Ultra Low Power Harvester Power Management IC with Boost Charger, and Nano-Powered Buck Converter

Check for Samples: bq25570

FEATURES

- **Ultra Low Power DC/DC Boost Charger**
  - **Cold-start Voltage: VIN ≥ 330 mV**
  - **Continuous Energy Harvesting From VIN as low as 120 mV**
  - **Input Voltage Regulation Prevents Collapsing High Impedance Input Sources**
  - **Full Operating Quiescent Current of 488 nA (typical)**
  - **Ship Mode with < 5 nA From Battery**
- **Energy Storage**
  - **Energy can be Stored to Re-chargeable Li-ion Batteries, Thin-film Batteries, Super-capacitors, or Conventional Capacitors**
- **Battery Charging and Protection**
  - **Internally Set Undervoltage Level**
  - **User Programmable Overvoltage Levels**
- **Battery Good Output Flag**
  - **Programmable Threshold and Hysteresis**
  - **Warn Attached Microcontrollers of Pending Loss of Power**
  - **Can be Used to Enable or Disable System Loads**
- **Programmable Step Down Regulated Output (Buck)**
  - **High Efficiency up to 98%**
  - **Supports Peak Output Current up to 110 mA (typical)**
- **Programmable Maximum Power Point Tracking (MPPT)**
  - **Provides Optimal Energy Extraction From a Variety of Energy Harvesters including Solar Panels, Thermal and Piezo Electric Generators**

APPLICATIONS

- **Energy Harvesting**
- **Solar Charger**
- **Thermal Electric Generator (TEG) Harvesting**
- **Wireless Sensor Networks (WSN)**
- **Low Power Wireless Monitoring**
- **Environmental Monitoring**
- **Bridge and Structural Health Monitoring (SHM)**
- **Smart Building Controls**
- **Portable and Wearable Health Devices**
- **Entertainment System Remote Controls**

DESCRIPTION

The bq25570 is a highly integrated energy harvesting Nano-Power management solution that is well suited for meeting the special needs of ultra low power applications. The product is specifically designed to efficiently acquire and manage the microwatts (µW) to milliwatts (mW) of power generated from a variety of DC sources like photovoltaic (solar) or thermal electric generators. The bq25570 is the first device of its kind to implement a highly efficient boost converter/charger with a nano-powered buck converter targeted toward products and systems, such as wireless sensor networks (WSN) which have stringent power and operational demands. The design of the bq25570 starts with a dc/dc boost converter/charger that requires only microwatts of power to begin operating. Once started, the boost converter/charger can effectively extract power from low voltage output harvesters such as thermoelectric generators (TEGs) or single or dual cell solar panels. The boost converter can be started with VIN as low as 330 mV, and once started, can continue to harvest energy down to VIN = 100 mV

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

DESCRIPTION CONTINUED

The bq25570 also implements a programmable maximum power point tracking sampling network to optimize the transfer of power into the device. The fraction of open circuit voltage that is sampled and held can be controlled by pulling VOC_SAMP high or low (80% or 50% respectively) or by using external resistors. This sampled voltage is maintained via internal sampling circuitry and held with an external capacitor (CREF) on the VREF_SAMP pin. For example, solar cells typically operate with a maximum power point (MPP) of 80% of their open circuit voltage. Connecting VOC_SAMP to VSTOR sets the MPPT threshold to 80% and results in the IC regulating the voltage on the solar cell to ensure that the VIN_DC voltage does not fail below the voltage on CREF which equals 80% of the solar panel's open circuit voltage. Alternatively, an external reference voltage can be provided by a MCU to produce a more complex MPPT algorithm. In addition to the boost charging front end, the bq25570 provides the system with an externally programmable regulated supply via the buck converter. The regulated output has been optimized to provide high efficiency across low output currents (< 10 μA) to high currents (~110 mA).

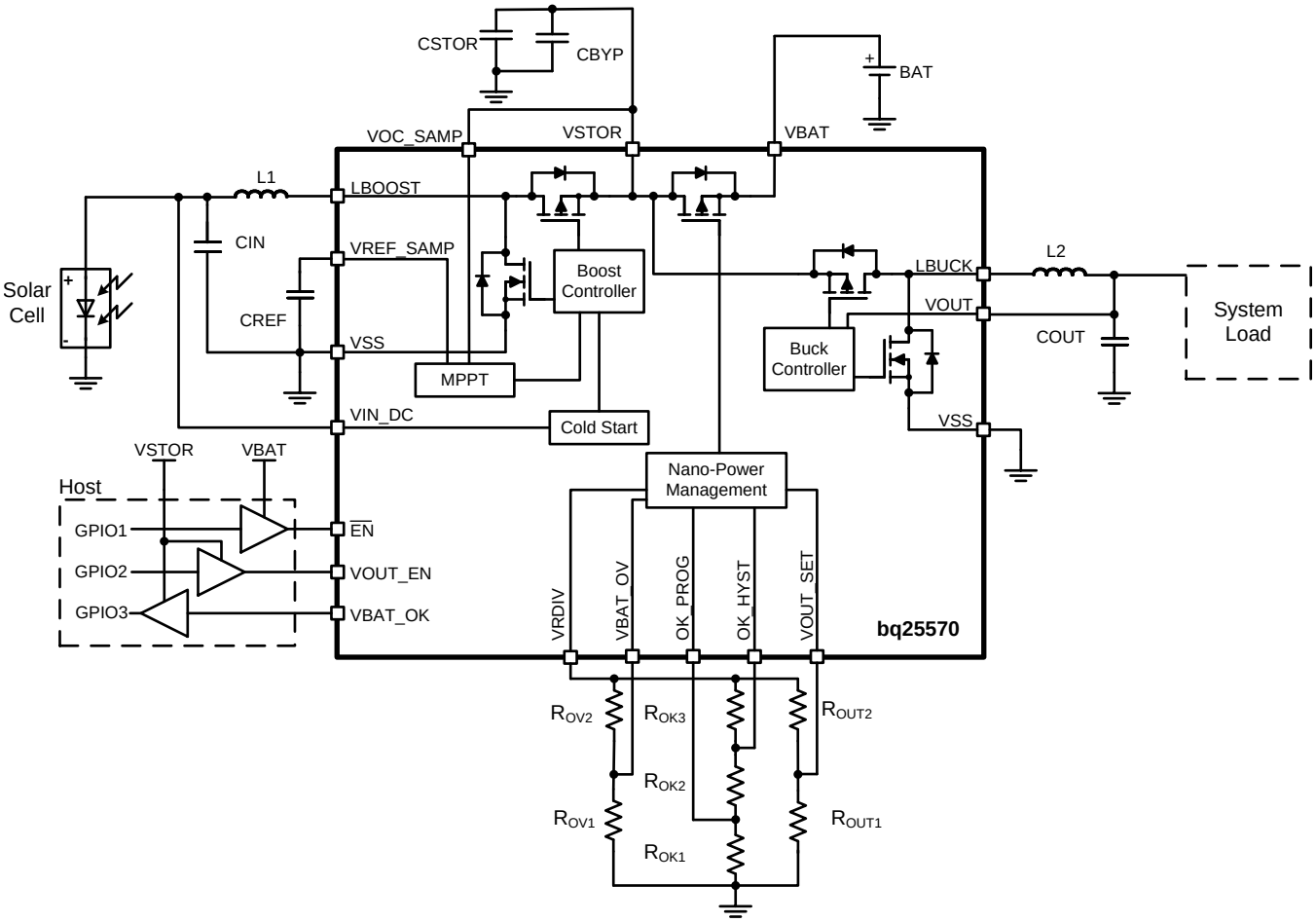
The bq25570 is designed with the flexibility to support a variety of energy storage elements. The availability of the sources from which harvesters extract their energy can often be sporadic or time-varying. Systems will typically need some type of energy storage element, such as a re-chargeable battery, super capacitor, or conventional capacitor. The storage element will make certain constant power is available when needed for the systems. The storage element also allows the system to handle any peak currents that can not directly come from the input source.

To prevent damage to a customer’s storage element, both maximum and minimum voltages are monitored against the internally set under-voltage (UV) and user programmable over-voltage (OV) levels.

To further assist users in the strict management of their energy budgets, the bq25570 toggles the battery good (VBAT_OK) flag to signal an attached microprocessor when the voltage on an energy storage battery or capacitor has dropped below a pre-set critical level. This should trigger the reduction of load currents to prevent the system from entering an under voltage condition. There is also independent enable signals to allow the system to control when to run the regulated output or even put the whole IC into an ultra-low quiescent current sleep state.

All the capabilities of bq25570 are packed into a small foot-print 20-lead 3.5mm x 3.5 mm QFN package (RGR).

TYPICAL APPLICATION SCHEMATIC



ORDERING INFORMATION

PART NO.	PACKAGE	ORDERING NUMBER (TAPE AND REEL)(1)	PACKAGE MARKING	QUANTITY
bq25570	QFN RGR	bq25570RGRR	B5570	3000
		bq25570RGRT	B5570	250

(1) The RGR package is available in tape on reel. Add R suffix to order quantities of 3000 parts per reel, T suffix for 250 parts per reel.

ABSOLUTE MAXIMUM RATINGS(1)

over operating free-air temperature range (unless otherwise noted)

		VALUE		UNIT
		MIN	MAX	
Input voltage	VIN_DC, VOC_SAMP, VREF_SAMP, VBAT_OV, VRDIV, OK_HYST, OK_PROG, VBAT_OK, VBAT, VSTOR, LBOOST, EN, VOUT_EN, VOUT_SET, LBUCK, VOUT(2)	–0.3	5.5	V
Peak Input Power, PIN_PK			400	mW
Operating junction temperature range, T_J		–40	125	°C
Storage temperature range, T_{STG}		–65	150	°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) All voltage values are with respect to V_{SS}/ground terminal.

THERMAL INFORMATION

THERMAL METRIC(1)(2)		bq25570	UNITS
		RGR (20 PINS)	
θ_{JA}	Junction-to-ambient thermal resistance	34.6	°C/W
θ_{JCtop}	Junction-to-case (top) thermal resistance	49.0	
θ_{JB}	Junction-to-board thermal resistance	12.5	
ψ_{JT}	Junction-to-top characterization parameter	0.5	
ψ_{JB}	Junction-to-board characterization parameter	12.6	
θ_{JCbot}	Junction-to-case (bottom) thermal resistance	1.0	

(1) For more information about traditional and new thermal metrics, see the *IC Package Thermal Metrics* application report, SPRA953.
(2) For thermal estimates of this device based on PCB copper area, see the TI PCB Thermal Calculator.

RECOMMENDED OPERATING CONDITIONS

		MIN	NOM	MAX	UNIT
VIN(DC)	DC input voltage into VIN_DC(1)	0.12		4.0	V
VBAT, VOUT	Voltage range(2)	2.0		5.5	V
CIN	Capacitance on VIN_DC pin	4.7			µF
CSTOR	Capacitance on VSTOR pin	4.7			µF
COUT	Capacitance on VOUT pin	10	22		µF
CBAT	Capacitance or battery with at least the same equivalent capacitance on VBAT pin	100			µF
CREF	Capacitance on VREF_SAMP that stores the samped VIN reference	9	10	11	nF
$R_{OC1} + R_{OC2}$	Total resistance for setting for MPPT reference if needed	18	20	22	MΩ
$R_{OK\ 1} + R_{OK\ 2} + R_{OK3}$	Total resistance for setting VBAT_OK threshold voltage.	11	13	15	MΩ
$R_{OUT1} + R_{OUT2}$	Total resistance for setting VOUT threshold voltage.	11	13	15	MΩ
$R_{OV1} + R_{OV2}$	Total resistance for setting VBAT_OV voltage.	11	13	15	MΩ
L1	Inductance on LBOOST pin	22			µH
L2	Inductance on LBUCK pin	4.7	10		µH
T_A	Operating free air ambient temperature	–40		85	°C
T_J	Operating junction temperature	–40		105	°C

(1) Maximum input power ≤ 400 mW. Cold start has been completed
(2) VBAT_OV setting must be higher than VIN_DC

ELECTRICAL CHARACTERISTICS

Over recommended temperature range, typical values are at T_A = 25°C. Unless otherwise noted, specifications apply for conditions of VSTOR = 4.2 V, VOUT = 1.8 V. External components, CIN = 4.7 µF, L1 = 22 µH, CSTOR= 4.7 µF, L2 = 10 µH, COUT = 22 µF

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
BOOST CHARGER						
VIN(DC)	DC input voltage into VIN_DC	Cold-start completed	120		4000	mV
I-CHG(CBC_LIM)	Cycle-by-cycle current limit of charger	0.5V < V_{IN} < 4.0 V; VSTOR = 4.2 V		230	285	mA
PIN	Input power range for normal charging	VBAT_OV > VSTOR > VSTOR_CHGEN	0.005		400	mW
VIN(CS)	Minimum input voltage for cold start circuit to start charging VSTOR	VBAT < VBAT_UV; VSTOR = 0 V; 0°C < T_A < 85°C		330	400	mV
VSTOR_CHGEN	Voltage on VSTOR when cold start operation ends and normal charger operation commences		1.6	1.73	1.9	V
PIN(CS)	Minimum cold-start input power for VSTOR to reach $VSTOR_{(CHGEN)}$ and allow normal charging to commence	VSTOR < $VSTOR_{(CHGEN)}$		5		µW
$t_{BAT\_HOT\_PLUG}$	Time for which switch between VSTOR and VBAT closes when battery is hot plugged into VBAT	Battery resistance = 300 Ω, Battery voltage = 3.3V		50		ms
QUIESCENT CURRENTS						
I_Q	$\overline{EN}$ = 0, VOUT_EN = 1 - Full operating mode	VIN_DC = 0V; VSTOR = 2.1V; T_J = 25°C		488	700	nA
		VIN_DC = 0V; VSTOR = 2.1V; –40°C < T_J < 85°C			900	
	$\overline{EN}$ = 0, VOUT_EN = 0 - Partial standby mode	VIN_DC = 0V; VSTOR = 2.1V; T_J = 25°C		445	615	
		VIN_DC = 0V; VSTOR = 2.1V; –40°C < T_J < 85°C			815	
	$\overline{EN}$ = 1, VOUT_EN = x - Ship mode	VBAT = 2.1 V; T_J = 25°C; VSTOR = VIN_DC = 0 V		1	5	
		VBAT = 2.1 V; –40°C < T_J < 85°C; VSTOR = VIN_DC = 0 V			30	
MOSFET RESISTANCES						
RDS(ON)-BAT	ON resistance of switch between VBAT and VSTOR	VBAT = 4.2 V		0.95	1.50	Ω
RDS(ON)_CHG	Charger low side switch ON resistance	VBAT = 4.2 V		0.70	0.90	Ω
	Charger high side switch ON resistance			2.30	3.00	
	Charger low side switch ON resistance	VBAT = 2.1 V		0.80	1.00	
	Charger high side switch ON resistance			3.70	4.80	
RDS(ON)_BUCK	Buck low side switch ON resistance	VBAT = 4.2 V		0.80	1.00	Ω
	Buck high side switch ON resistance			1.60	2.00	
	Buck low side switch ON resistance	VBAT = 2.1 V		1.00	1.20	
	Buck high side switch ON resistance			2.40	2.90	
f_{SW_CHG}	Maximum charger switching frequency			1.0		MHz
f_{SW_BUCK}	Maximum buck switching frequency			500		kHz
T_{TEMP_SD}	Junction temperature when charging is discontinued	VBAT_OV > VSTOR > 1.8V		125		C

ELECTRICAL CHARACTERISTICS (continued)

Over recommended temperature range, typical values are at T_A = 25°C. Unless otherwise noted, specifications apply for conditions of VSTOR = 4.2 V, VOUT = 1.8 V. External components, CIN = 4.7 µF, L1 = 22 µH, CSTOR= 4.7 µF, L2 = 10 µH, COUT = 22 µF

