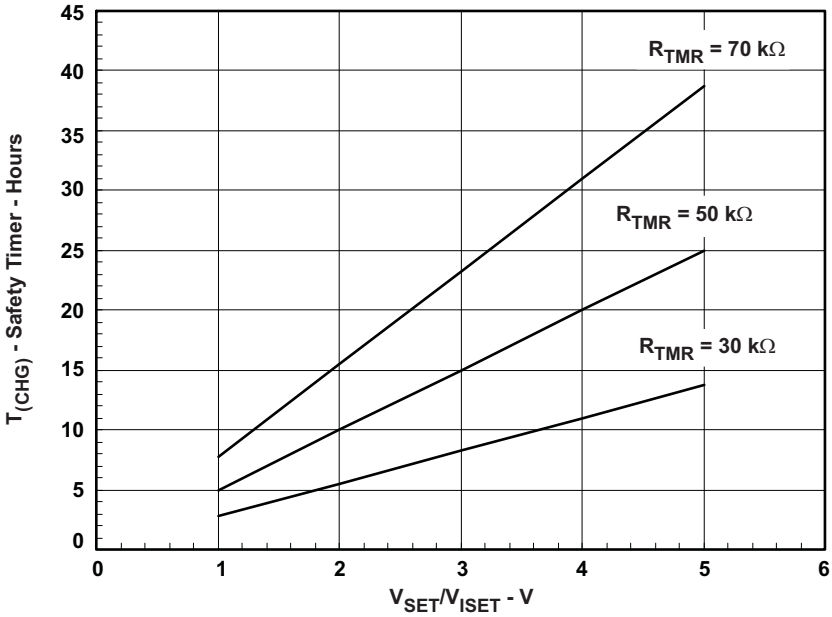


Figure 8. bq2406x Safety Timer Linearity for R_{TMR} Values

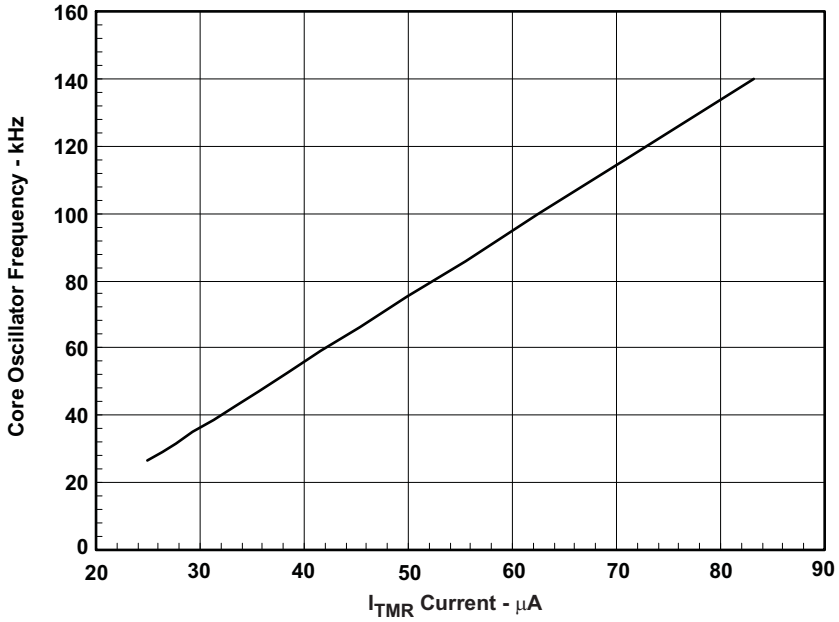


Figure 9. bq2406x Oscillator Linearity vs I_{TMR}
R_{TMR} 30 KΩ – 100 KΩ

THERMAL SHUTDOWN AND PROTECTION

Internal circuits monitor the junction temperature, T_J, of the die and suspends charging if T_J exceeds an internal threshold $T_{(SHUT)}$ (155°C typ). Charging resumes when T_J falls below the internal threshold $T_{(SHUT)}$ by approximately 20°C.

CHARGE TERMINATION DETECTION AND RECHARGE

The charging current is monitored the during the voltage regulation phase. Charge termination is indicated at the STATx pins (STAT1 = STAT2 = Hi-Z) once the charge current falls below the termination current threshold $I_{(TERM)}$. A deglitch period $T_{DGL(TERM)}$ is added to avoid false termination indication during transient events.

Charge termination is not detected if the charge current falls below the termination threshold as a result of the thermal loop activation. Termination is also not detected when charger enters the suspend mode, due to detection of invalid pack temperature or internal thermal shutdown.

The termination detection is latched; charger is disabled if termination is detected. If the charger is disabled by the host or a new charge cycle starts the termination latch is reset. Table 6 describes the termination latch functionality.

Table 6. Termination Latch Functionality

TERMINATION DETECTED LATCHED WHEN	TERMINATION LATCH RESET AT
$I(OUT) < I_{(TERM)}$ **AND** $t > T_{DGL(TERM)}$ **AND** $V(OUT) > V_{(RCH)}$	$\overline{CE}$ rising edge of OVP detected
	New charging cycle started; see state diagram
	Termination disabled

The termination function is DISABLED:

1. In bq24060/61/62/64/65 the termination is disabled when the TMR pin is left open (floating).
2. In bq24063 leaving TMR pin open (floating) does NOT disable the termination. The only way to disable termination in the bq24063 is to set $\overline{TE}$ = HIGH.

