POWERSMART

PS331

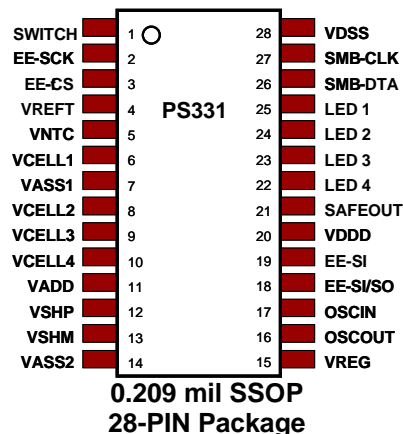## *Multichemistry Smart Battery Monitor*

Features

- Performs all major Li Ion, NiMH battery monitoring and reporting functions providing up to 1% accuracy in capacity measurement
- Additional output pin for over voltage or over temperature safety fuse operation (SAFEOUT)
- Fully compliant with industry standard Smart Battery Data Specification V1.1a
  - SMBus V1.1 with PEC/CRC-8 communication with system host
- High accuracy measurement of charge / discharge current, voltage, and temperature with on-chip 14-bit integrating A/D
- Precise capacity reporting for all lithium and nickel chemistries using PowerSmart patented algorithms and 3D battery cell models
- 3D models and "learned" parameters stored in external EEPROM; fully field re-programmable via SMBus interface
- Supports cell configurations of 1-4 cells in series
- Extremely low power operation:
  - Sleep Mode: < 10 uA typical
  - Run Mode: < 500 uA typical
  - Sample Mode: < 250 uA typical
- PS31XX Modules available for quick prototyping or production
- Complete hardware and software development tools available

Pin Description

```
            SWITCH  ┤1  ○      28├  VDSS
            EE-SCK  ┤2          27├  SMB-CLK
             EE-CS  ┤3          26├  SMB-DTA
             VREFT  ┤4  PS331   25├  LED 1
              VNTC  ┤5          24├  LED 2
            VCELL1  ┤6          23├  LED 3
             VASS1  ┤7          22├  LED 4
            VCELL2  ┤8          21├  SAFEOUT
            VCELL3  ┤9          20├  VDDD
            VCELL4  ┤10         19├  EE-SI
              VADD  ┤11         18├  EE-SI/SO
              VSHP  ┤12         17├  OSCIN
              VSHM  ┤13         16├  OSCOUT
             VASS2  ┤14         15├  VREG
```

**0.209 mil SSOP
28-PIN Package**

Pin Summary

Pin Name	Function
INPUT	LED Switch Input
EE-SCK, EE-CS, EE-SI/SO	SPI Serial EEPROM Interface
VREFT	Reference Voltage Output
VNTC	Temperature A/D Input
VCELL1-4	Single Cell Voltage Inputs
VASS1, VADD, VASS2	Analog Supply Voltage Inputs
VSHP, VSHM	Current Sense Resistor Inputs
VREG	Voltage Reg. Control Output
OSCOUT, OSCIN	Xtal Oscillator Inputs (32 KHz)
VDDD, VDSS	Digital Power Supply Inputs
SAFEOUT	Safety Control Output
LED1-4	LED Output Driver pins
SMB-CLK, SMB-DTA	SMBus Interface Pins

Product Overview

The PS331 is an advanced Smart Battery Monitor IC from PowerSmart, incorporating the latest Smart Battery System (SBS) Specification updates and revisions. Included is an advanced SMBus communications engine that is compliant with the SMBus V1.1 Packet Error Checking (PEC) CRC-8 error correction protocols. The PS331 implements updated firmware to process all the revised Smart Battery Data (SBData) V1.1 data values. The PS331 integrates an advanced RISC microprocessor, a precise 14-bit digital to analog converter, and an external serial EEPROM for storage of key operational parameters. An output pin is provided that can be set to activate on an over-voltage or over-temperature condition. This 'SAFEOUT' pin can be used to activate a fuse or other safety device for added safety in battery pack designs.

The PS331 can be easily customized for applications of Nickel or Lithium based battery cell chemistries using the external EEPROM. Upgrades to previously assembled battery packs are simple via the standard SMBus serial communications interface.