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
BATTERY MANAGEMENT						
VBAT_OV	Programmable voltage range for overvoltage threshold	VBAT increasing	2.2		5.5	V
VBAT_OV_HYST	Battery over-voltage hysteresis (internal)	VBAT decreasing; VBAT_OV = 5.25V		24	55	mV
VBAT_UV	Under-voltage threshold	VBAT decreasing	1.91	1.95	2.0	V
VBAT_UV_HYST	Battery under-voltage hysteresis (internal)	VBAT increasing		15	32	mV
VBAT_OK_HYST	Programmable voltage range of digital signal indicating VSTOR (=VBAT) is OK	VBAT increasing	VBAT_UV		VBAT_OV	V
VBAT_OK_PROG	Programmable voltage range of digital signal indicating VSTOR (=VBAT) is OK	VBAT decreasing	VBAT_UV		VBAT_OK_HYST – 50	mV
VBAT_ACCURACY	Overall Accuracy for threshold values VBAT_OV, VBAT_OK	Selected resistors are 0.1% tolerance	-2		2	%
VBAT_OK(H)	VBAT_OK (High) threshold voltage	Load = 10 µA			VSTOR – 200	mV
VBAT_OK(L)	VBAT_OK (Low) threshold voltage	Load = 10 µA			100	mV
ENABLE THRESHOLDS						
$\overline{EN}$(H)	Voltage for $\overline{EN}$ high setting. Relative to VBAT.	VBAT = 4.2V	VBAT – 0.2			V
$\overline{EN}$(L)	Voltage for $\overline{EN}$ low setting	VBAT = 4.2V			0.3	V
VOUT_EN(H)	Voltage for VOUT_EN High setting. Relative to VSTOR.	VSTOR = 4.2V	VSTOR – 0.2			V
VOUT_EN(L)	Voltage for VOUT_EN Low setting.	VSTOR = 4.2V			0.3	V
BIAS and MPPT CONTROL STAGE						
VOC_SAMPLE	Time period between two MPPT samples			16		s
VOC_STLG	Settling time for MPPT sample measurement of VIN_DC open circuit voltage	Device not switching		256		ms
VIN_REG	Regulation of VIN_DC during charging	0.5 V < VIN < 4 V; IIN(DC) = 10 mA			10%	
MPPT_80	Voltage on VOC_SAMP to set MPPT threshold to 0.80 of open circuit voltage of VIN_DC		VSTOR – 0.015			V
MPPT_50	Voltage on VOC_SAMP to set MPPT threshold to 0.50 of open circuit voltage of VIN_DC				15	mV
VBIAS	Internal reference for the programmable voltage thresholds	VSTOR ≥ VSTOR_CHGEN	1.205	1.21	1.217	V

ELECTRICAL CHARACTERISTICS

Over recommended ambient temperature range, typical values are at T_A = 25°C. Unless otherwise noted, specifications apply for conditions of V_{STOR} = 4.2 V, V_{OUT} = 1.8 V. External components, C_{IN} = 4.7 µF, L1 = 22 µH, C_{STOR} = 4.7 µF, L2 = 10 µH, C_{OUT} = 22 µF

PARAMETER		TEST CONDITIONS	MIN	TYP	MAX	UNIT
BUCK CONVERTER						
VOUT	Output regulation (excluding resistor tolerance error)	IOUT = 10 mA; 1.3 V < VOUT < 3.3 V	–2		2	%
	Output line regulation	IOUT = 10 mA; VSTOR = 2.1 V to 5.5 V, COUT = 22 µF		0.09		%/V
	Output load regulation	IOUT = 100 µA to 95 mA, VSTOR = 3.6 V, COUT = 22 µF		-0.01		%/mA
	Output ripple	VSTOR = 4.2V, IOUT = 1 mA, COUT = 22 µF		30		mVpp
	Programmable voltage range for output voltage threshold		1.3		VSTOR – 0.2(1)	V
IOUT	Output Current	VSTOR = 3.3V; VOUT = 1.8 V	93	110		mA
$t_{START-STBY}$	Startup time with $\overline{EN}$ low and VOUT_EN transition to high (Standby Mode)	COUT = 22 µF		250		µs
$t_{START-SHIP}$	Startup time with VOUT_EN high and $\overline{EN}$ transition from high to low (Ship Mode)	COUT = 22 µF		100		ms
I-BUCK(CBC-LIM)	Cycle-by-cycle current limit of buck converter	2.4 V < VSTOR < 5.5 V; 1.3 V < VOUT < 3.3 V	160	185	205	mA

(1) The dropout voltage can be computed as the maximum output current times the buck high side resistance.

DEVICE INFORMATION

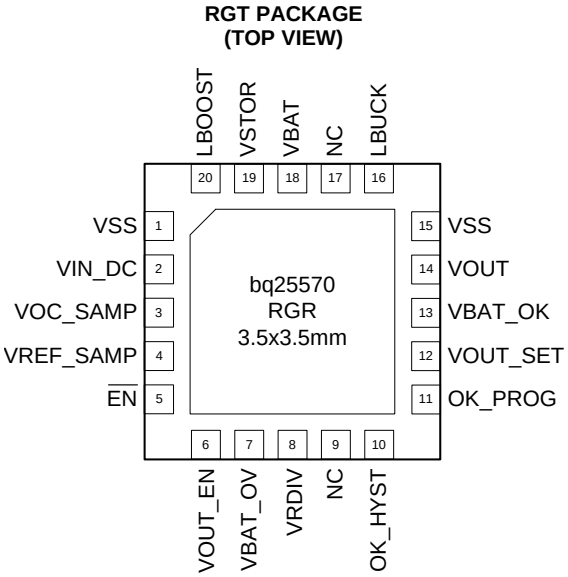


Figure 1. bq25570 3.5mm x 3.5mm QFN-20 Package

PIN FUNCTIONS

PIN		I/O TYPE	DESCRIPTION
NO.	NAME		
1	VSS	Input	Power ground for the boost converter.
2	VIN_DC	Input	DC voltage input from energy harvesting source. Connect at least a 4.7 µF capacitor as close as possible between this pin and pin 1.
3	VOC_SAMP	Input	Sampling pin for MPPT network. Connect to VSTOR to sample at 80% of input soure open circuit voltage. Connect to GND for 50% or connect to the mid-point of external resistor divider between VIN_DC and GND.
4	VREF_SAMP	Input	Sample and hold circuit output for the reference set by the MPPT per VOC_SAMP. Connect a 0.01 µF capacitor from this pin to GND.
5	$\overline{EN}$	Iinput	Active low digital programming input for enabling/disabling the IC. Connect to GND to enable the IC.
6	VOUT_EN	Input	Active high digital programming input for enabling/disabling the buck converter. Connect to VSTOR to enable the buck converter.
7	VBAT_OV	Input	Connect to the mid-point of external resistor divider between VRDIV and GND for setting the VBAT overvoltage threshold.
8	VRDIV	Output	Connect high side of resistor divider networks to this biasing voltage.
9	NC	Input	Connect to ground using the IC's PowerPad.
10	OK_HYST	Input	Connect to the mid-point of external resistor divider between VRDIV and GND for setting the VBAT_OK hystersis threshold.
11	OK_PROG	Input	Connect to the mid-point of external resistor divider between VRDIV and GND for setting the VBAT_OK threshold.
12	VOUT_SET	Input	Connect to the mid-point of external resistor divider between VRDIV and GND for setting the VOUT regulation set point.
13	VBAT_OK	Output	Digital output for battery good indicator. Internally referenced to the VSTOR voltage.
14	VOUT	Output	Buck converter output. Connect at least 22 µF output capacitor between this pin and pin 15 (VSS).
15	VSS	Supply	Power ground for the buck converter and analog/signal ground for the resistor dividers and VREF_SAMP capacitor.
16	LBUCK	I/O	Inductor connection for the buck converter switching node. Connect at least a 4.7 µH inductor between this pin and pin 14 (VOUT).

PIN FUNCTIONS (continued)

PIN		I/O TYPE	DESCRIPTION
NO.	NAME		
17	NC	Input	Connect to ground using the IC's PowerPad.
18	VBAT	I/O	Connect a rechargeable storage element with at least 100uF of equivalent capacitance between this pin and either VSS pin.
19	VSTOR	Output	Connection for the output of the boost converter/charger. Connect at least a 4.7 µF capacitor in parallel with a 0.1 µF capacitor as close as possible to between this pin and pin 1 (VSS).
20	LBOOST	I/O	Inductor connection for the boost converter switching node. Connect a 22 µH inductor between this pin and pin 2 (VIN_DC).

TYPICAL APPLICATION CIRCUITS

VBAT_OV = 3.11 V, VBAT_OK = 2.39 V, VBAT_OK_HYST = 2.80 V, VOUT=1.80V, MPPT (V_{OC}) = 80%

L1 = 22 µH, L2 = 10 µH, CIN = CSTOR = 4.7 µF, CBYP=0.1 µF, CREF = 10 nF, COUT = 22 µF

R_{OK1} = 5.62 MΩ, R_{OK2} = 5.49 MΩ, R_{OK3} = 1.87 MΩ, R_{OV1} = 7.5 MΩ, R_{OV2} = 5.36 MΩ,

R_{OUT1}= 8.66 MΩ, R_{OUT2} = 4.22 MΩ

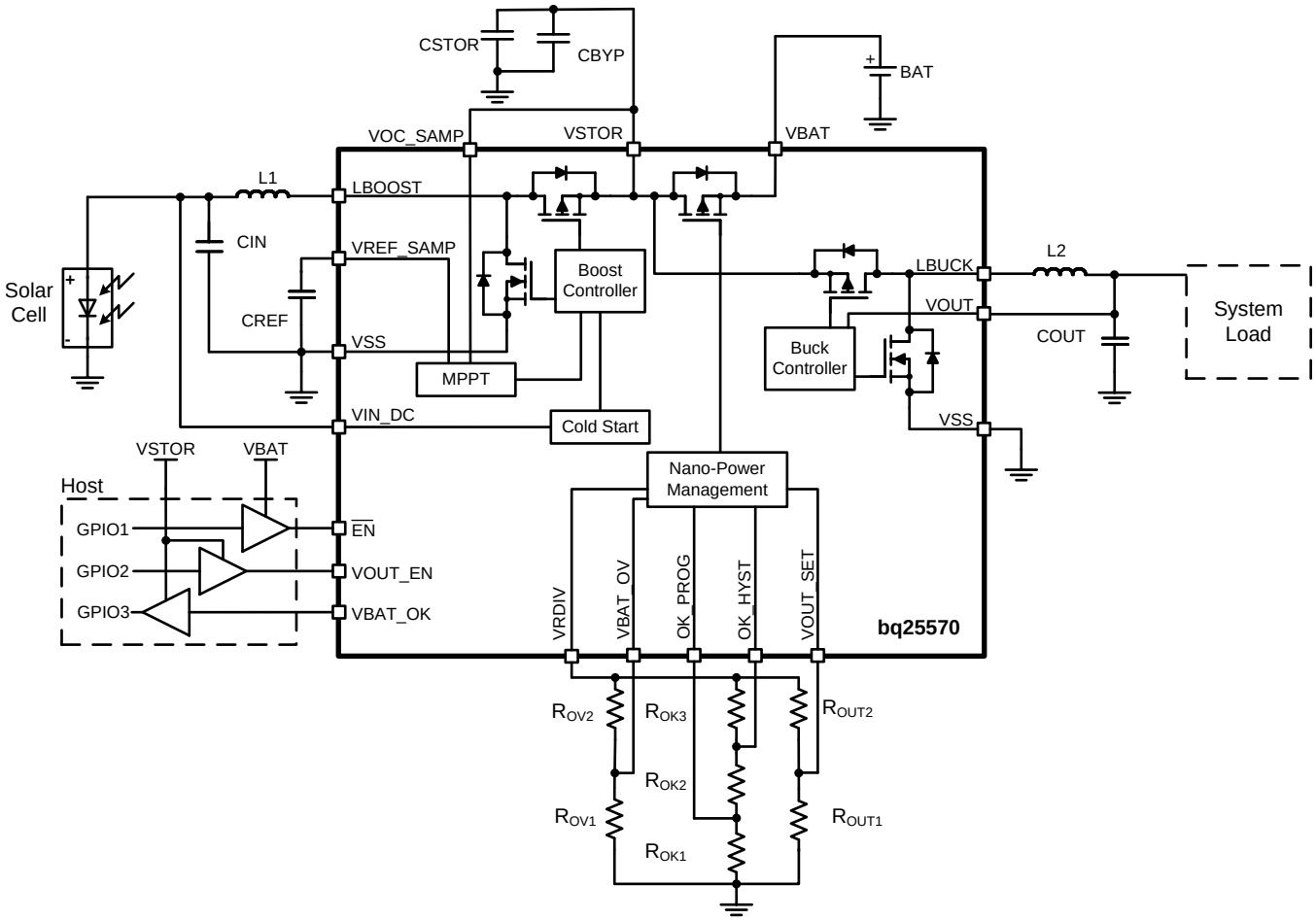


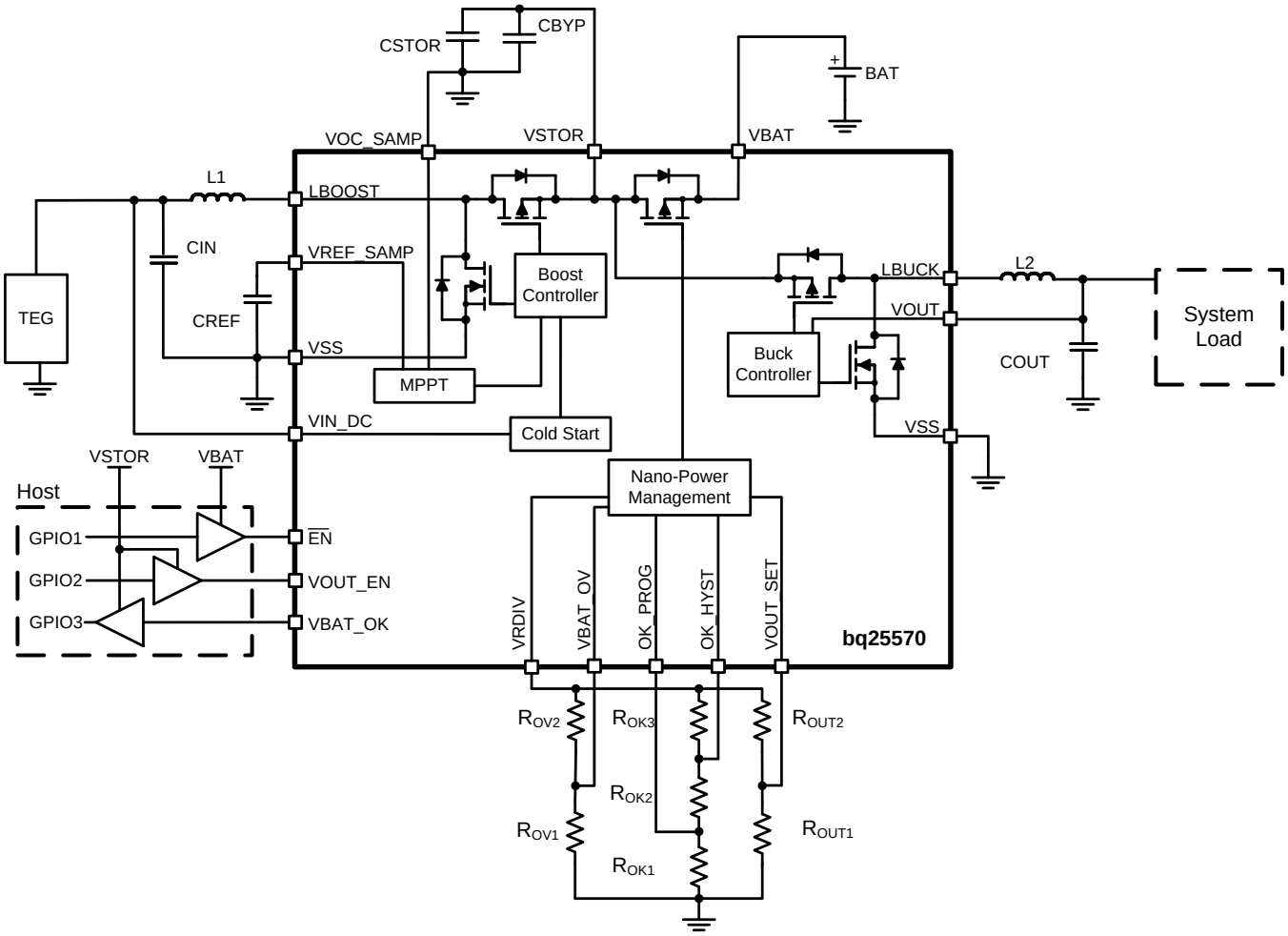
Figure 2. Typical Solar Application Circuit