BATTERY ABSENT DETECTION – VOLTAGE MODE ALGORITHM

The bq2406x provides a battery absent detection scheme to reliably detect insertion and/or removal of battery packs. The detection circuit applies an internal current to the battery terminal, and detects battery presence based on the terminal voltage behavior. Figure 10 has a typical waveform of the output voltage when the battery absent detection is enabled and no battery is connected:

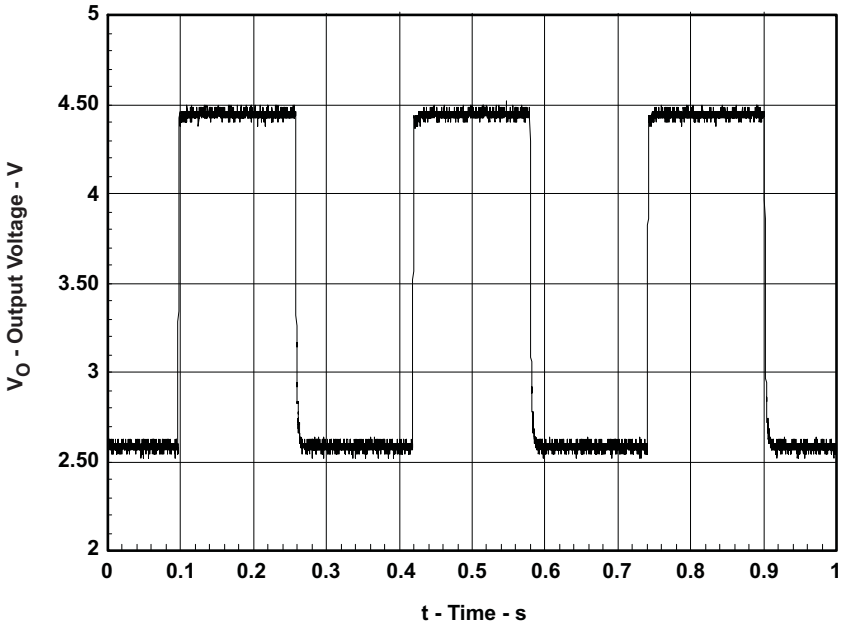


Figure 10. Battery-Absent Detection Waveforms

The battery absent detection function is disabled if the voltage at the BAT pin is held above the battery recharge threshold, $V_{(RCH)}$, after termination detection. When the voltage at the BAT pin falls to the recharge threshold, either by connection of a load to the battery or due to battery removal, the bq2406x begins a battery absent detection test. This test involves enabling a detection current, $I_{(DETECT)}$, for a period of $T_{(DETECT)}$ and checking to see if the battery voltage is below the pre-charge threshold, $V_{(LOWV)}$. Following this, the precharge current, $I_{O(PRECHG)}$ is applied for a period of $T_{(DETECT)}$ and the battery voltage checked again to be above the recharge threshold.

Passing both of the discharge and charging tests (battery terminal voltage being below the pre-charge and above the recharge thresholds on the battery detection test) indicates a battery absent fault at the STAT1 and STAT2 pins. Failure of either test starts a new charge cycle. For the absent battery condition the voltage on the BAT pin rises and falls between the $V_{(LOWV)}$ and $V_{O(REG)}$ thresholds indefinitely. See the operation flowchart for more details on this algorithm.

The battery absent detection function is disabled when the termination is disabled.

The bq2406x provides a small battery leakage current, IBAT(DONE) (1 μA typical), after termination to pull down the BAT pin voltage in the event of battery removal. If the leakage on the OUT pin is higher than this pulldown current, then the voltage at the pin remains above termination and a battery-absent state will not be detected. This problem is fixed with the addition of a pulldown resistor of 2 MΩ to 4 MΩ from the OUT pin to VSS. A resistor too large (> 4 MΩ) can cause the OUT pin voltage to drop below the V(LOWV) threshold before the recharge deglitch (typ 25 ms) expires, causing a fault condition. In this case the bq2406x provides a fault current (typ 750 μA) to pull the pin above the termination threshold.

CHARGE SAFETY TIMER

As a safety mechanism the bq2406x has a user-programmable timer that monitors the total fast charge time. This timer (charge safety timer) is started at the end of the pre-conditioning period. The safety charge timeout value is set by the value of an external resistor connected to the TMR pin (R_{TMR}); if pin TMR is left open (floating) the charge safety timer is disabled.

The charge safety timer time-out value is calculated as follows:

$T_{(CHG)} = [K_{(CHG)} \times R_{(TMR)}]$

The safety timer operation modes are shown in Table 7

Table 7. Charge Safety Timer Operational Modes

bq2460X	V(OUT) > $V_{(LOWV)}$	CHARGE SAFETY TIMER MODE
STANDBY	X	***RESET***
CHARGING	No	***RESET***
SUSPEND	No	***RESET***
SUSPEND	Yes	***SUSPEND***
CHARGING, TMR PIN NOT OPEN	Yes	***COUNTING***
CHARGING, TMR PIN OPEN	X	***RESET***

In SUSPEND mode the charge safety timer is put on hold (i.e., charge safety timer is not reset), normal operation resumes when the timer returns to the normal operating mode (COUNTING). If charge termination is not reached within the timer period a fault condition is detected. Under those circumstances the LED status is updated to indicate a fault condition and :

1. bq24060/61/62/64/65/66: charger is turned off and the charge safety timer fault condition is latched.
2. bq24063, $\overline{TE}$ = LO: charger is turned off and the charge safety timer fault condition is latched.
3. bq24063 $\overline{TE}$ pin, = HI: charger is not turned OFF, timer fault condition is latched and indicated in STAT1, STAT2 pins. Charger is turned OFF when $\overline{TE}$:HI→LO, and charge current is below termination threshold $I_{(TERM)}$.