Table of Contents:

1.   General Description

The PS331 contains battery measurement, control, and communications features all in a fully integrated system. Functionally the IC can form the basis of a complete 'smart battery' system for integration in a battery pack or embedded (non-removable) battery system. ('Smart battery' can include the standard data reporting as detailed by the 'Smart Battery System Specifications (SBS)' via the SMBus protocols, or it can be alternate data content using the standard, on-board SMBus communications port.)

The PowerSmart PS331 continuously monitors charge and discharge currents, battery pack and cell voltages, and pack temperature. The IC continuously monitors, records, and reports numerous data values including the present state-of-charge (SOC) of the battery cells in percentages, Ampere-Hours, or Watt-Hours. Additional data predicting both present and future operating run-time, charge time, and operating capacity is also available. The PS331 also communicates various alarms when the predicted capacity is below a user-set limit (time and/or capacity) and when the battery cells are completely empty. This allows a smart battery-enabled system to use the battery energy 'down to the last drop' without need for extensive 'buffers' to permit final suspend or save-to-disk operation.

The PS331 communicates how and when to charge the smart battery based on preset algorithms, present battery conditions and externally provided charge inputs (voltage and current.) When charging parameters exceed desired limits, a stop charging instruction is sent to all external smart battery charging circuits. When correct charging is complete, a stop charge signal is also sent to the external smart battery charger indicating completion. A secondary signaling mechanism using the SAFEOUT pin output is also available to signal an over-charge condition via the

'T-pin' or thermistor ('Safety Signal') connection present on some battery packs. (The SAFEOUT pin may be used for other functions as well. It is activated either on over-voltage or over-temperature and is polarity programmable.)

2.   Module Versions

The PowerSmart PS31XX series modules offer complete, board-level battery monitoring and control modules that incorporate the advanced PS331 Smart Battery IC. The PS31XX subsystems include the EEPROM memory for parameter storage as well as all of the necessary support electronics so that they can be simply integrated in a battery pack. As a result, they are an ideal vehicle to support both prototyping and production requirements. These module designs are available with safety electronics for Li chemistries and can be configured for multiple pack configurations.   Please refer to the PowerSmart web site for ordering information and design documentation (including schematics) for PowerSmart module products (www.powersmart.com).

3.   Development Tool Summary

PowerSmart provides all the necessary hardware and software to enable easy tailoring of battery control algorithm parameters and cell performance models to meet specific application requirements and attain the highest accuracy available anywhere. Table 1 summarizes the development tool offering from PowerSmart to support the PS331. Please refer to the PowerSmart web site for ordering information at www.powersmart.com.

Table 1: P3 Family Development Tool Summary

Tool	Description
P3 Li Ion Workbook	Microsoft Excel ™ based tool used to edit the initial configuration of a P3 battery pack and create a .p3i file for programming into the EEPROM. Available for download at www.powersmart.com.
SBTool Software	Development software package of multiple programs for configuration, calibration, and testing of P3-based battery packs including: - PROG: Programs and verifies external serial EEPROM - CAL: Calibration software that can automatically calibrate up to 4 packs at once - WINFO: Read/write of 34 Smart Battery Data values - FTEST: Final Test program to verify end-of-line module/pack values Supplied with all of the hardware tools listed below:
P3 Eval System (PS033N-500)	Low cost platform for the P3 family of IC's for immediate evaluation of P3 functionality. Supplied with a PS331 and circuitry for PC COM port to SMBus translation to facilitate communication over the SMBus. Can be connected to an external lithium ion battery cells to emulate final battery pack operation.
P3 Cal System (PS010N-150)	Cost effective, single board calibration system used for programming and calibration of a P3 battery pack. Provides circuitry for PC COM port to SMBus translation to facilitate communication between a P3 battery pack and the PC. Also provides A/D and D/A hardware for calibrating the P3 on-chip A/D converter.
Info / Test Board (PS011-501)	The INFO/FTEST hardware interface board is a simple circuit that permits a PC's serial COMx port to be used as an SMBus interface.