VBAT_OV = 4.18V, VBAT_OK = 3.5 V, VBAT_OK_HYST = 3.7 V, VOUT=2.5V, MPPT (V_{OC}) = 50%

L1 = 22 µH, L2 = 10 µH, CIN = CSTOR = 4.7 µF, CBYP=0.1 µF, CREF = 10 nF, COUT = 22 µF

R_{OK1} = 4.22 MΩ, R_{OK2} = 8.06 MΩ, R_{OK3} = 0.698 MΩ, R_{OV1} = 6.04 MΩ, R_{OV2} = 7.87 MΩ,

R_{OUT1} = 6.19 MΩ, R_{OUT2} = 6.65 MΩ



(1) See the Capacitor Selection section for guidance on sizing C_{STOR}

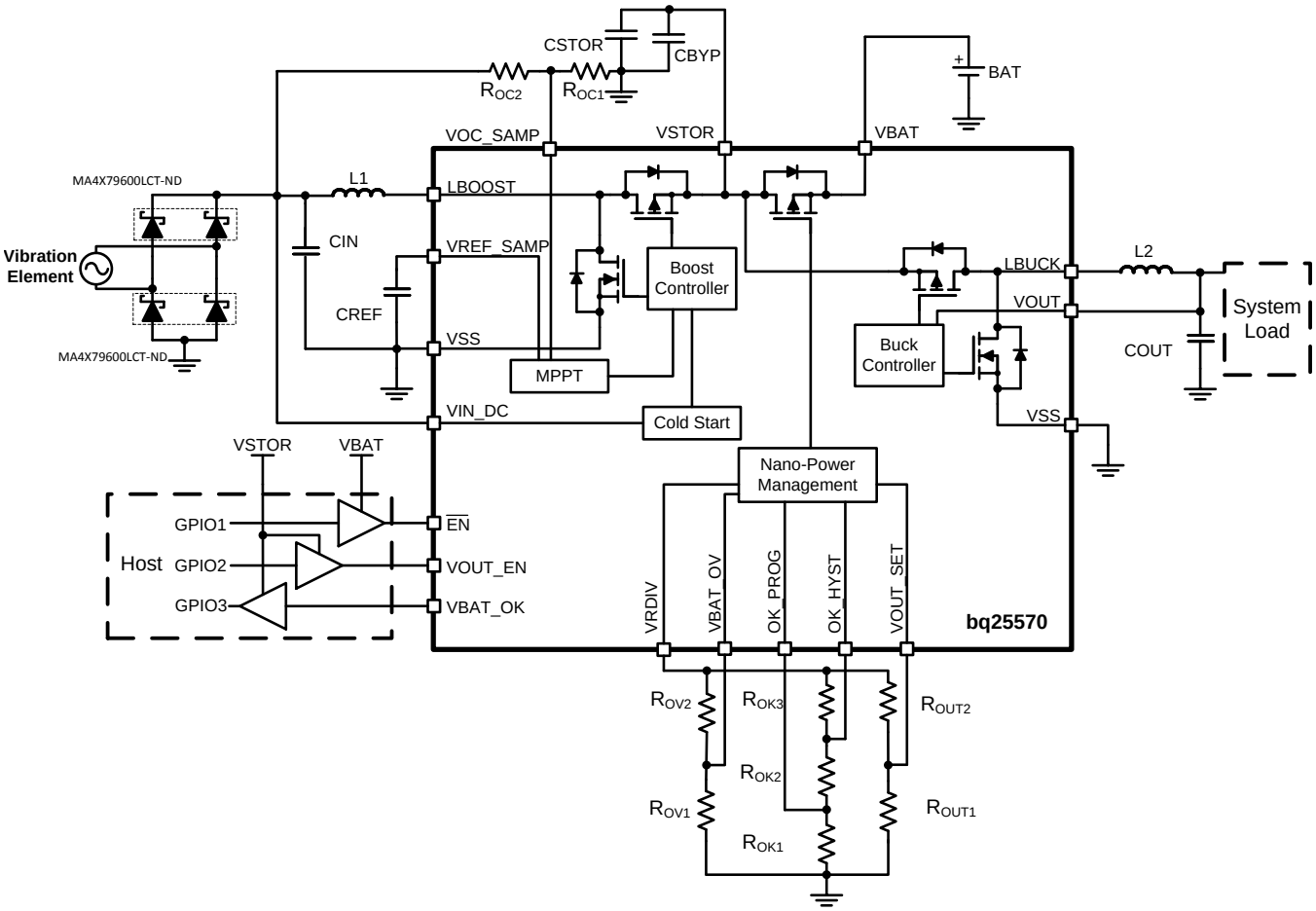
Figure 3. Typical TEG Application Circuit

VBAT_OV = 3.31 V, VBAT_OK = 2.82 V, VBAT_OK_HYST = 3.12 V, VOUT = 1.30V, MPPT (V_{OC}) = 40%

L1 = 22 µH, L2 = 10 µH, CIN = CSTOR = 4.7 µF, CBYP=0.1 µF, CREF = 10 nF, COUT = 22 µF

R_{OK1} = 4.99 MΩ, R_{OK2} = 6.65 MΩ, R_{OK3} = 1.24 MΩ, R_{OV1} = 6.98 MΩ, R_{OV2} = 5.76 MΩ

R_{OUT1} = 12.1 MΩ, R_{OUT2} = 0.909 MΩ, R_{OC1} = 8.06 MΩ, R_{OC2} = 12 MΩ



(1) See the Capacitor Selection section for guidance on sizing C_{STOR}

Figure 4. Typical Externally Set MPPT Application Circuit

VBAT_OV = 3.11 V, VBAT_OK = 2.39 V, VBAT_OK_HYST = 2.80 V, VOUT=1.80V, MPPT (V_{OC}) = 80%

L1 = 22 µH, L2 = 10 µH, CIN = CSTOR = 4.7 µF, CBYP=0.1 µF, CREF = 10 nF, COUT = 22 µF

R_{OV1} = 7.5 MΩ, R_{OV2} = 5.36 MΩ

R_{OUT1}= 8.66 MΩ, R_{OUT2} = 4.22 MΩ,

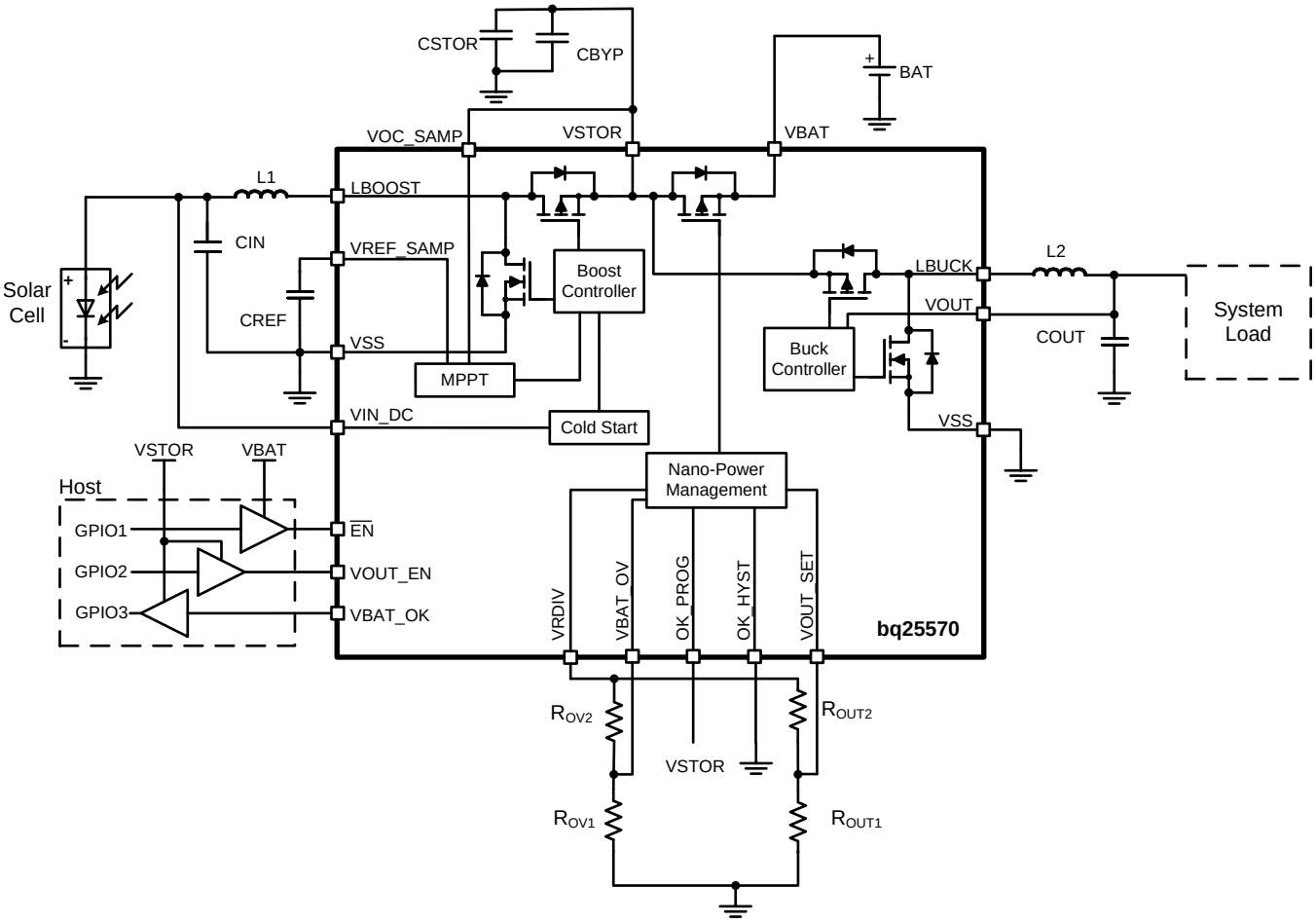


Figure 5. Typical VBAT_OK Disabled Application Circuit

HIGH-LEVEL FUNCTIONAL BLOCK DIAGRAM

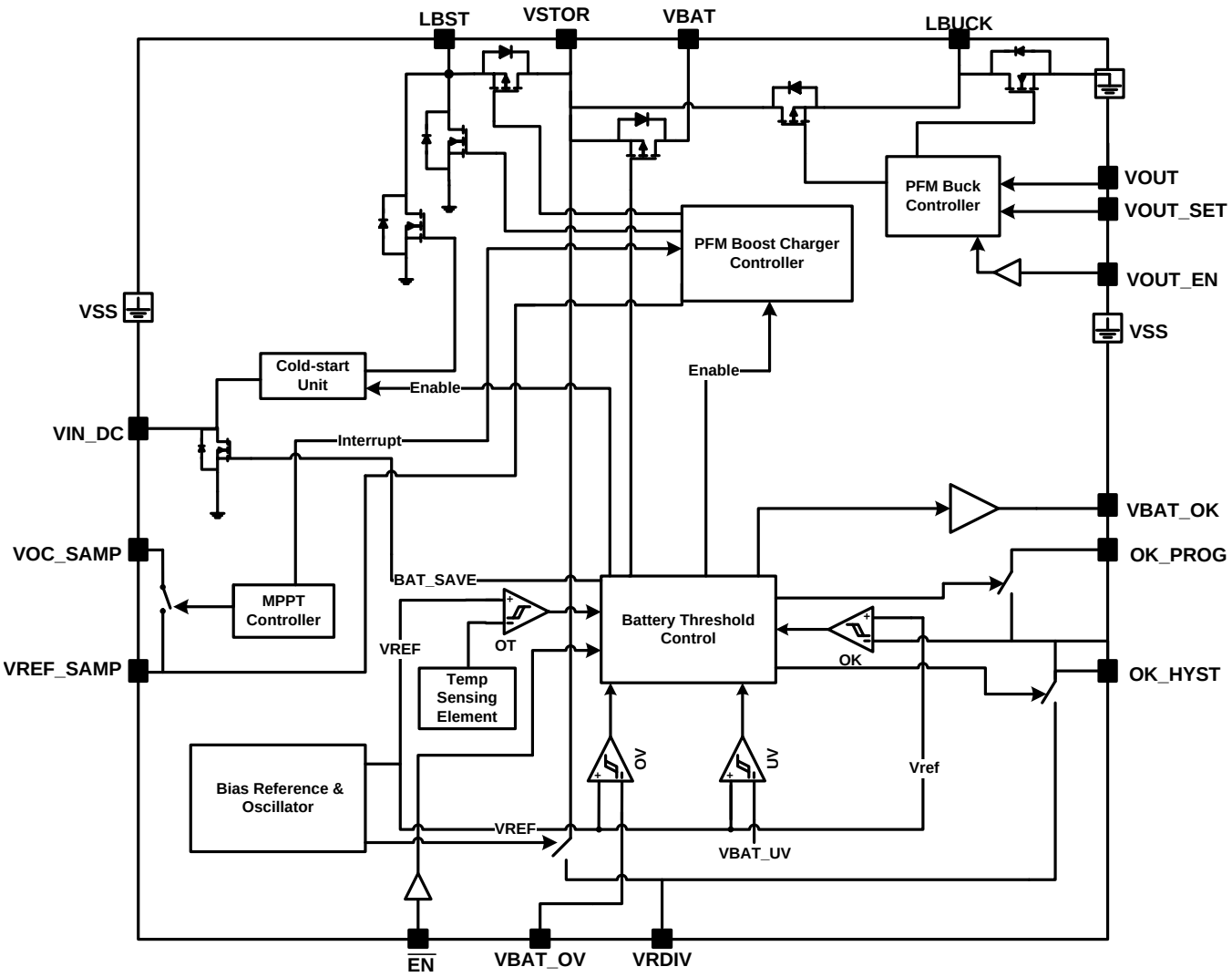


Figure 6. High-Level Functional Diagram

TYPICAL CHARACTERISTICS

Table of Graphs

Unless otherwise noted, graphs were taken using Figure 2 with CIN = 4.7µF, L1 = Coilcraft 22µH LPS4018, CSTOR = 4.7µF, L2 = Toko 10 µH DFE252012C, COUT = 22µF, VBAT_OV=4.2V, VOUT=1.8V			FIGURE
Charger Efficiency (η)(1)	vs. Input Voltage	IN= 10 µA	Figure 7
		IN= 100 µA	Figure 8
		IIN = 10 mA	Figure 9
	vs. Input Current	VIN = 2.0 V	Figure 10
		VIN = 1.0 V	Figure 11
		VIN = 0.5 V	Figure 12
		VIN = 0.2 V	Figure 13
VSTOR Quiescent Current	vs. VSTOR Voltage	$\overline{EN}$ = 1, VOUT_EN = X (Ship Mode)	Figure 14
		$\overline{EN}$ = 0, VOUT_EN = 0 (Standby Mode)	Figure 15
VBAT Quiescent Current	vs. VBAT Voltage	$\overline{EN}$ = 0, VOUT_EN = 1 (Active Mode)	Figure 16
Buck Efficiency (η)		vs. Output Current	Figure 17
		vs. Input Voltage	Figure 18
Normalized Buck Output Voltage		vs. Output Current	Figure 19
		vs. Input Voltage	Figure 20
		vs. Temperature	Figure 21
Buck Maximum Output Current vs. Input Voltage	VOUT = 1.8V - 100mV		Figure 22
Buck Major Switching Frequency		vs. Output Current	Figure 23
		vs. Input Voltage	Figure 24
Buck Output Ripple		vs.Output Current	Figure 25
		vs. Input Voltage	Figure 26
Startup by taking EN low (from ship mode)	VBAT = 3.4-V charged Li coin cell; VIN_DC = 1.0 V power supply; MPPT=50%; ZIN = 100Ω	ROUT = open	Figure 27
Startup by taking EN low (from ship mode), including VOUT	VBAT = 3.4-V charged Li coin cell; VIN_DC = 1.0 V power supply; MPPT=50%; ZIN = 100Ω	ROUT = 90 Ω	Figure 28
Startup by taking VOUT_EN high (from Standby mode)	VBAT = 3.2-V charged Li coin cell; VIN_DC = 2.0 V power supply; MPPT=50%; ZIN = 100Ω	ROUT = 90 Ω	Figure 29
MPPT Operation	VBAT = 3.2-V charged Li coin cell; VIN_DC = 2.0 V power supply; ZIN = 100Ω	VOC_SAMP = VSTOR to GND to VSTOR	Figure 30
100mA Load Transient on VOUT	VBAT = 3.9-V charged 0.5F super cap; VIN_DC = 2.0 V power supply; MPPT=50%; ZIN=100Ω	ROUT = open to 18 Ω to open	Figure 31
50mA Load Transient on VOUT	VBAT = 3.2-V charged Li coin cell; VIN_DC = 2.0 V power supply; MPPT=50%; ZIN = 100Ω	ROUT = open to 36 Ω to open	Figure 32
Charger Operational Waveform during 50mA Load Transient		ROUT = 36 Ω	Figure 33
Buck Operational Waveform during 50mA Load Transient			Figure 34
VRDIV Waveform	VSTOR = 4.2V; VOUT = 1.8V		Figure 35
VRDIV Waveform - Zoom			Figure 36
VBAT_OK Operation	VSTOR ramped from 0 V to 4.2 V to 0 V		Figure 37
Charging a Super Cap on VBAT	VIN_DC = sourcemeter with compliance = 1.2 V and ISC = 1.0 mA	VBAT = 120 mF super capacitor	Figure 38
Charging a Super Cap on VOUT		VOUT = 120 mF super capacitor	Figure 39

(1) See SLUA691 for an explanation on how to take these measurements. Because the MPPT feature cannot be disabled on the bq25570, these measurements need to be taken in the middle of the 16 s sampling period.