When the charge safety timer fault latch is set and the charger is turned off a small current IFAULT is applied to the OUT pin, as long as input power (IN) is detected **AND** V(OUT) < $V_{(RCHG)}$, as part of a timer fault recovery protocol. This current allows the output voltage to rise above the recharge threshold $V_{(RCHG)}$ if the pack is removed, and assures that the charge safety timer fault latch is reset if the pack is removed and re-inserted. Table 8 further details the charge safety timer fault latch operation.

Table 8. Charge Safety Timer Latch Functionality

CHARGE SAFETY TIMER FAULT LATCHED AND	CHARGE SAFETY TIMER FAULT LATCH RESET AT
V(OUT) > $V_{(RCHG)}$	$\overline{CE}$ rising edge, or OVP detected
	Input power removed (not detected)
	New charging cycle started; see state diagram
V(OUT) < $V_{(RCHG)}$	$\overline{CE}$ rising edge, or OVP detected
	Input power removed (not detected)
	New charging cycle started; see state diagram

LDO MODE OPERATION

The bq24060/61/62/64/65/66 devices operate as a LDO when the timer pin TMR is left open (floating). The bq24063 operates as an LDO when $\overline{TE}$ = HI.

When the LDO mode is set, the termination is disabled, and the charger is ON as long as the charging process is enabled.

When the LDO mode is set the termination is disabled and an external host can monitor the charge current at pin ISET, making it possible to continue the battery charging process until the charge current tapers down to a value lower than the internally set termination threshold (10% of fast charge programmed current).

SHORT CIRCUIT PROTECTION

The internal comparators monitor the battery voltage and detect when a short circuit is applied to the battery terminal. If the voltage at the BAT pin is less than the internal threshold V(scind) (1.8 V typical), the STAT pins indicate a fault condition (STAT1 = STAT2 = Hi-Z). When the voltage at the BAT pin falls below a second internal threshold V(sc) (1.4 V typical), the charger power stage is turned off. A recovery current, I(short) (22 mA typical), is applied to the BAT pin, enabling detection of the short circuit removal. The battery output current versus battery voltage is shown in the graph, Figure 11

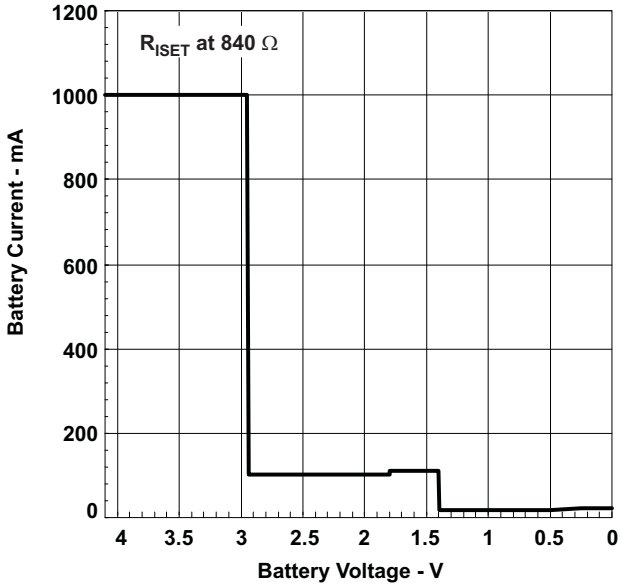


Figure 11. bq2406x Short Circuit Behavior

See the application section for additional details on start-up operation with V(BAT) < $V_{(SC)}$.

STARTUP WITH DEEPLY DEPLETED BATTERY CONNECTED

The bq2406x charger furnishes the programmed charge current if a battery is detected. If no battery is connected the bq2406x operates as follows:

- The output current is limited to 22 mA (typ), if the voltage at BAT pin is below the short circuit detection threshold $V_{(SC)}$, 1.8 V typical.
- The output current is regulated to the programmed pre-charge current if $V_{(SC)}$ < V(BAT) < $V_{(LOWV)}$.
- The output current is regulated to the programmed fast charge current If V(BAT) > $V_{(LOWV)}$ **AND** voltage regulation is not reached.

The output voltage collapses if no battery is present and the end equipment requires a bias current larger that the available charge current.

TYPICAL OPERATING CHARACTERISTICS

Measured using the typical application circuit shown previously.

THERMAL LOOP OPERATION
WITH POWERPAD ATTACHED

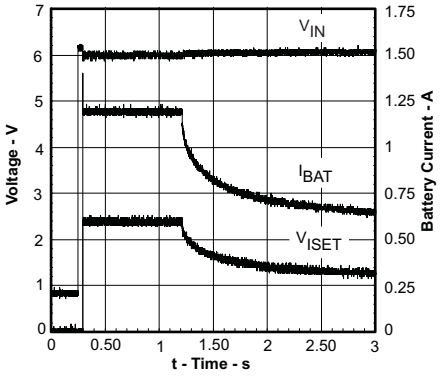


Figure 12.

THERMAL LOOP AND DTC OPERATION

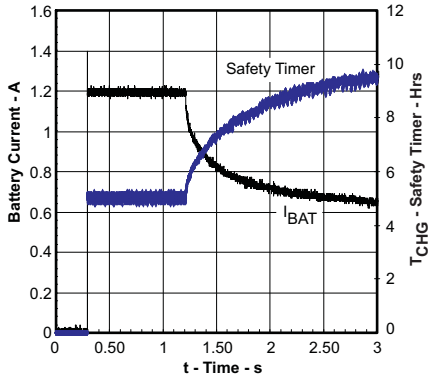


Figure 13.