Figure 1: PS334 Applications Circuit – Removable Smart Battery Block Diagram

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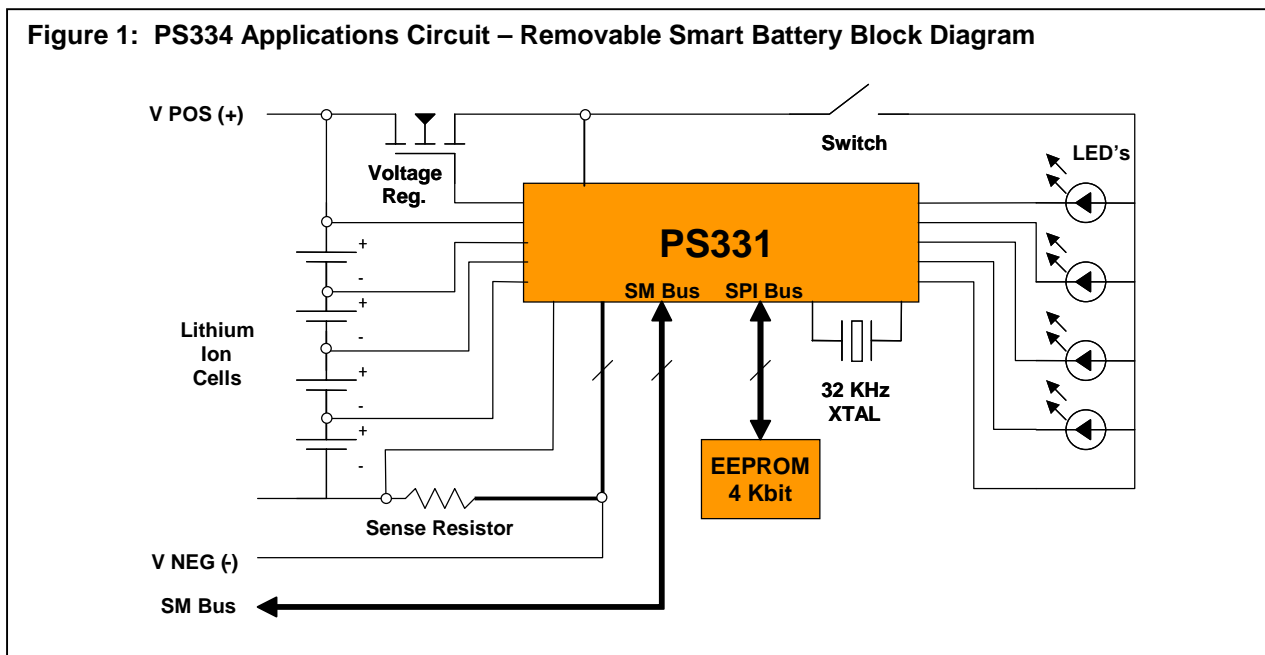
Table 2: PS331 Pin Description

PIN #	NAME	DESCRIPTION
1	SWITCH	(Input) Edge triggered input pin typically used for LED activation. May also be used for 'Sleep Mode' wake-up comparator input.
2	EE-SCK	(Output) External serial EEPROM Clock . Connect to SCK pin on external serial EEPROM.
3	EE-CS	(Output) External serial EEPROM Chip Select . Connect to CS pin on external serial EEPROM.
4	VREFT	(Output) Reference voltage output for use with temperature measuring A/D circuit . This 150 mV output is the top leg of a voltage divider thermistor circuit.
5	VNTC	(Input) Temperature measurement A/D input for use with temperature circuit. This is the mid-point connection of a voltage divider where the upper leg is a thermistor (103ETB-type) and the lower leg is a 3.65K ohm resistor . This input should not go above 150 mV.
6	VCELL1	(Input) Lowest level input for A/D measurement of cell voltages.
7	VASS1	Analog ground reference point.
8	VCELL2	(Input) Second to lowest level input for A/D measurement of cell voltages.
9	VCELL3	(Input) Second to highest level input for A/D measurement of cell voltages .
10	VCELL4	(Input) Highest level input for A/D measurement of cell voltages.
11	VADD	(Input) Analog supply voltage input.
12	VSHP	(Input) Current measurement A/D input from positive side of the current sense resistor.
13	VSHM	(Input) Current measurement A/D input from negative side of the current sense resistor.
14	VASS2	Analog ground reference point.
15	VREG	(Output) Used to control an external small signal MOSFET to provide a regulated voltage to the IC . Only required for battery packs with voltages greater than 3.6V.
16	OSCOUT	(Output) Oscillator connection for an external low-power 32.768 kHz crystal which provides accurate timing for self-discharge and capacity calculations.
17	OSCIN	(Input) Other oscillator connection . (See OSCOUT description.)
18	EE-SO	(Output) External SPI serial EEPROM data input. Connect to the SO pin on external SPI serial EEPROM.
19	EE-SI	(Input) External serial EEPROM data input. Connected to the SO pin on external serial EEPROM
20	VDDD	(Input) Digital supply voltage input.
21	SAFEOUT	(Output) Programmable over-voltage and/or over-temperature output. Default non-active output is low (0V)
22	LED4	(Output) Relative or Absolute State-Of-Charge visual display
23	LED3	(Output) Same as LED4 pin
24	LED2	(Output) Same as LED4 pin
25	LED1	(Output) Same as LED4 pin
26	SMB-DTA	SMBus Data pin connection.
27	SMB-CLK	SMBus Clock pin connection.
28	VDSS	Digital ground reference point.