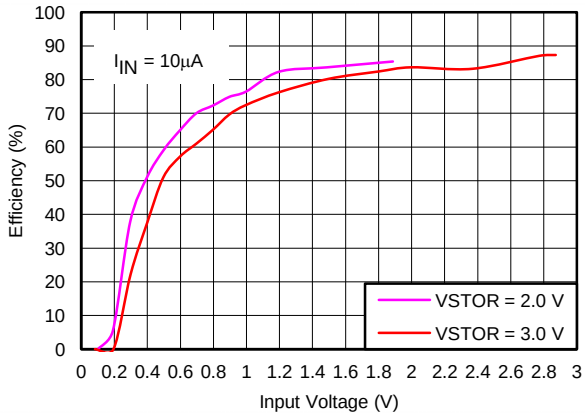


Figure 7. Charger Efficiency vs Input Voltage

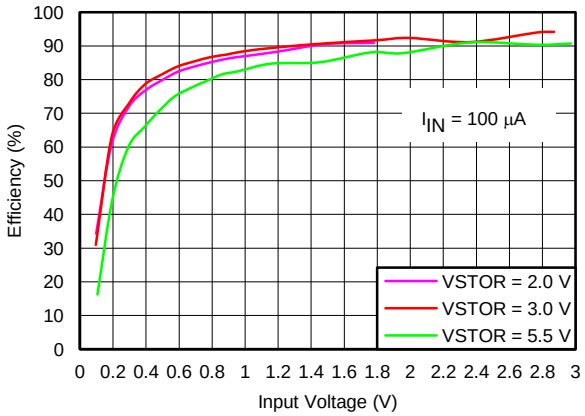


Figure 8. Charger Efficiency vs Input Voltage

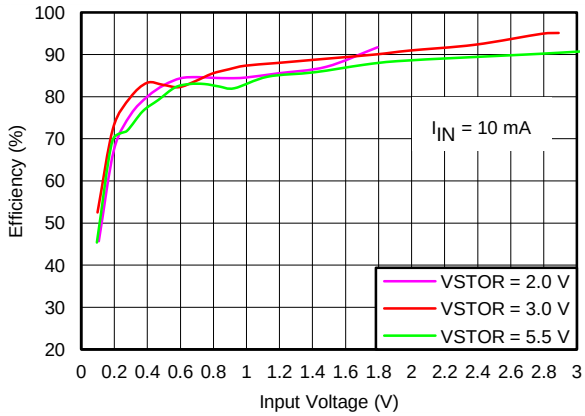


Figure 9. Charger Efficiency vs Input Voltage

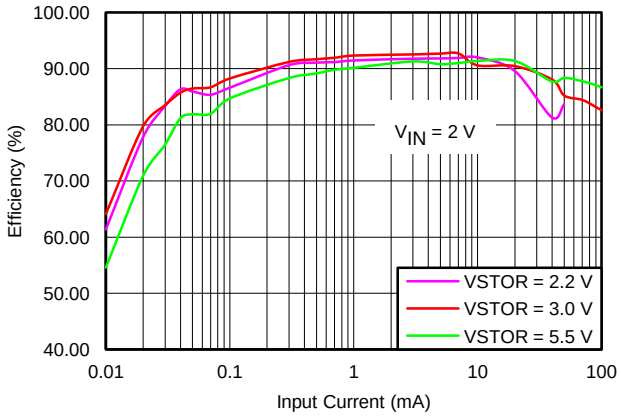


Figure 10. Charger Efficiency vs Input Current

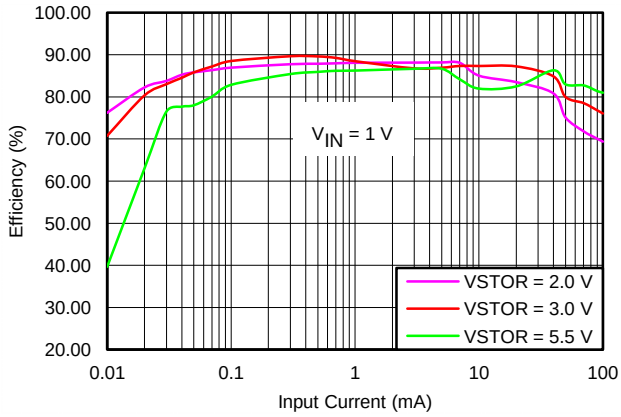


Figure 11. Charger Efficiency vs Input Current

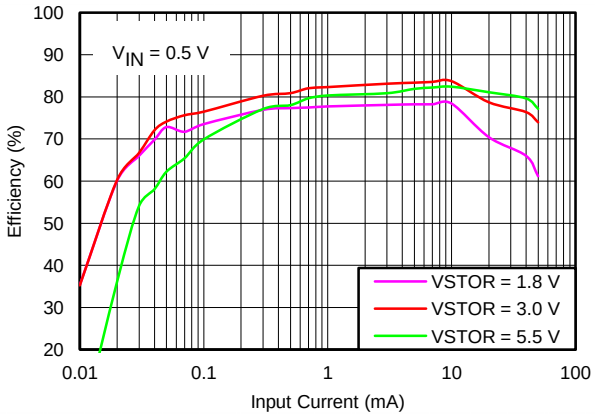


Figure 12. Charger Efficiency vs Input Current

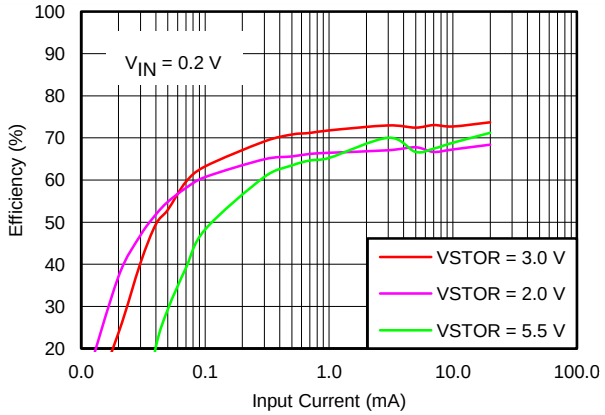


Figure 13. Charger Efficiency vs Input Current

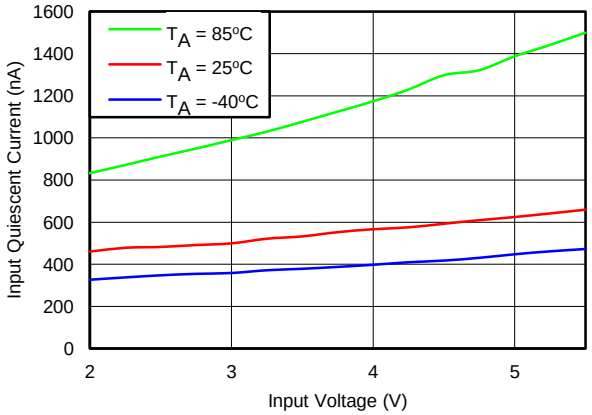


Figure 14. VSTOR Quiescent Current vs VSTOR Voltage: Standby Mode

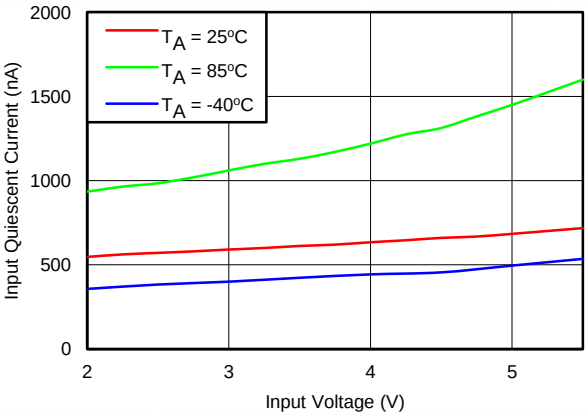


Figure 15. VSTOR Quiescent Current vs VSTOR Voltage: Active Mode

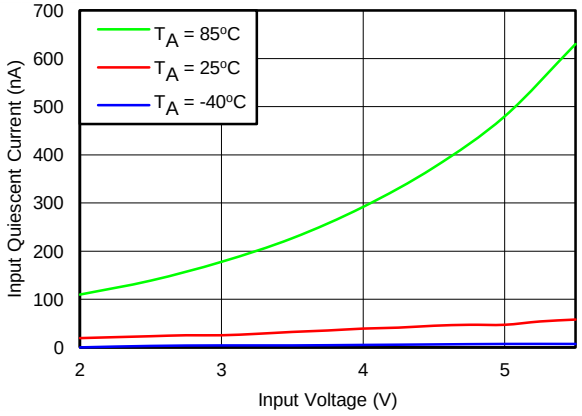


Figure 16. VBAT Quiescent Current vs VBAT Voltage: Ship Mode

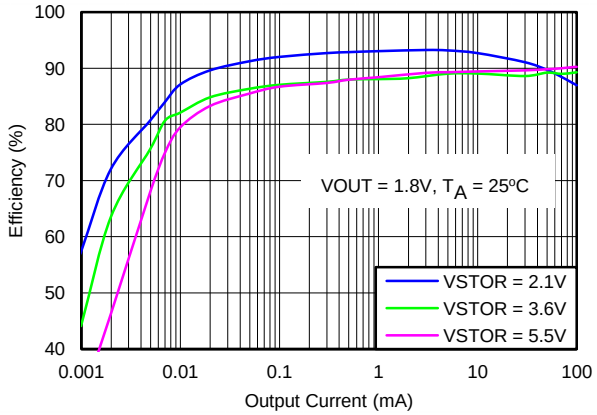


Figure 17. Buck Efficiency vs Output Current

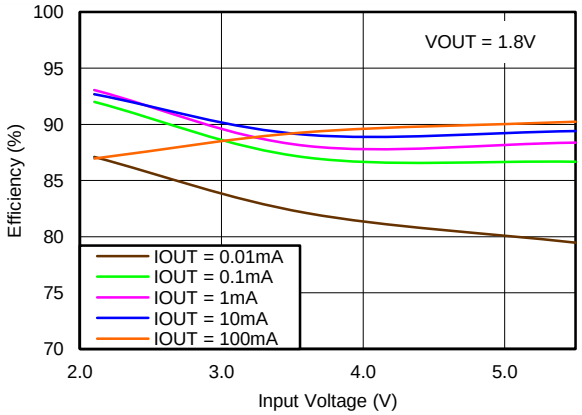


Figure 18. Buck Efficiency vs Input Voltage

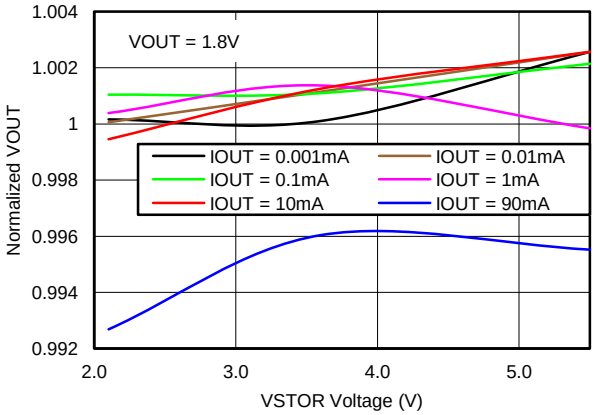


Figure 19. Normalized Buck Output Voltage vs Input Voltage

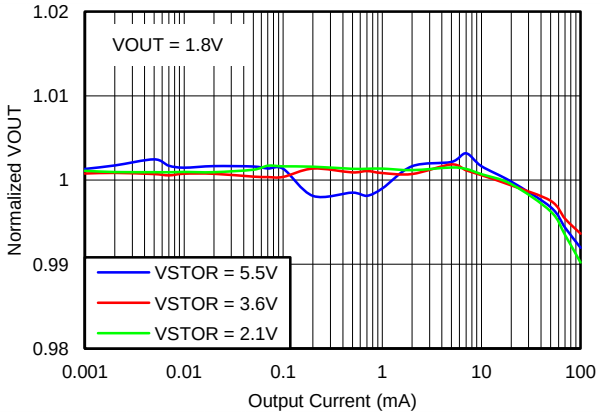


Figure 20. Normalized Buck Output Voltage vs Output Current

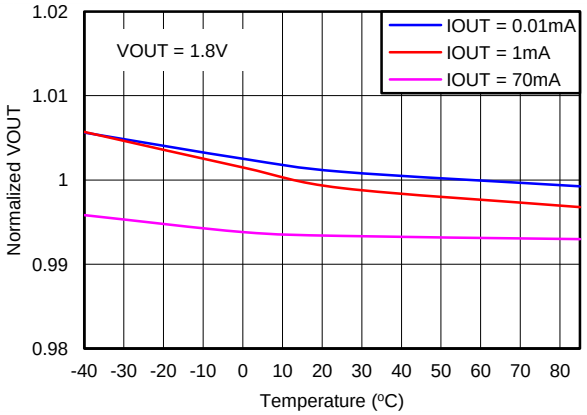


Figure 21. Normalized Buck Output Voltage vs Temperature

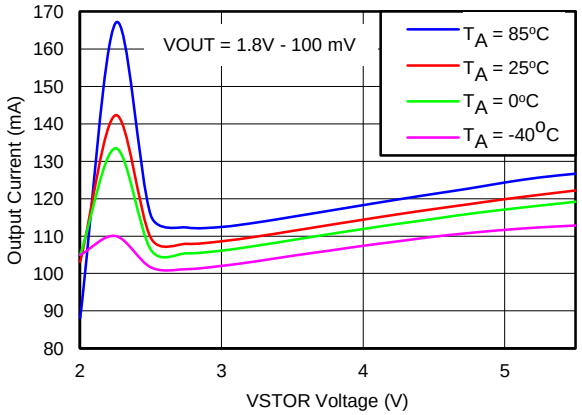


Figure 22. Buck Maximum Output Current vs Input Voltage

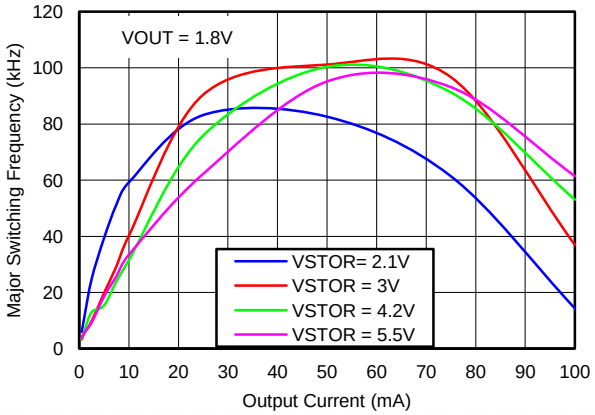


Figure 23. Buck Major Switching Frequency vs Output Current

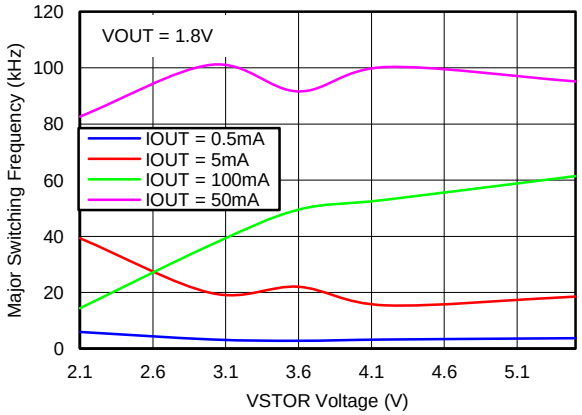


Figure 24. Buck Major Switching Frequency vs Input Voltage

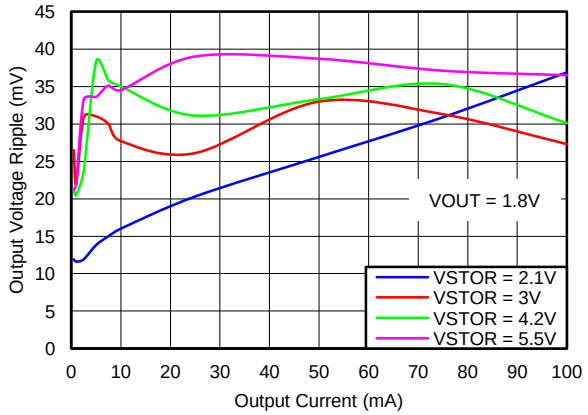


Figure 25. Buck Output Voltage Ripple vs Output Current

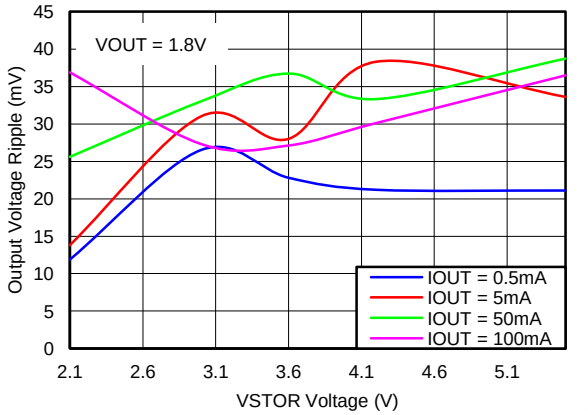


Figure 26. Buck Output Voltage Ripple vs Input Voltage

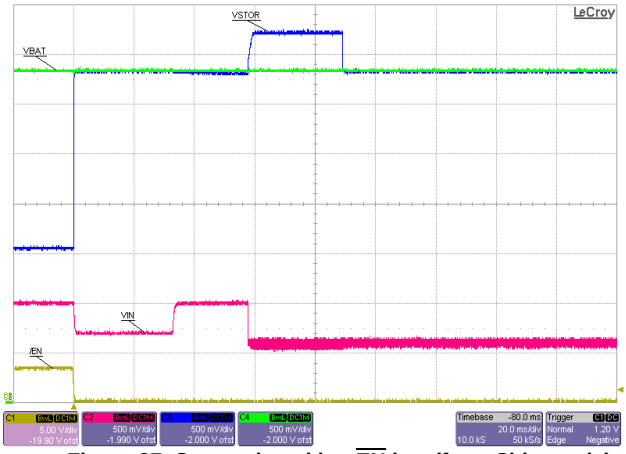


Figure 27. Startup by taking $\overline{EN}$ low (from Ship mode)

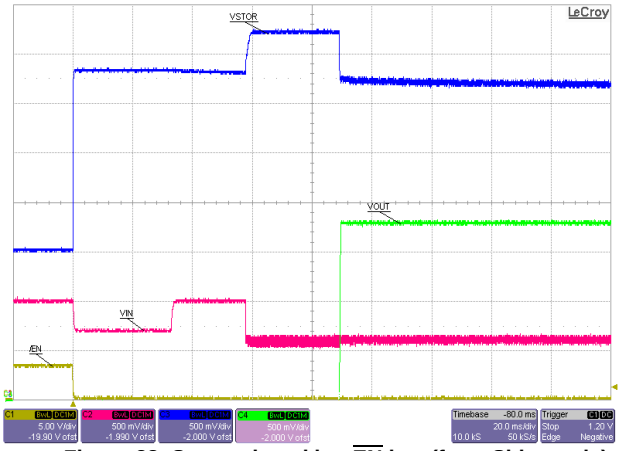