PACK REMOVAL TRANSIENT

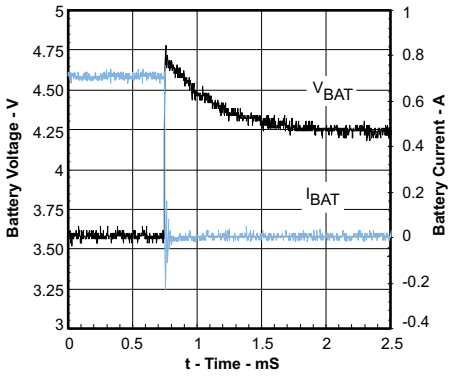


Figure 14.

OVP TRANSIENTS

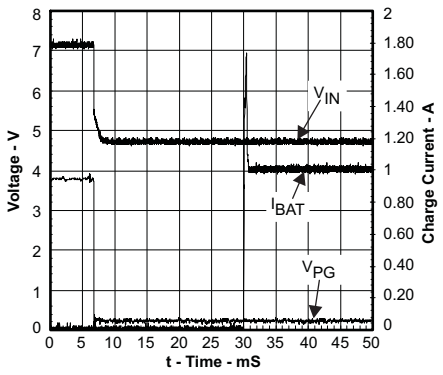


Figure 15.

PG DEGLITCH TIME

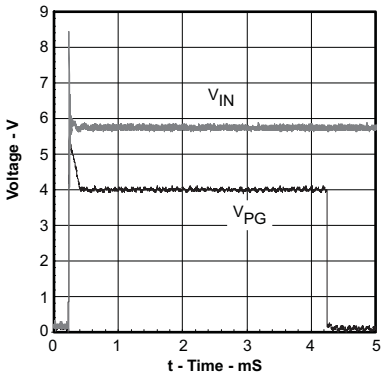


Figure 16.

POWER UP – NO BATTERY
$\overline{CE}$ = H

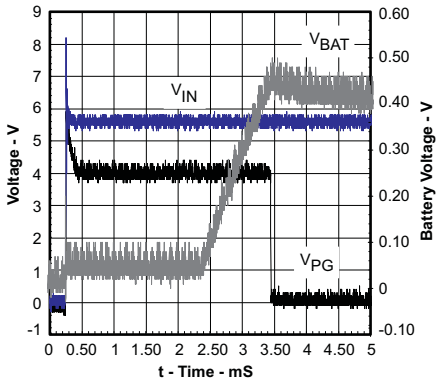


Figure 17.

TYPICAL OPERATING CHARACTERISTICS (continued)

Measured using the typical application circuit shown previously.

bq2406x ACTIVE SUPPLY CURRENT vs TEMPERATURE

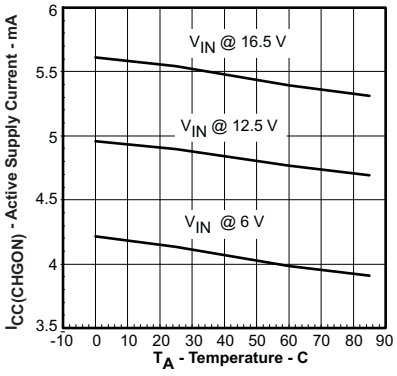


Figure 18.