Figure 28. Startup by taking $\overline{EN}$ low (from Ship mode), including VOUT

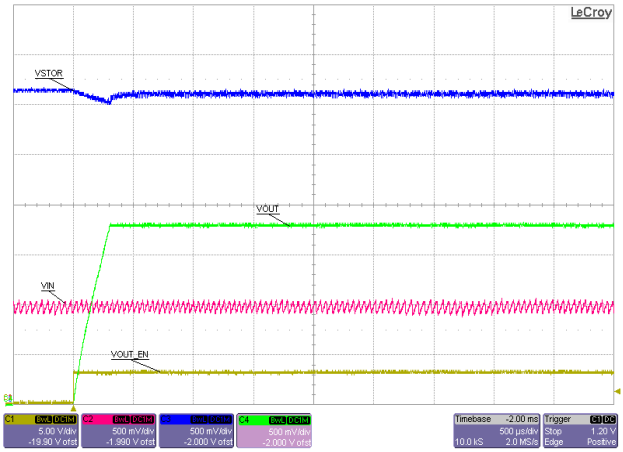


Figure 29. Startup by taking VOUT_EN high (from Standby mode)

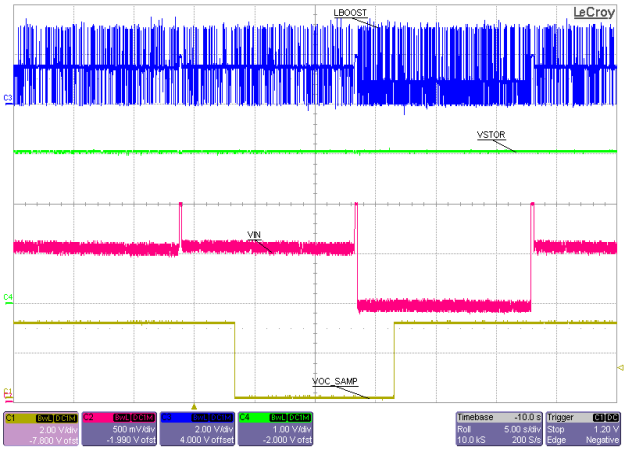


Figure 30. MPPT Operation

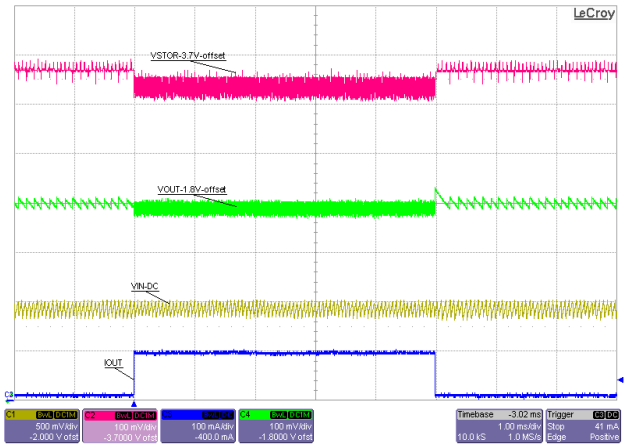


Figure 31. 100mA Load Transient on VOUT

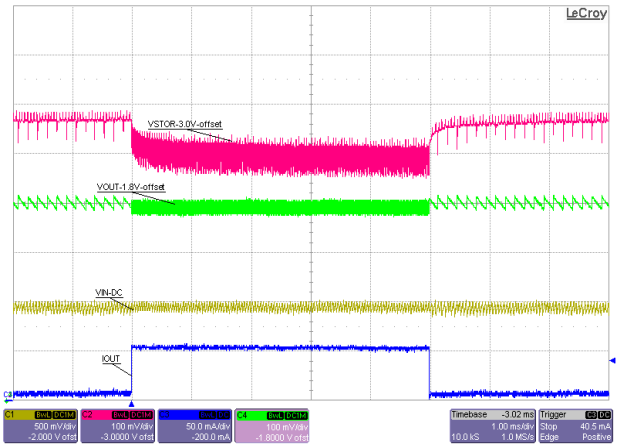


Figure 32. 50 mA Load Transient on VOUT

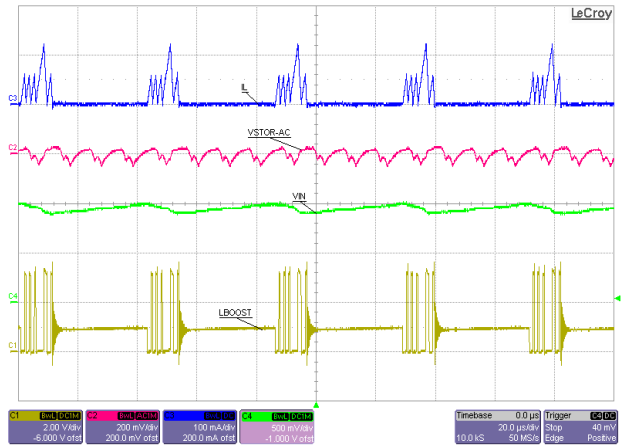


Figure 33. Charger Operational Waveforms during 50mA Load Transient

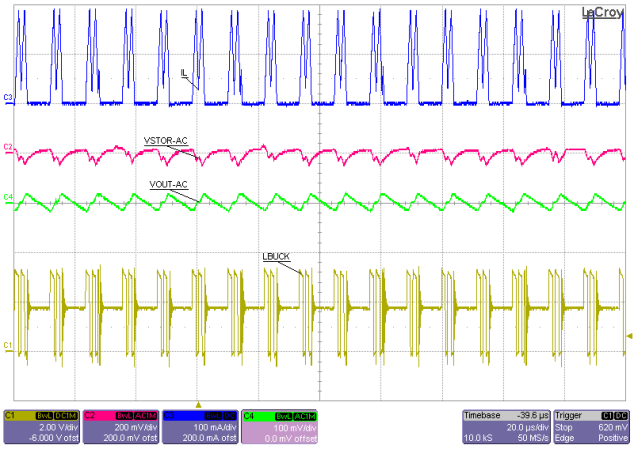


Figure 34. Buck Operational Waveforms during 50mA Load Transient

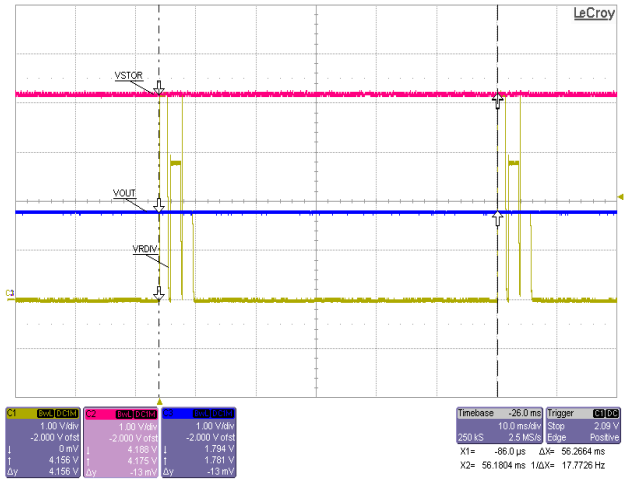


Figure 35. VRDIV Waveform

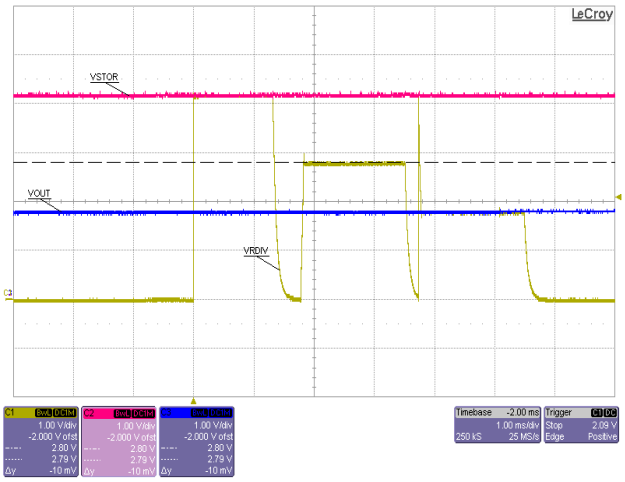


Figure 36. VRDIV Waveform - Zoom

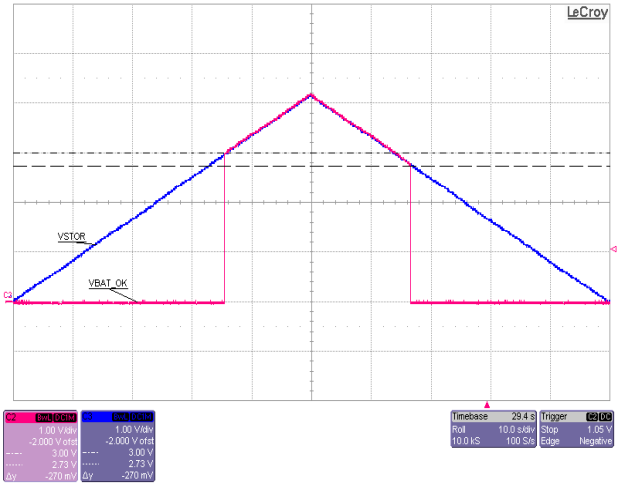


Figure 37. VBAT_OK Operation

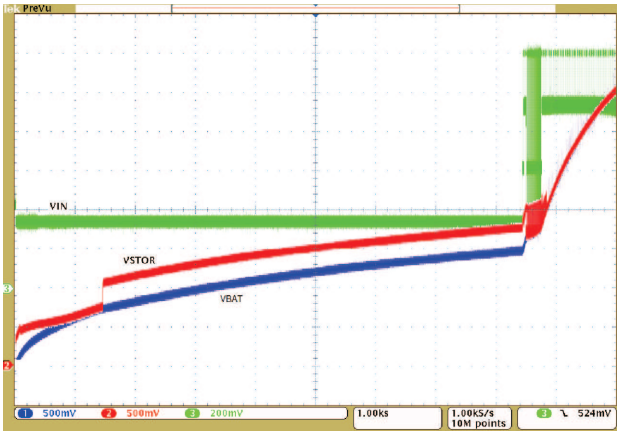


Figure 38. Charging a Super Cap on VBAT

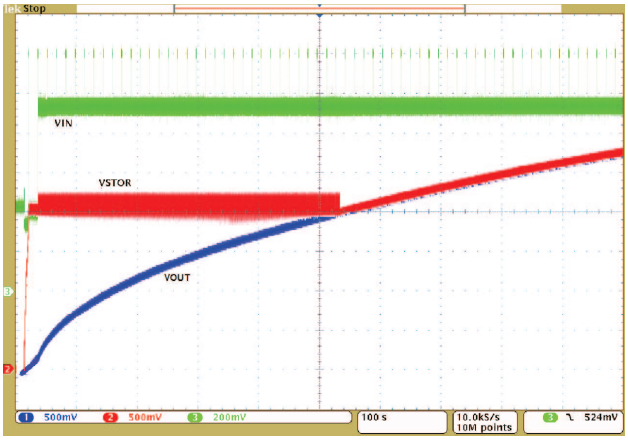


Figure 39. Charging a Super Cap on VOUT

DETAILED DESCRIPTION

Boost Charger Overview

The bq25570 includes both an ultra low quiescent current, efficient synchronous boost converter/charger and buck converter. The boost converter is intended to be powered from a high impedance DC source, such as a solar panel, TEG or piezoelectric module; therefore, it regulates its input voltage (VIN_DC) in order to prevent the input source from collapsing. The boost converter monitors its output voltage (VSTOR) and stops switching when VSTOR reaches a resistor programmable threshold level. The buck converter is powered from VSTOR. Both converters are based on a switching regulator architecture which maximizes efficiency while minimizing start-up and operation power. Both use pulse frequency modulation (PFM) to maintain efficiency, even under light load conditions. In addition, the boost converter implements battery protection features so that either rechargeable batteries or capacitors can be used as energy storage elements at the storage element output (VBAT). Figure 6 is a high-level functional block diagram which highlights most of the major functional blocks inside the bq25570.