PRE-CHARGE CURRENT vs BATTERY VOLTAGE

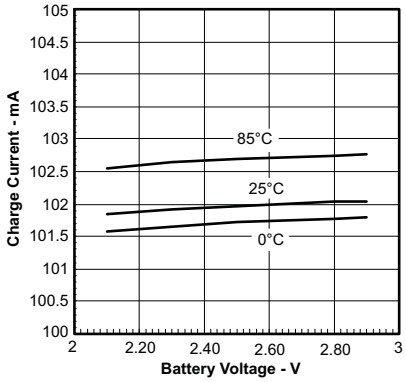


Figure 19. HIGH CHARGE RATE

PRE-CHARGE CURRENT vs BATTERY VOLTAGE

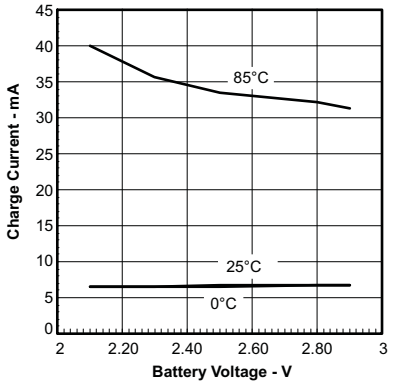


Figure 20. LOW CURRENT RATE

FAST-CHARGE CURRENT vs BATTERY VOLTAGE

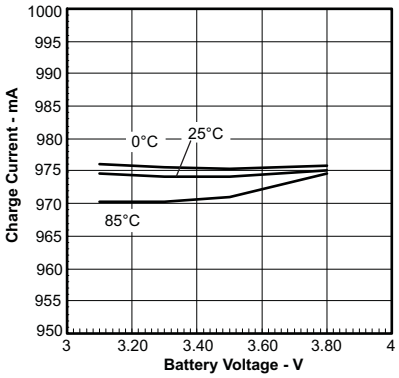


Figure 21. HIGH CHARGE RATE

FAST-CHARGE CURRENT vs BATTERY VOLTAGE

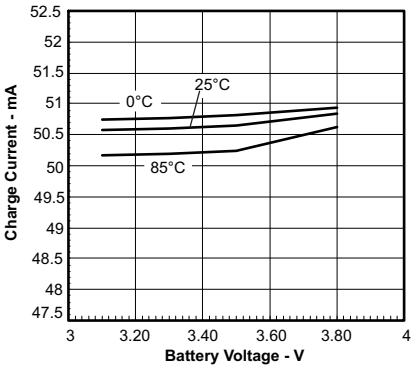


Figure 22. LOW CHARGE RATE

KSET LINEARITY vs CHARGE CURRENT

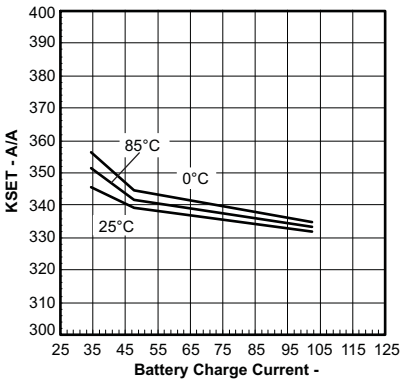


Figure 23. 2.0 < $V_{(BAT)}$ < 3.0 V

KSET LINEARITY vs CHARGE CURRENT

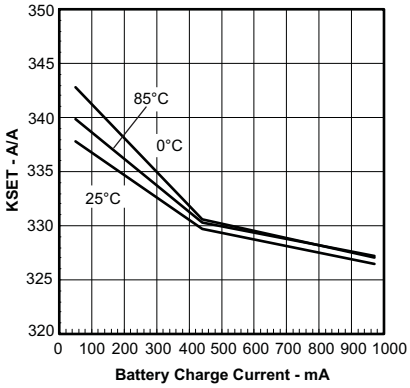


Figure 24. 3.0 < $V_{(BAT)}$ < 4.0 V

BATTERY REGULATION VOLTAGE vs INPUT VOLTAGE

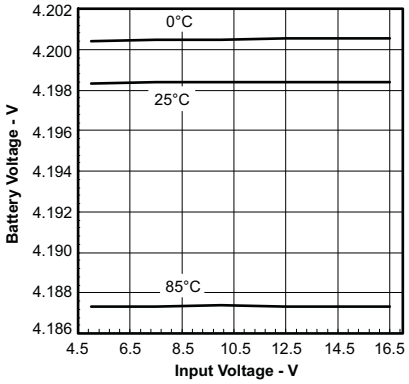


Figure 25.

DROPOUT VOLTAGE vs TEMPERATURE

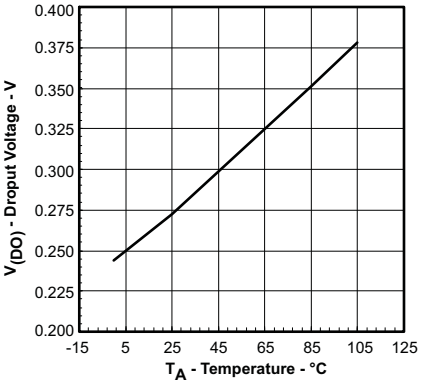


Figure 26.

APPLICATION INFORMATION

SELECTING INPUT AND OUTPUT CAPACITOR

In most applications, all that is needed is a high-frequency decoupling capacitor on the input power pin. A 1-µF ceramic capacitor, placed in close proximity to the IN pin and GND pad, works fine. In some applications, depending on the power supply characteristics and cable length, it may be necessary to increase the input filter capacitor to avoid exceeding the IN pin maximum voltage rating during adapter hot plug events.

The bq2406x only requires a small output capacitor for loop stability. A 0.47 µF ceramic capacitor placed between the BAT and ISET pad is typically sufficient.

bq2406x CHARGER DESIGN EXAMPLE

Requirements

- Supply voltage = 5 V
- Safety timer duration of 5 hours for fast charge
- Fast charge current of approximately 750 mA
- Battery temp sense is not used

Calculations

Program the charge current for 750 mA:

$R_{ISET} = [V_{(SET)} \times K_{(SET)} / I_{(OUT)}]$

from electrical characteristics table. . . $V_{(SET)} = 2.5$ V

from electrical characteristics table. . . $K_{(SET)} = 335$

$R_{ISET} = [2.5\ V \times 335 / 0.75\ A] = 1.12\ k\Omega$

Selecting the closest standard value, use a 1.13 kΩ resistor connected between ISET (pin 6) and ground.

Program 5-hour safety timer timeout:

$R_{(TMR)} = [T_{(CHG)} / K_{(CHG)}]$

from the electrical characteristics table. . . $K_{(CHG)} = 0.1$ hr / kΩ

$K_{(TMR)} = [5\ hrs / (0.1\ hr / k\Omega)] = 50\ k\Omega$

Selecting the closest standard value, use a 49.9 kΩ resistor connected between TMR (pin 2) and ground.

Disable the temp sense function:

A constant voltage between V_{TS1} and V_{TS2} on the TS input disables the temp sense function.

from electrical characteristics table. . . $V_{(TS1)} = 30\% \times V_{IN}$

from electrical characteristics table. . . $V_{(TS2)} = 61\% \times V_{IN}$

A constant voltage of 50% × Vin disables the temp sense function, so a divide-by-2 resistor divider connected between Vin and ground can be used. Two 1-mΩ resistors keeps the power dissipated in this divider to a minimum.

PIN	COMPONENTS
IN	In most applications, the minimum input capacitance needed is a 0.1 µF ceramic decoupling capacitor near the input pin connected to ground (preferably to a grond plane through vias). The recommended amount of input capacitance is 1 µF or at least as much as on the output pin. This added capacitance helps with hot plug transients, input inductance and initial charge transients.
OUT	There is no minimum value for capacitance for this output, but it is recommended to connect a 1 µF ceramic capacitor between OUT and ground. This capacitance helps with termination, and cycling frequency between *charge done* and refresh charge when no battery is present. It also helps cancel out any battery lead inductance for long leaded battery packs. It is recommended to put as much ceramic capacitance on the input as the output so as not to cause a drop out of the input when charging is initiated.