Enable Controls

There are two enable pins for the bq25570 in order to maximize the flexibility of control for the system. $\overline{EN}$ high voltage is relative to VBAT and VOUT_EN is relative to VSTOR. When taken high (relative to VBAT), the $\overline{EN}$ pin shuts down the IC completely including the boost converter, battery management circuitry and buck converter. It also turns off the PFET that connects VBAT to VSTOR. This mode can be described as ship mode, because it will put the IC in the lowest leakage state and provide a long storage period without discharging the battery attached to VBAT. If it is not desired to control $\overline{EN}$, it is recommended that this pin be tied to VSS, or system ground. When $\overline{EN}$ is low, VOUT_EN is used to enable and disable the buck converter. The table below summarizes the functionailty.

Table 1. Enable Functionality Table

$\overline{EN}$ PIN	VOUT_EN PIN	FUNCTIONAL STATE
0	0	Partial standby mode. Buck switching converter is off, but VBAT_OK indication is on
0	1	Buck mode and VBAT_OK enabled
1	x	Full standby mode. Switching converter and VBAT_OK indication is off (ship mode)

Startup Operation

The bq25570 has two circuits for boosting the input voltage, a low-power cold-start circuit, drawing power excluxively from VIN_DC when ≥ VIN(CS), and the high efficiency main boost converter, with the bias rails drawing power from VSTOR when ≥ VSTOR_CHGEN and the power stage drawing power from VIN_DC when ≥ VIN(DC) minimum. When $\overline{EN}$ = 0 and VSTOR ≤ VSTOR_CHGEN, there are two options for charging the VSTOR capacitor capacitor, CSTOR, to VSTOR_CHGEN for the main boost converter to turn on. The first option is to allow the cold start circuit to charge VSTOR to VSTOR_CHGEN. Due to the body diode of the PFET connecting VSTOR and VBAT, the cold start circuit must charge both the capacitor on CSTOR and the storage element connected to VBAT up to VSTOR_CHGEN. When a rechargeable battery with an open protector is attached, the charge time is typically short due to the minimum charge needed to close the FET. When large, discharged super capacitors are attached, the charge time can be signficant. The second option is to connect a storage element, charged above VSTOR_CHGEN, to VBAT. Assuming the voltages on VSTOR and VBAT are both below 100mV, when a charged storage element is attached (i.e. hot-plugged) to VBAT, the IC turns on the internal PFET between the VSTOR and VBAT pins for $t_{BAT\_HOT\_PLUG}$ in order to charge CSTOR to VSTOR_CHGEN. If a system load tied to VSTOR prevents the storage element from charging VSTOR within $t_{BAT\_HOT\_PLUG}$, it is recommended to add an external PFET between the system load and VSTOR. An inverted VBAT_OK signal can be used to drive the gate of this system-isolating PFET. Once the VSTOR pin voltage reaches the internal under voltage threshold (VBAT_UV), the internal PFET stays on and the main boost converter / charger begins to charge the storage element if there is sufficient power available at the VIN_DC pin, as explained below. If VSTOR does not reach VBAT_UV within 50ms, then the PFET turns off and the cold-start boost converter turns on, also as explained below.

Boost Charger Cold-Start Operation (VSTOR < VSTOR_CHGEN and VIN_DC > VIN(CS))

If the attached storage element does not charge CSTOR above VSTOR_CHGEN, VIN_DC ≥ VIN(CS) and $\overline{EN}$ = 0, the cold-start circuit turns on. The cold-start circuit is essentially an unregulated boost converter with lower efficiency compared to the main boost converter. The energy harvester must supply sufficient power for the IC to exit cold start. See the Energy Harvester Selection applications section for guidance.

When the CSTOR voltage reaches VSTOR_CHGEN, the main boost regulator starts up. The VSTOR voltage from the main boost regulator is compared against the battery undervoltage threshold (VBAT_UV). When the VBAT_UV threshold is reached, the PMOS switch between VSTOR and VBAT turns on, which allows the energy storage element attached to VBAT to charge up. Cold start is not as efficient as the main boost regulator. If there is not sufficient power available, it is possible that the cold start circuit continuously runs and the VSTOR output does not increase above VSTOR_CHGEN for the main boost conveter to start up. The battery management thresholds are explained later is this section. See the Energy Harvester Selection applications section for guidance on minimum input power requirements.

Main Boost Converter / Charger Operation (VSTOR > VSTOR_CHGEN and VIN_DC > VIN(DC))

The main boost converter charges the storage element attached at VBAT with the energy available from the high impedance input source. For the first 32 ms (typical) after the main converter is turned ON (assuming $\overline{EN}$ is low), the charger is disabled to let the input rise to its open-circuit voltage. This is needed to get the reference voltage which will be used for the remainder of the charger operation till the next MPPT sampling cycle turns ON. The boost converter employs pulse frequency modulation (PFM) mode of control to regulate the voltage at VIN_DC close to the desired reference voltage. The reference voltage is set by the MPPT control scheme as described in the next section. Input voltage regulation is obtained by transferring charge from the input to VSTOR only when the input voltage is higher than the voltage on pin VREF_SAMP. The current through the inductor is controlled through internal current sense circuitry. The peak current in the inductor is dithered internally to pre-determined levels in order to maintain high efficiency of the converter across a wide input current range. The converter transfers up to a maximum of 100 mA average input current (200mA typical peak inductor current). The boost converter is disabled when the voltage on VSTOR reaches the OV condition to protect the battery connected at VBAT from overcharging. In order for the battery to charge to VBAT_OV, the input power must exceed the power needed for the load on VSTOR. See the Energy Harvester Selection applications section for guidance on minimum input power requirements.

Maximum Power Point Tracking

Maximum power point tracking (MPPT) is implemented in order to maximize the power extracted from an energy harvester source. MPPT is performed by periodically sampling a ratio of the open-circuit voltage of the energy harvester and using that as the reference voltage (VREF_SAMP) to the boost converter. Internally, the boost converter indirectly modulates the impedance of the energy transfer circuitry by regulating the input voltage (VIN_DC) to the sampled reference voltage (VREF_SAMP). A new reference voltage is obtained every 16 s (typical) by periodically disabling the charger for 256 ms (typical) and sampling a ratio of the open-circuit voltage. For solar harvesters, the maximum power point is typically 70%-80% and for thermoelectric harvesters, the MPPT is typically 50%. Tying VOC_SAMP to VSTOR internally sets the MPPT regulation point to 80%. Tying VOC_SAMP to GND internally sets the MPPT regulation point to 50%. If need, the exact ratio for MPPT can be optimized to meet the needs of the input source being used by connecting external resistors R_{OC1} and R_{OC2} between VRDIV and GND with mid-point at VOC_SAMP.

The reference voltage is set by the following expression:

$$VREF\_SAMP = VIN\_DC(OpenCircuit)\left(\frac{R_{OC1}}{R_{OC1} + R_{OC2}}\right) \quad (1)$$

Storage Element / Battery Management

In this section the battery management functionality of the bq25570 integrated circuit (IC) is presented. The IC has internal circuitry to manage the voltage across the storage element and to optimize the charging of the storage element. For successfully extracting energy from the source, two different threshold voltages must be programmed using external resistors, namely battery good threshold (VBAT_OK) and over voltage (OV) threshold. The two user programmable threshold voltages and the internally set undervoltage threshold determine the IC's region of operation. Figure 40 show plots of the voltage at the VSTOR pin and the various

threshold voltages for two use cases 1) when a depleted battery is attached and the charger enters cold start and 2) when a batttery charged above VBAT_UV is attached. For the best operation of the system, the VBAT_OK should be used to determine when a load can be applied or removed. A detailed description of the three voltage thresholds and the procedure for designing the external resistors for setting the three voltage thresholds are described next.

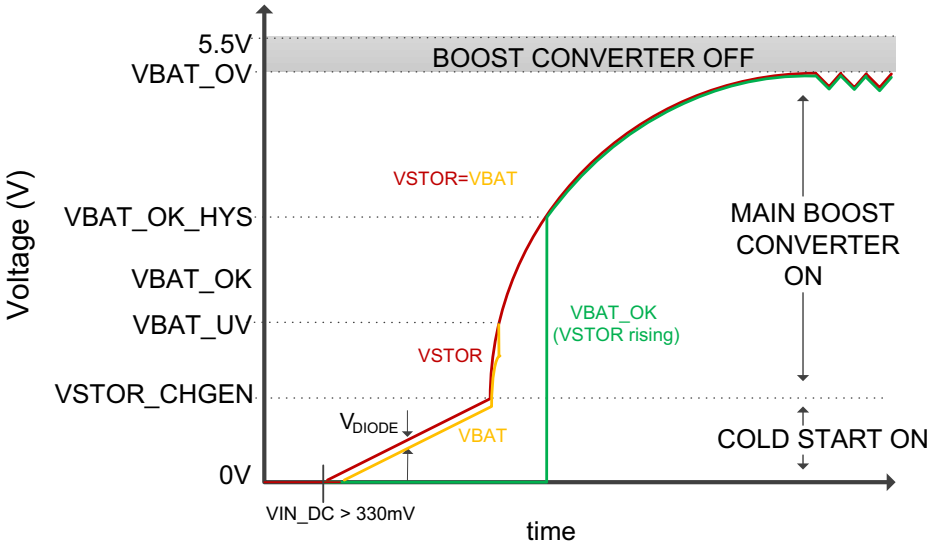


Figure 40. Charger Operation after a Depleted Storage Element is Attached

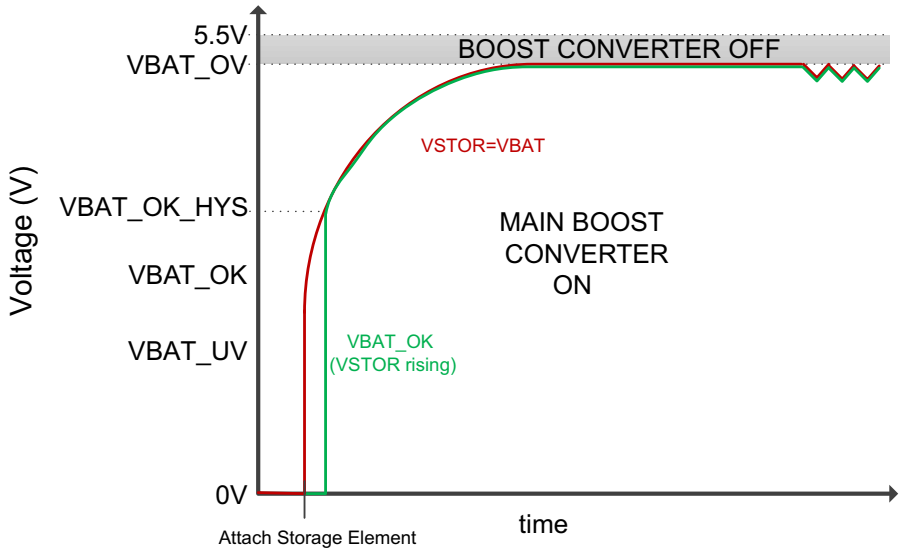


Figure 41. Charger Operation after a Partially Charged Storage Element is Attached

When no input source is attached, the VSTOR node should be discharged to ground before attaching a storage element. Hot-plugging a storage element that is charged (e.g., the battery protector is closed) and with the VSTOR node above ground results in the PFET between VSTOR and VBAT remaining off until an input source is attached. In addition, if a system load attached to VSTOR has fast transients that could pull VSTOR below VBAT_UV, the internal PFET switch will turn off in order to recharge the CSTOR capacitor to VSTOR_CHGEN. See the application section for guidance on sizing the VSTOR and/or VBAT capacitance to account for transients. If the voltage applied at VIN_DC is greater than VSTOR or VBAT then current may flow until the voltage at the input is reduced or the voltage at VSTOR and VBAT rise. This is considered an abnormal condition and the boost converter/charger does not operate.

Battery Undervoltage Protection

To prevent rechargeable batteries from being deeply discharged and damaged, and to prevent completely depleting charge from a capacitive storage element, the IC has an internally set undervoltage (VBAT_UV) threshold plus an internal hysteresis voltage (VBAT_UV_HYST). The VBAT_UV threshold voltage when the battery voltage is decreasing is internally set to 1.95V (typical). The undervoltage threshold when battery voltage is increasing is given by VBAT_UV plus VBAT_UV_HYST. For most applications, the system load should be connected to the VSTOR pin while the storage element should be connected to the VBAT pin. Once the VSTOR pin voltage goes above the VBAT_UV_HYST threshold, the VSTOR pin and the VBAT pins are shorted. The switch remains closed until the VSTOR pin voltage falls below VBAT_UV. The VBAT_UV threshold should be considered a fail safe to the system and the system load should be removed or reduced based on the VBAT_OK signal.

Battery Overvoltage Protection

To prevent rechargeable batteries from being exposed to excessive charging voltages and to prevent over charging a capacitive storage element, the over-voltage (VBAT_OV) threshold level must be set using external resistors. This is also the voltage value to which the charger will regulate the VSTOR/VBAT pin when the input has sufficient power. The VBAT_OV threshold when the battery voltage is rising is given by Equation 2:

$$VBAT\_OV = \frac{3}{2} VBIAS \left(1 + \frac{R_{OV2}}{R_{OV1}} \right) \quad (2)$$

The sum of the resistors is recommended to be no higher than 13 MΩ that is, $R_{OV1} + R_{OV2} = 13$ MΩ. The overvoltage threshold when battery voltage is decreasing is given by OV_HYST. It is internally set to the over voltage threshold minus an internal hysteresis voltage denoted by VBAT_OV_HYST. Once the voltage at the battery exceeds VBAT_OV threshold, the boost converter is disabled. The charger will start again once the battery voltage falls below the VBAT_OV_HYST level. When there is excessive input energy, the VBAT pin voltage will ripple between the VBAT_OV and the VBAT_OV_HYST levels. SLUC484 provides help on sizing and selecting the resistors.

CAUTION

If VIN_DC is higher than VSTOR and VSTOR is equal to VBAT_OV, the input VIN_DC is pulled to ground through a small resistance to stop further charging of the attached battery or capacitor. It is critical that if this case is expected, the impedance of the source attached to VIN_DC be higher than 20 Ω and not a low impedance source.

Battery Voltage within Operating Range (VBAT_OK Output)

The IC allows the user to set a programmable voltage independent of the overvoltage and undervoltage settings to indicate whether the VSTOR voltage (and therefore the VBAT voltage when the PFET between the two pins is turned on) is at an acceptable level. When the battery voltage is decreasing the threshold is set by Equation 3:

$$VBAT\_OK\_PROG = VBIAS \left(1 + \frac{R_{OK2}}{R_{OK1}} \right) \quad (3)$$

When the battery voltage is increasing, the threshold is set by Equation 4:

$$VBAT\_OK\_HYST = VBIAS \left(1 + \frac{R_{OK2} + R_{OK3}}{R_{OK1}} \right) \quad (4)$$

The sum of the resistors is recommend to be no higher than approximately i.e., $R_{OK1} + R_{OK2} + R_{OK3} = 13$ MΩ. The logic high level of this signal is equal to the VSTOR voltage and the logic low level is ground. The logic high level has ~20 KΩ internally in series to limit the available current to prevent MCU damage until it is fully powered. The VBAT_OK_PROG threshold must be greater than or equal to the UV threshold. For the best operation of the system, the VBAT_OK should be setup to drive an external PFET between VSTOR and the system load in order to determine when the load can be applied or removed to optimize the storage element capacity. SLUC484 provides help on sizing and selecting the resistors.

Step Down (Buck) Converter Operation

The buck regulator takes input power from VSTOR, steps it down and provides a regulated voltage at the OUT pin. It employs pulse frequency modulation (PFM) control to regulate the voltage close to the desired reference voltage. The reference voltage is set by the user programmed resistor divider. The current through the inductor is controlled through internal current sense circuitry. The peak current in the inductor is controlled to maintain high efficiency of the converter across a wide input current range. The converter delivers an output current up to 110mA typical with a peak inductor current of 200 mA. The buck regulator is disabled when the voltage on VSTOR drops below the VBAT_UV condition. The buck regulator continues to operate in pass (100% duty cycle) mode, passing the input voltage to the output, as long as VSTOR is greater than VBAT_UV and less than VOUT.