APPLICATION INFORMATION (continued)

ISET/BAT	For stability reasons, it may be necessary to put a 0.47-µF capacitor between the ISET and BAT pin..
STAT1/2 and $\overline{PG}$	Optional (LED STATUS – See below, Processor Monitored; or no status)
STAT1	Connect the cathode of a red LED to the open-collector STAT1 output, and connect the anode of the red LED to the input supply through a 1.5 kΩ resistor that limits the current.
STAT2	Connect the cathode of a green LED to the open-collector STAT2 output, and connect the anode of the green LED to the input supply through a 1.5 kΩ resistor that limits the current.
$\overline{PG}$	Connect the cathode of an LED to the open-collector $\overline{PG}$ output, and connect the anode of the LED to the input supply through a 1.5 kΩ resistor to limit the current.

THERMAL CONSIDERATIONS

The bq2406x family is packaged in a thermally enhanced MLP package. The package includes a thermal pad to provide an effective thermal contact between the IC and the printed circuit board (PCB). Full PCB design guidelines for this package are provided in the application note entitled: *QFN/SON PCB Attachment Application Note* (SLUA271).

The most common measure of package thermal performance is thermal impedance (θ_{JA}) measured (or modeled) from the chip junction to the air surrounding the package surface (ambient). The mathematical expression for θ_{JA} is:

$$\theta(JA) = \frac{T_J - T_A}{P} \quad (6)$$

Where:

T_J = chip junction temperature

T_A = ambient temperature

P = device power dissipation

Factors that can greatly influence the measurement and calculation of θ_{JA} include:

- Whether or not the device is board mounted
- Trace size, composition, thickness, and geometry
- Orientation of the device (horizontal or vertical)
- Volume of the ambient air surrounding the device under test and airflow
- Whether other surfaces are in close proximity to the device being tested

The device power dissipation, P, is a function of the charge rate and the voltage drop across the internal PowerFET. It can be calculated from the following equation when a battery pack is being charged :

$P = [V(IN) – V(OUT)] \times I(OUT)$

Due to the charge profile of Li-Ion batteries the maximum power dissipation is typically seen at the beginning of the charge cycle when the battery voltage is at its lowest. See the charging profile, Figure 1 .

If the board thermal design is not adequate the programmed fast charge rate current may not be achieved under maximum input voltage and minimum battery voltage, as the thermal loop can be active effectively reducing the charge current to avoid excessive IC junction temperature.

USING ADAPTERS WITH LARGE OUTPUT VOLTAGE RIPPLE

Some low cost adapters implement a half rectifier topology, which causes the adapter output voltage to fall below the battery voltage during part of the cycle. To enable operation with low cost adapters under those conditions the bq2406x family keeps the charger on for at least 30 msec (typical) after the input power was not detected. This feature enables use of external low cost adapters using 50 Hz networks.

The backgate control circuit prevents any reverse current flowing from the battery to the adapter terminal during the charger off delay time.

APPLICATION INFORMATION (continued)

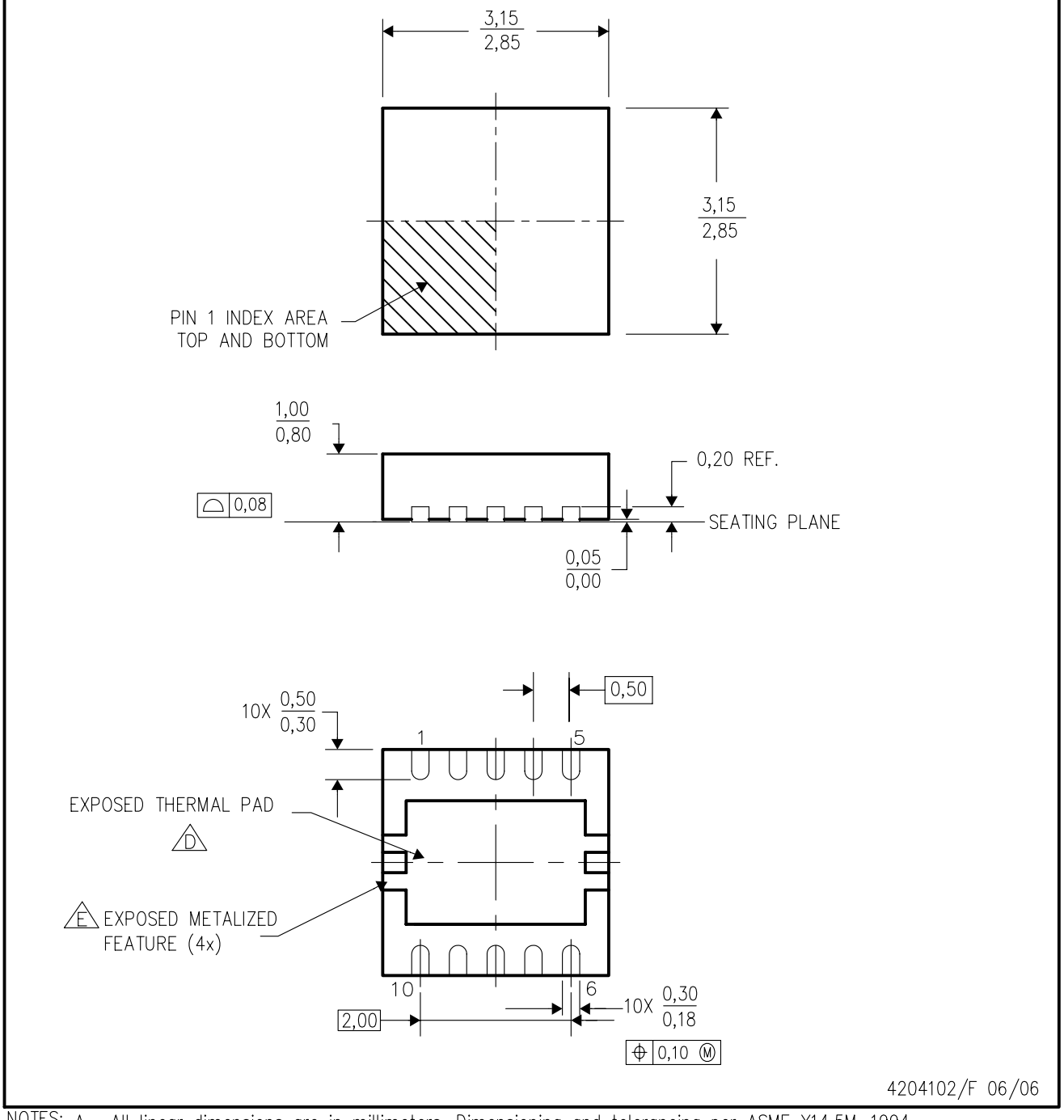
Note that the $\overline{PG}$ pin is not deglitched, and it indicates input power loss immediately after the input voltage falls below the output voltage. If the input source frequently drops below the output voltage and recovers, a small capacitor can be used from $\overline{PG}$ to VSS to prevent /PG flashing events.