Programming OUT Regulation Voltage

To set the proper output regulation voltage and input voltage power good comparator, the external resistors must be carefully selected.

The OUT regulation voltage is then given by Equation 5:

$$VOUT = VBIAS\left(\frac{R_{OUT2} + R_{OUT1}}{R_{OUT1}}\right) \quad (5)$$

Note that VBIAS is nominally 1.21V per the electrical specification table. The sum of the resistors is recommended to be no greater than 13 MΩ , that is, R_{OUT1} + R_{OUT2} = 13 MΩ. Higher resistors may result in poor output voltage regulation and/or input voltage power good threshold accuracies due to noise pickup via the high impedance pins or reduction of effective resistance due to parasitic resistances created from board assembly residue. See Layout Considerations section for more details. SLUC484 provides help on sizing and selecting the resistors.

Buck Converter Startup Behavior

The bq25570 buck converter has two startup responses: 1) from the ship-mode state ($\overline{EN}$ transitions from high to low), and 2) from the standby state (VOUT_EN transitions from low to high). The first startup response out of the ship-mode state has the longest time duration due to the internal circuitry being disabled. This response is shown in Figure 28. The startup time takes approximately 100ms due to the internal Nano-Power management circuitry needing to first, complete the 64 ms sample and hold cycle.

Startup from the standby state is shown in Figure 29. This response is much faster due to the internal circuitry being pre-enabled. The startup time from this state is entirely dependent on the size of the output capacitor. The larger the capacitor, the longer it will take to charge during startup. With COUT = 22 µF, the startup time is approximately 400 µs. The buck converter can startup into a pre-biased output voltage.

Steady State Operation and Cycle by Cycle Behavior

Steady state operation for the boost charger is shown in Figure 33 and for the buck converter in Figure 34. These plots highlight the inductor current waveform, the VSTOR and VOUT voltage ripple, and the LBOOST and LBUCK switching nodes, respectively. The converters both use hysteretic control and pulse frequency modulation (PFM) switching in order to maintain high efficiency at light load. As long as the VIN_DC voltage is above the MPPT regulation set point (i.e. voltage at VREF_SAMP), the boost converter's low-side power FET turns on and draws current until it reaches its respective peak current limit. These switching bursts continue until VSTOR reaches the VBAT_OV threshold. The buck converter high-side power FET also turns on and draws current until it reaches its respective peak current limit, with its switching bursts continuing until VOUT reaches the VOUT_SET point. This cycle-by-cycle minor switching frequency is a function of each converter's inductor value, peak current limit and voltage levels on each side of each inductor.

Once each respective capacitor, CSTOR for the boost and COUT for the buck, droops below a minimum value, the hysteretic switching repeats. The DC voltages on CSTOR and COUT have a ripple voltage riding on top, caused by each capacitor charging due to the switching bursts and then discharging to a minimum value. The major frequency and duty cycle of CSTOR's ripple are a function of the VIN_DC regulation, VSTOR system load and/or VBAT charging current, L1 inductance value and CSTOR capacitance value. The major frequency and

duty cycle of COUT's ripple are a function of the VSTOR voltage, VOUT system load, L2 inductance value and COUT capacitance value. At heavier output loads (larger output current), the time the converter is off is smaller when compared to light load conditions. Figure 23 and Figure 24 show the major switching frequency versus load current and VSTOR voltage, respectively, for the buck converter. Figure 25 and Figure 26 show the output voltage ripple with COUT = 22 µF versus load current and VSTOR voltage, respectively, for the buck converter.

Nano-Power Management and Efficiency

The high efficiency of the bq25570 converters is achieved via the proprietary Nano-Power management circuitry and algorithm. This feature essentially samples and holds all references in order to reduce the average quiescent current. That is, the internal circuitry is only active for a short period of time and then off for the remaining period of time at the lowest feasible duty cycle. A portion of this feature can be observed in Figure 35 where the VRDIV node is monitored. Here the VRDIV node provides a connection to the VSTOR voltage (first pulse) and then generates the reference levels for the VBAT_OV, VBAT_OK and VOUT_SET resistor dividers for a short period of time. The divided down values at each pin are sampled and held for comparison against VBIAS as part of the hysteretic control. Since this biases a resistor string, the current through these resistors is only active when the Nano-Power management circuitry makes the connection—hence reducing the overall quiescent current due to the resistors. This process repeats every 64 ms.

The bq25570's boost charger efficiency is shown for various input power levels in Figure 7 through Figure 13. The bq25570's buck converter efficiency versus output current is plotted in Figure 17 and versus input voltage in Figure 18. All data points were captured by averaging the overall input current. This must be done due to the periodic biasing scheme implemented via the Nano-Power management circuitry. In order to properly measure the resulting input current when calculating the output to input efficiency, the input current efficiency data was gathered using a source meter set to average over at least 50 samples.

Thermal Shutdown

Rechargeable Li-ion batteries need protection from damage due to operation at elevated temperatures. The application should provide this battery protection and ensure that the ambient temperature is never elevated greater than the expected operational range of 85°C.

The bq25570 uses an integrated temperature sensor to monitor the junction temperature of the device. Once the temperature threshold is exceeded, the boost converter/charger is disabled and charging ceases. Once the temperature of the device drops below this threshold, the boost charger resumes operation. To avoid unstable operation near the overtemp threshold, a built-in hysteresis of approximately 5°C has been implemented. Care should be taken to not over discharge the battery in this condition since the boost converter/charger is disabled. However, if the supply voltage drops to the VBAT_UV setting, then the switch between VBAT and VSTOR will open and protect the battery even if the device is in thermal shutdown.

APPLICATION INFORMATION

Energy Harvester Selection

The energy harvesting source (e.g., solar panel, TEG, vibration element) must provide a minimum level of power for the IC to operate as designed. The IC's minimum input power required to exit cold start can be estimated as

$$PIN > [(I\text{-}STR\_ELM\_LEAK_{@1.8V} \times 1.8V) + (1.8V^2 / RSTOR(CS))] / 0.05$$

where $I\text{-}STR\_ELM\_LEAK_{@1.8V}$ is the storage element leakage current at 1.8V and

RSTOR(CS) is the equivalent resitive load on VSTOR during cold start and 0.05 is an estimate of the worst case efficiency of the cold start circuit.

Once the IC is out of cold start and the system load has been activated (e.g., using the VBAT_OK signal), the energy harvesting element must provide the main boost charger with at least enough power to meet the average system load. Assuming RSTOR(AVG) represents the average resistive load on VSTOR, the simplified equation below gives an estimate of the IC's minimum input power needed during system operation:

$$PIN \times \eta_{EST} > PLOAD = (VBAT\_OV^2 / RSTOR(AVG) + VBAT\_OV * I\text{-}STR\_ELM\_LEAK_{@VBAT\_OV})$$

where η_{EST} can be derived from the datasheet efficiency curves for the given input voltage and current and VBAT_OV. The simplified equation above assumes that, while the harvester is still providing power, the system goes into low power or sleep mode long enough to charge the storage element so that it can power the system when the harvester eventually is down. Refer to SLUC461 for a design example that sizes the energy harvester.

Storage Element Selection

In order for the charge management circuitry to protect the storage element from over-charging or discharging, the storage element must be connected to VBAT pin and the system load tied to the VSTOR pin. Many types of elements can be used, such as capacitors, super capacitors or various battery chemistries. A storage element with 100uF equivalent capacitance is required to filter the pulse currents of the PFM switching converter. The equivalent capacitance of a battery can be computed as computed as

$$C_{EQ} = 2 \times mAHr_{BAT(CHRGD)} \times 3600\ s/Hr / V_{BAT(CHRGD)}$$

In order for the storage element to be able to charge VSTOR capacitor (CSTOR) within the $t_{VB\_HOT\_PLUG}$ (50 ms typical) window at hot-plug; therefore preventing the IC from entering cold start, the time constant created by the storage element's series resistance (plus the resistance of the internal PFET switch) and equivalent capacitance must be less than $t_{VB\_HOT\_PLUG}$. For example, a battery's resistance can be computed as

$R_{BAT} = V_{BAT} / I_{BAT(CONTINUOUS)}$ from the battery specifications.

The storage element must be sized large enough to provide all of the system load during periods when the harvester is no longer providing power. The harvester is expected to provide at least enough power to fully charge the storage element while the system is in low power or sleep mode. Assuming no load on VSTOR (i.e., the system is in low power or sleep mode), the following equation estimates charge time from voltage VBAT1 to VBAT2 for given input power is

$$PIN \times \eta_{EST} \times t_{CHRG} = 1/2 \times CEQ \times (VBAT2^2 - VBAT1^2)$$

Refer to SLUC461 for a design example that sizes the storage element.

Note that if there are large load transients or the storage element has significant impedance then it may be necessary to increase the CSTOR capacitor from the 4.7uF minimum or add additional capacitance to VBAT in order to prevent a droop in the VSTOR voltage. See below for guidance on sizing capacitors.

Inductor Selection

The boost charger and the buck converter each need an appropriately sized inductor for proper operation. The inductor's saturation current should be at least 25% higher than the expected peak inductor currents recommended below if system load transients on VSTOR and/or VOUT are expected. Since this device uses hysteretic control for both the boost charger and buck converter, both are considered naturally stable systems (single order transfer function).

Boost Charger Inductor Selection

For boost charger to operate properly, an inductor of appropriate value must be connected between LBOOST, pin 20, and VIN_DC, pin 2. The boost converter internal control circuitry is designed to control the switching behavior with a nominal inductance of 22 µH ± 20%. The inductor must have a peak current capability of > 300 mA with a low series resistance (DCR) to maintain high efficiency.

A list of inductors recommended for this device is shown in Table 2.

Table 2.

INDUCTANCE (µH)	DIMENSIONS (mm)	PART NUMBER	MANUFACTURER
22	4.0x4.0x1.7	LPS4018-223M	Coilcraft
22	3.8x3.8x1.65	744031220	Wuerth

Buck Converter Inductor Selection

For buck converter to operate properly, an inductor of appropriate value must be connected between LBUCK, pin 16, and VOUT, pin 14. The buck converter internal control circuitry is designed to control the switching behavior with a nominal inductance of 10 µH ± 20%. The inductor must have a peak current capability of > 200 mA with a low series resistance (DCR) to maintain high efficiency. The speed of the peak current detect circuit sets the inductor's lower bound to 4.7 µH. When using a 4.7 uH, the peak inductor current will increase when compared to that of a 10 µH inductor, resulting in slightly higher major frequency.

A list of inductors recommended for this device is shown in Table 3.

Table 3.

INDUCTANCE (µH)	DIMENSIONS (mm)	PART NUMBER	MANUFACTURER
10	2.0 x 2.5 x 1.2	DFE252012C-H-100M	Toko
10	4.0x4.0x1.7	LPS4018-103M	Coilcraft
10	2.8x2.8x1.35	744029100	Wuerth
10	3.0x3.0x1.5	74438335100	Wuerth
10	2.5x2.5x1.2	74479889310	Wuerth
4.7	2.0 x 2.5 x 1.2	DFE252012R-H-4R7M	Toko

Capacitor Selection

In general, all the capacitors need to be low leakage. Any leakage the capacitors have will reduce efficiency, increase the quiescent current and diminish the effectiveness of the IC for energy harvesting.

VREF_SAMP Capacitance

The MPPT operation depends on the sampled value of the open circuit voltage and the input regulation follows the voltage stored on the CREF capacitor. This capacitor is sensitive to leakage since the holding period is around 16 seconds. As the capacitor voltage drops due to any leakage, the input regulation voltage also drops preventing proper operation from extraction the maximum power from the input source. Therefore, it is recommended that the capacitor be an X7R or COG low leakage capacitor.

VIN_DC Capacitance

Energy from the energy harvester input source is initially stored on a capacitor, CIN, connected to VIN_DC, pin 2, and VSS, pin 1. For energy harvesters which have a source impedance which is dominated by a capacitive behavior, the value of the harvester capacitor should scaled according to the value of the output capacitance of the energy source, but a minimum value of 4.7 µF is recommended.

VSTOR Capacitance

Operation of the bq25570 requires two capacitors to be connected between VSTOR, pin 19, and VSS, pin 1. A high frequency bypass capacitor of at 0.01 µF should be placed as close as possible between VSTOR and VSS. In addition, a low ESR capacitor of at least 4.7 µF should be connected in parallel.

VOUT Capacitance

The output capacitor is chosen based on transient response behavior and ripple magnitude. The lower the capacitor value, the larger the ripple will become and the larger the droop will be in the case of a transient response. It is recommended to use at least a 22 µF output capacitor between VOUT, pin 14 and VSS, pin 15, for most applications.

Additional Capacitance on VSTOR or VBAT

If there are large, fast system load transients and/or the storage element has high resistance, then the CSTOR capacitors may momentarily discharge below the VBAT_UV threshold in response to the transient. This causes the bq25570 to turn off the PFET switch between VSTOR and VBAT and turn on the boost converter. The CSTOR capacitors may further discharge below the VSTOR_CHGEN threshold and cause the bq25570 to enter Cold Start. For instance, some Li-ion batteries or thin-film batteries may not have the current capacity to meet the surge current requirements of an attached low power radio. To prevent VSTOR from drooping, either increasing the CSTOR capacitance or adding additional capacitance in parallel with the storage element is recommended. For example, if boost charger is configured to charge the storage element to 4.2 V and a 500 mA load transient of 50 µs duration infrequently occurs, then, solving I = C x dv/dt for CSTOR gives :

$$CSTOR \geq 500\ mA \times 50\ \mu s/(4.2\ V - 1.8\ V) = 10.5\ \mu F \quad (6)$$

Note that increasing CSTOR is the recommended solution but will cause the boost charger to operate in the less efficient cold start mode for a longer period at startup compared to using CSTOR = 4.7 µF. If longer cold start run times are not acceptable, then place the additional capacitance in parallel with the storage element.

LAYOUT CONSIDERATIONS

As for all switching power supplies, the PCB layout is an important step in the design, especially at high peak currents and high switching frequencies. If the layout is not carefully done, the boost converter/charger and buck converter could show stability problems as well as EMI problems. Therefore, use wide and short traces for the main current path and for the power ground paths. The input and output capacitors as well as the inductors should be placed as close as possible to the IC. For the boost converter / charger, first priority are the output capacitors, including the 0.1uF bypass capacitor (CBYP), followed by CSTOR, which should be placed as close as possible between VSTOR, pin 19, and VSS, pin 1. Next, the input capacitor, CIN, should be placed as close as possible between VIN_DC, pin 2, and VSS, pin 1. Last in priority is the boost converter inductor, L1, which should be placed close to LBOOST, pin 20, and VIN_DC, pin 2. For the buck converter, the output capacitor COUT should be placed as close as possible between VOUT, pin 14, and VSS, pin 15. The buck converter inductor (L2) should be placed as close as possible beween the switching node LBUCK, pin 16, and VOUT, pin 14. It is best to use vias and bottom traces for connecting the inductors to their respective pins instead of the capacitors.

To minimize noise pickup by the high impedance voltage setting nodes (VBAT_OV, OK_PROG, OK_HYST, VOUT_SET), the external resistors should be placed so that the traces connecting the midpoints of each divider to their respective pins are as short as possible. When laying out the non-power ground return paths (e.g. from resistors and CREF), it is recommended to use short traces as well, separated from the power ground traces and connected to VSS pin 15. This avoids ground shift problems, which can occur due to superimposition of power ground current and control ground current. The PowerPad should not be used as a power ground return path.

The remaining pins are either NC pins, that should be connected to the PowerPad as shown below, or digital signals with minimal layout restrictions. See the EVM user's guide for an example layout (SLUUAA7).