PCB LAYOUT CONSIDERATIONS

It is important to pay special attention to the PCB layout. The following provides some guidelines:

- To obtain optimal performance, the decoupling capacitor from IN to GND (thermal pad) and the output filter capacitors from OUT to GND (thermal pad) should be placed as close as possible to the bq2406x, with short trace runs to both IN, OUT and GND (thermal pad).
- All low-current GND connections should be kept separate from the high-current charge or discharge paths from the battery. Use a single-point ground technique incorporating both the small signal ground path and the power ground path.
- The high current charge paths into IN pin and from the OUT pin must be sized appropriately for the maximum charge current in order to avoid voltage drops in these traces.
- The bq2406x family are packaged in a thermally enhanced MLP package. The package includes a thermal pad to provide an effective thermal contact between the IC and the printed circuit board (PCB); this thermal pad is also the main ground connection for the device. Connect the thermal pad to the PCB ground connection. Full PCB design guidelines for this package are provided in the application note entitled: *QFN/SON PCB Attachment Application Note* (SLUA271).

DRC (S–PDSO–N10) PLASTIC SMALL OUTLINE



NOTES:
A. All linear dimensions are in millimeters. Dimensioning and tolerancing per ASME Y14.5M–1994.
B. This drawing is subject to change without notice.
C. Small Outline No–Lead (SON) package configuration.
D. The package thermal pad must be soldered to the board for thermal and mechanical performance. See the Product Data Sheet for details regarding the exposed thermal pad dimensions.
E. Metalized features are supplier options and may not be on the package.

THERMAL PAD MECHANICAL DATA

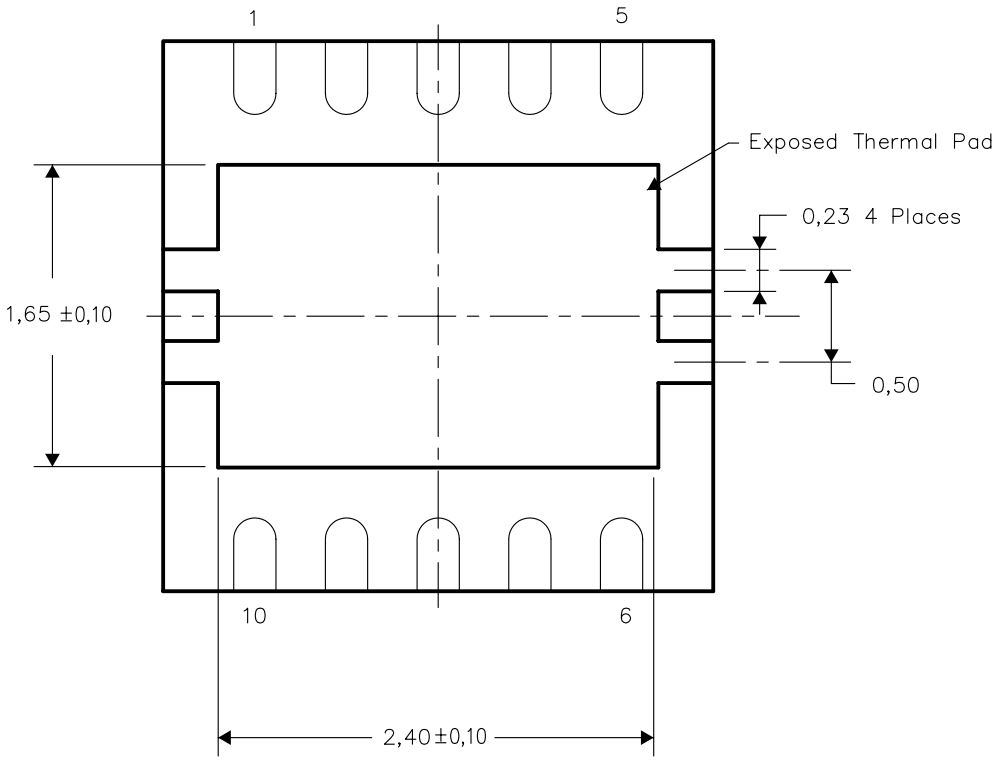
DRC (S–PDSO–N10)

THERMAL INFORMATION

This package incorporates an exposed thermal pad that is designed to be attached directly to an external heatsink. The thermal pad must be soldered directly to the printed circuit board (PCB). After soldering, the PCB can be used as a heatsink. In addition, through the use of thermal vias, the thermal pad can be attached directly to a ground or power plane (whichever is applicable), or alternatively, a special heatsink structure designed into the PCB. This design optimizes the heat transfer from the integrated circuit (IC).

For information on the Quad Flatpack No–Lead (QFN) package and its advantages, refer to Application Report, Quad Flatpack No–Lead Logic Packages, Texas Instruments Literature No. SCBA017. This document is available at www.ti.com.

The exposed thermal pad dimensions for this package are shown in the following illustration.

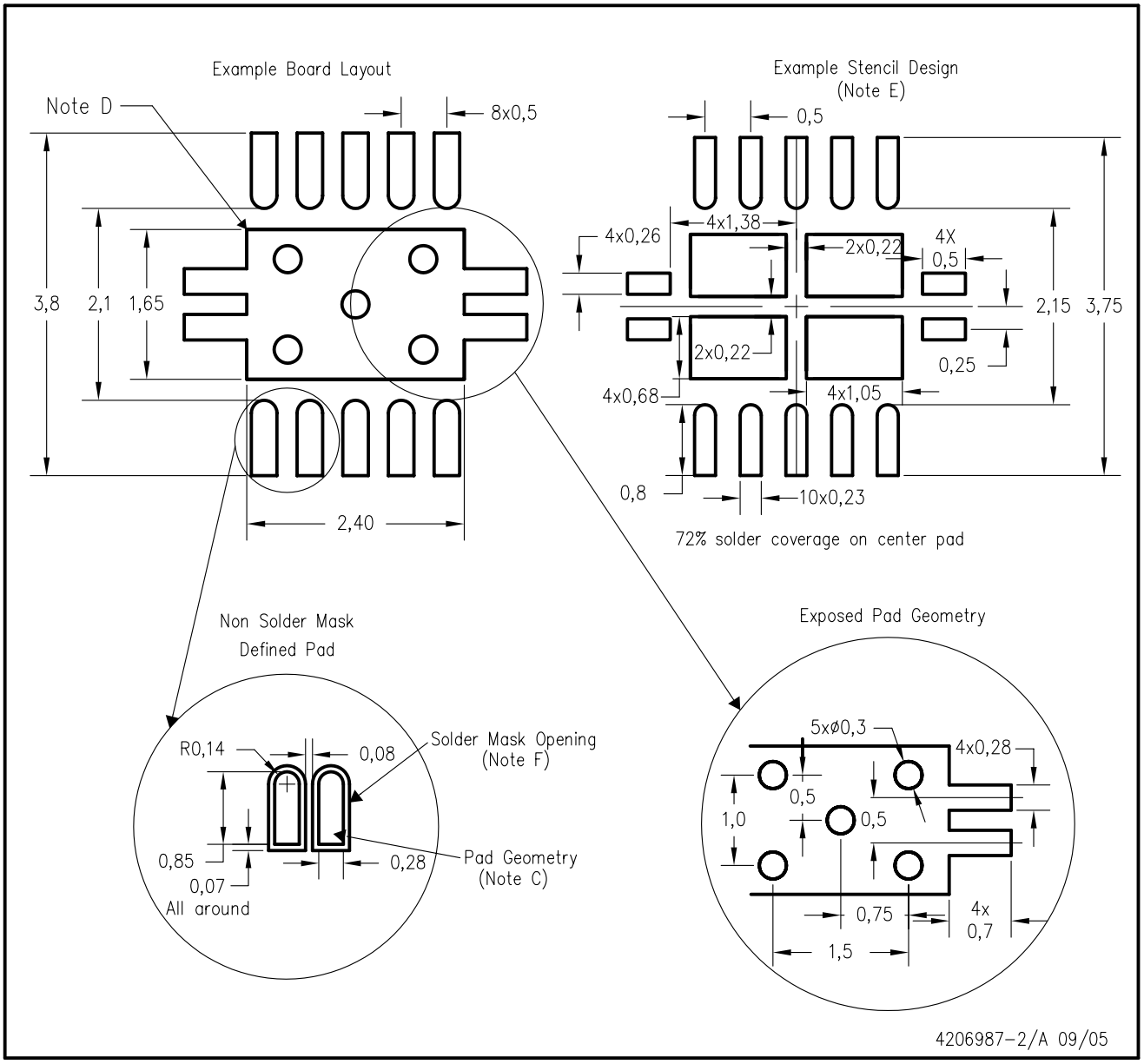


Bottom View

NOTE: All linear dimensions are in millimeters

Exposed Thermal Pad Dimensions

DRC (S–PDSO–N10)



NOTES:
A. All linear dimensions are in millimeters.
B. This drawing is subject to change without notice.
C. Publication IPC–7351 is recommended for alternate designs.
D. This package is designed to be soldered to a thermal pad on the board. Refer to Application Note, Quad Flat–Pack Packages, Texas Instruments Literature No. SCBA017, SLUA271, and also the Product Data Sheets for specific thermal information, via requirements, and recommended board layout. These documents are available at www.ti.com <http: //www.ti.com>.
E. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC 7525 for stencil design considerations.
F. Customers should contact their board fabrication site for minimum solder mask web tolerances between signal pads.

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