In order to maximize efficiency at light load, the use of voltage level setting resistors > 1MΩ is recommended. In addition, the sample and hold circuit output capacitor on VREF_SAMP must hold the voltage for 16s. During board assembly, contaminants such as solder flux and even some board cleaning agents can leave residue that may form parasitic resistors across the physical resistors/capacitors and/or from one end of a resistor/capacitor to ground, especially in humid, fast airflow environments. This can result in the voltage regulation and threshold levels changing significantly from those expected per the installed components. Therefore, it is highly recommended that no ground planes be poured near the voltage setting resistors or the sample and hold capacitor. In addition, the boards must be carefully cleaned, possibly rotated at least once during cleaning, and then rinsed with de-ionized water until the ionic contamination of that water is well above 50 MOhm. If this is not feasible, then it is recommended that the sum of the voltage setting resistors be reduced to at least 5X below the measured ionic contamination.

THERMAL CONSIDERATIONS

Implementation of integrated circuits in low-profile and fine-pitch surface-mount packages typically requires special attention to power dissipation. Many system-dependent issues such as thermal coupling, airflow, added heat sinks and convection surfaces, and the presence of other heat-generating components affect the power-dissipation limits of a given component.

Three basic approaches for enhancing thermal performance are listed below.

- Improving the power-dissipation capability of the PCB design
- Improving the thermal coupling of the component to the PCB
- Introducing airflow in the system

For more details on how to use the thermal parameters in the Thermal Table, check the Thermal Characteristics Application Note (SZZA017) and the IC Package Thermal Metrics Application Note (SPRA953).

REVISION HISTORY

Changes from Original (March 2013) to Revision A	Page
• Changed the data sheet from a Product Brief to Production data	3

Changes from Revision A (September 2013) to Revision B	Page
• Changed values in the THERMAL INFORMATION table	4

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead/Ball Finish	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
BQ25570RGRR	ACTIVE	VQFN	RGR	20	3000	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR		BQ570	Samples
BQ25570RGRT	ACTIVE	VQFN	RGR	20	250	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1 YEAR		BQ570	Samples

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

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

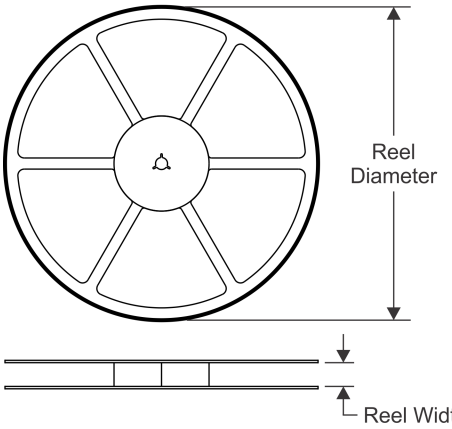
(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

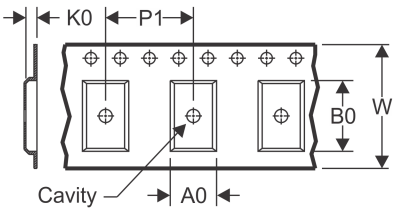
(5) Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

TAPE AND REEL INFORMATION

REEL DIMENSIONS

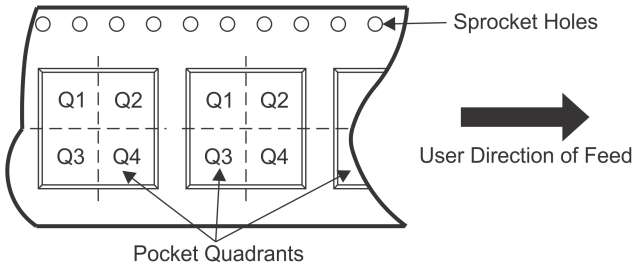


TAPE DIMENSIONS



A0	Dimension designed to accommodate the component width
B0	Dimension designed to accommodate the component length
K0	Dimension designed to accommodate the component thickness
W	Overall width of the carrier tape
P1	Pitch between successive cavity centers

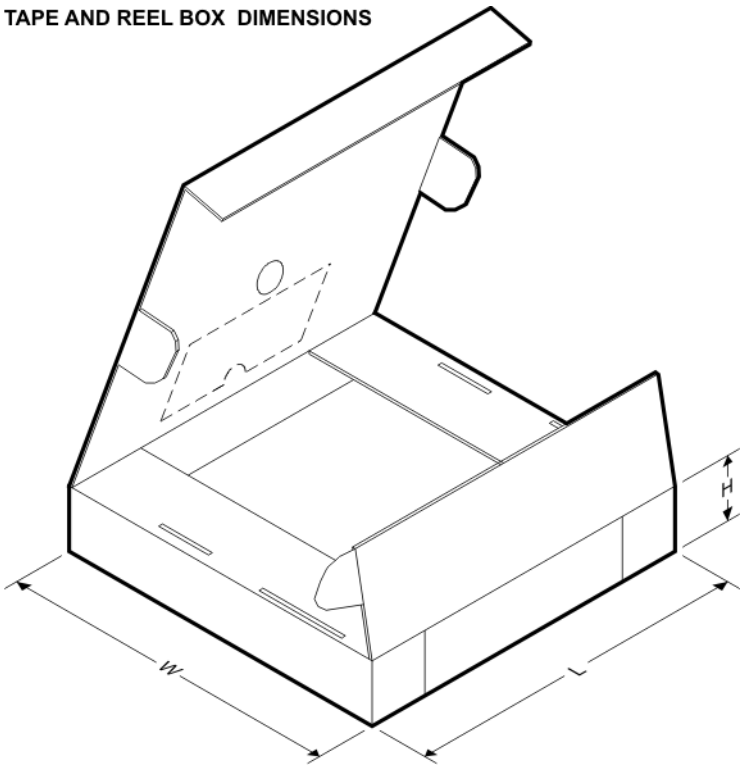
QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE



*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
BQ25570RGRR	VQFN	RGR	20	3000	330.0	12.4	3.75	3.75	1.15	8.0	12.0	Q1
BQ25570RGRT	VQFN	RGR	20	250	180.0	12.4	3.75	3.75	1.15	8.0	12.0	Q1

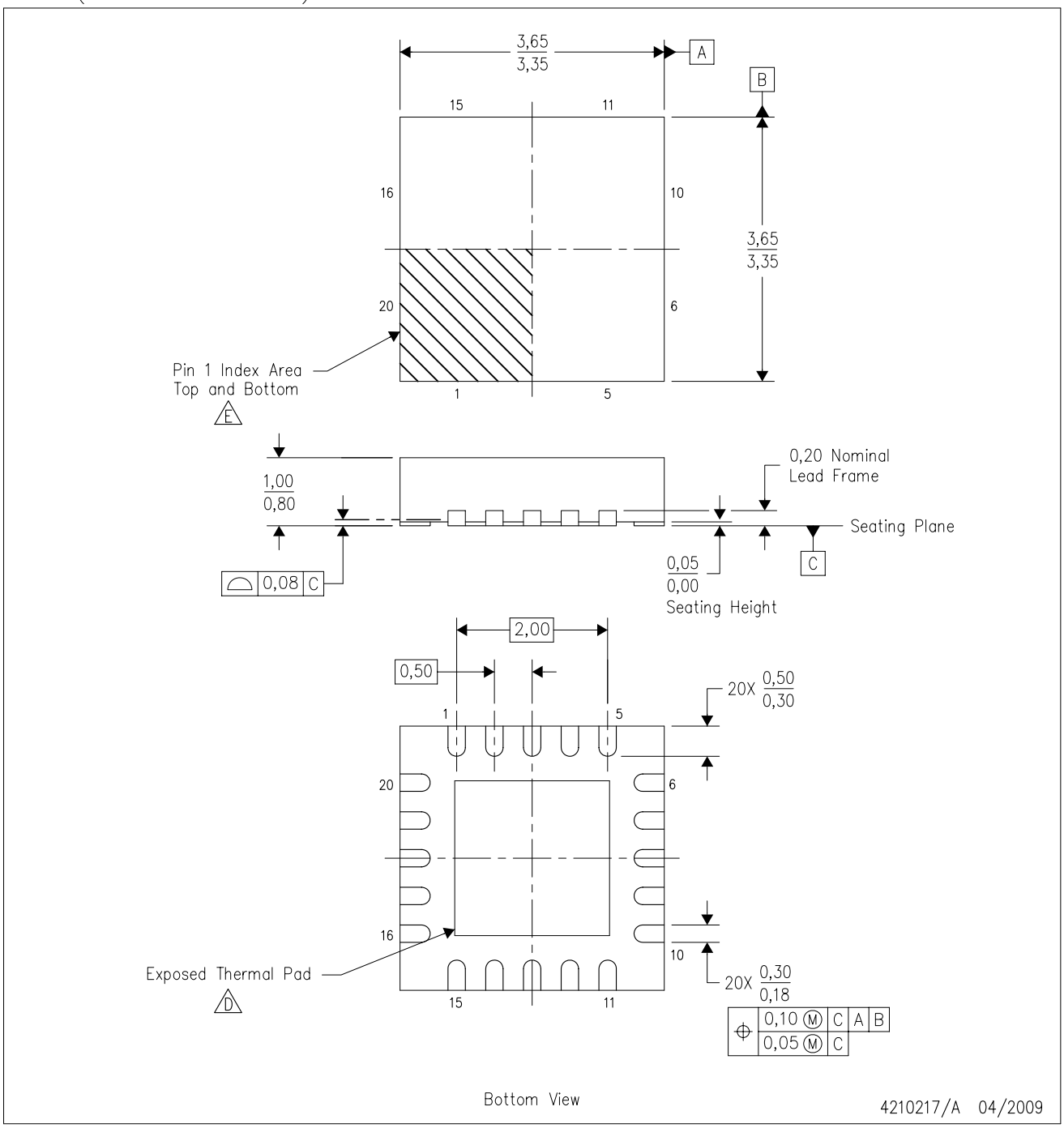
TAPE AND REEL BOX DIMENSIONS



*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
BQ25570RGRR	VQFN	RGR	20	3000	367.0	367.0	35.0
BQ25570RGRT	VQFN	RGR	20	250	210.0	185.0	35.0

RGR (S–PVQFN–N20) PLASTIC QUAD FLATPACK NO–LEAD



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. QFN (Quad Flatpack No–Lead) 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. Pin 1 identifiers are located on both top and bottom of the package and within the zone indicated. The Pin 1 identifiers are either a molded, marked, or metal feature.

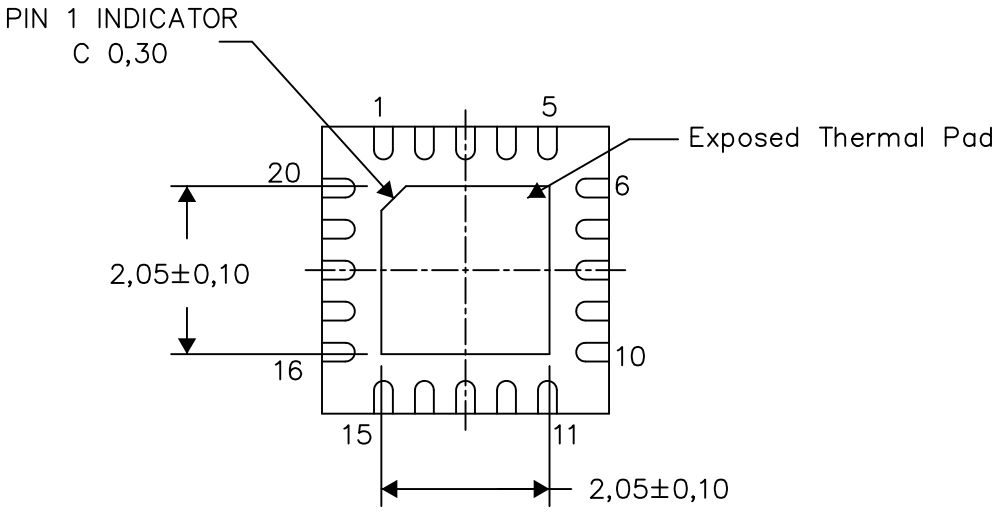
RGR (S–PVQFN–N20) PLASTIC QUAD FLATPACK NO–LEAD

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 the appropriate copper plane shown in the electrical schematic for the device, or alternatively, can be attached to 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, QFN/SON PCB Attachment, Texas Instruments Literature No. SLUA271. This document is available at www.ti.com.

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



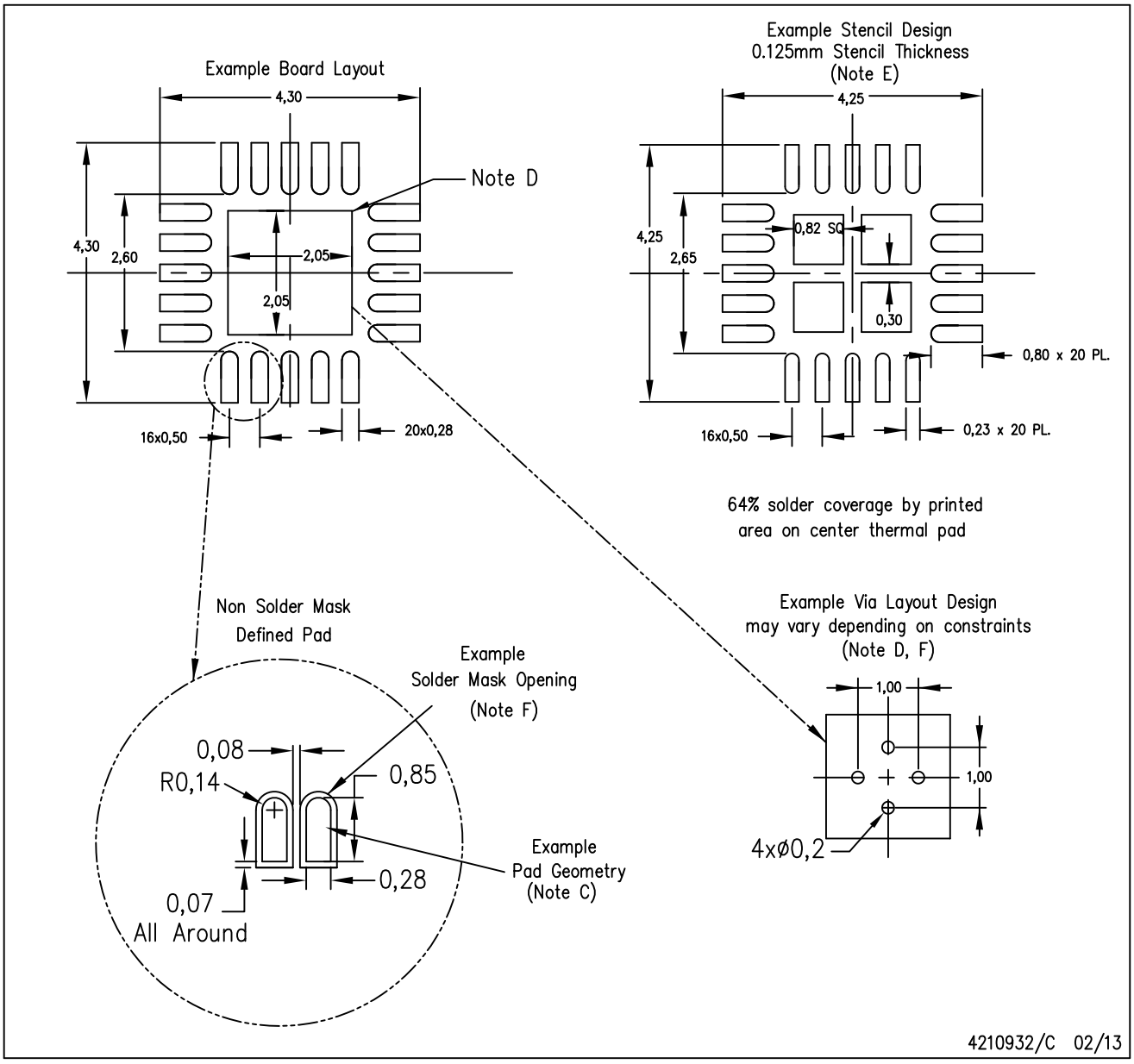
Bottom View

Exposed Thermal Pad Dimensions

4210218/D 02/13

NOTE: All linear dimensions are in millimeters

RGR (S–PVQFN–N20) PLASTIC QUAD FLATPACK NO–LEAD



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 QFN/SON PCB Attachment, Texas Instruments Literature No. 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>.
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. Customers should contact their board fabrication site for minimum solder mask web tolerances between signal pads.

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