4. Reference Documents

This data sheet provides an overview of the PS331 as well as features that apply to the entire P3 family. For further information on P3 device and development tool operations, please refer to the following documents available for download at www.powersmart.com

P3 Family User's Guide:
Applications Notes:
      P3 Ex. Connection Diagrams
      P3 PC Board Layout Guide
      P3 Temperature Alarm Operation
      P3 Calibration Explanations
Development Tool Documentation:
      Lithium Ion Workbook Guide
      SBTool User's Guide
      P3 Eval System Data Sheet
      P3 Cal System Data Sheet
      P3 Info / Test Board Data Sheet
      SBToolBox Data Sheet

5. LED Pins

If LED's are connected to the LEDX pins to form a fuel-gauge display, and the SWITCH pin is shorted to the VDDD pin (IC supply), then the LED's will illuminate for a duration of N_DISPLAY periods of TWS:

N_DISPLAY x TWS (500 msec) =

LED 'on' duration

The fuel-gauge display is based on the SBData value of RelativeStateOfCharge but may be configured for AbsoluteStateOfCharge using bit 3 in the MANUF_MODE register in the external EEPROM.

For PS331 products, LEDx pins are fixed for fuel-gauge display configuration only. The LED display is lit to indicate the state of charge of the battery as follows:

OUTPUT Pin #:	4	3	2	1
SOC Value:	100%	75%	50%	25%

In all cases, the least significant output pin assigned as an LED output will always flash if the SOC value is below 10%.

The "Polarity" bit in LED_POLARITY is used to select an active high or active low output. Normal polarity for an LED SOC bar-graph requires this bit be set to active low output. LED_POLARITY is valid for all methods described below (bar graphs, conditional outputs). In case that an output is calculated to 0 and the polarity bit was set to 1, then the output is inverted and will become HIGH.

6. SAFEOUT Pin

The PowerSmart PS331 SMBus Smart Battery IC offers an additional safety output for use in Li Ion battery pack applications. As in any SMBus/SBS system, the first level of safety is the SMBus communications between the Smart Battery, the System Host, and the Smart Battery Charger. Charging messages such as ChargingCurrent and ChargingVoltage are sent between the Smart Battery and the Smart Battery Charger. AlarmWarning messages are sent between the Smart Battery, the Host, and the Smart Charger if the battery detects any incorrect or unsafe conditions.

The PowerSmart PS331 IC has an additional output pin (SAFEOUT pin) that is activated whenever any individual cell voltage is measured above the SAFETY_VOLT limit or when the measured temperature is greater than the SAFETY_TEMP limit. The pin is reset to an inactive state when the measured temperature is below the AL_HI_TEMP limit and all the individual cell voltages are below the SAFE_VOLT limit. To prevent false triggering, a re-check timer requires the activation limits to be exceeded for a programmable duration before the SAFEOUT pin is activated.

This SAFEOUT pin may be used to activate a safety fuse; signal or control another safety device to disable a charge control MOSFET; or to indicate an error condition to a host system through an interrupt line. The SAFEOUT pin may be configured to output either logic HI (3.3V) or LOW (0V.)

NOTE: During EEPROM programming and default power-up operation, the SAFEOUT pin is normally LOW (0V) in the PS331.

Figure 1: PS331 SAFEOUT Pin Connected to an Independent Safety Fuse
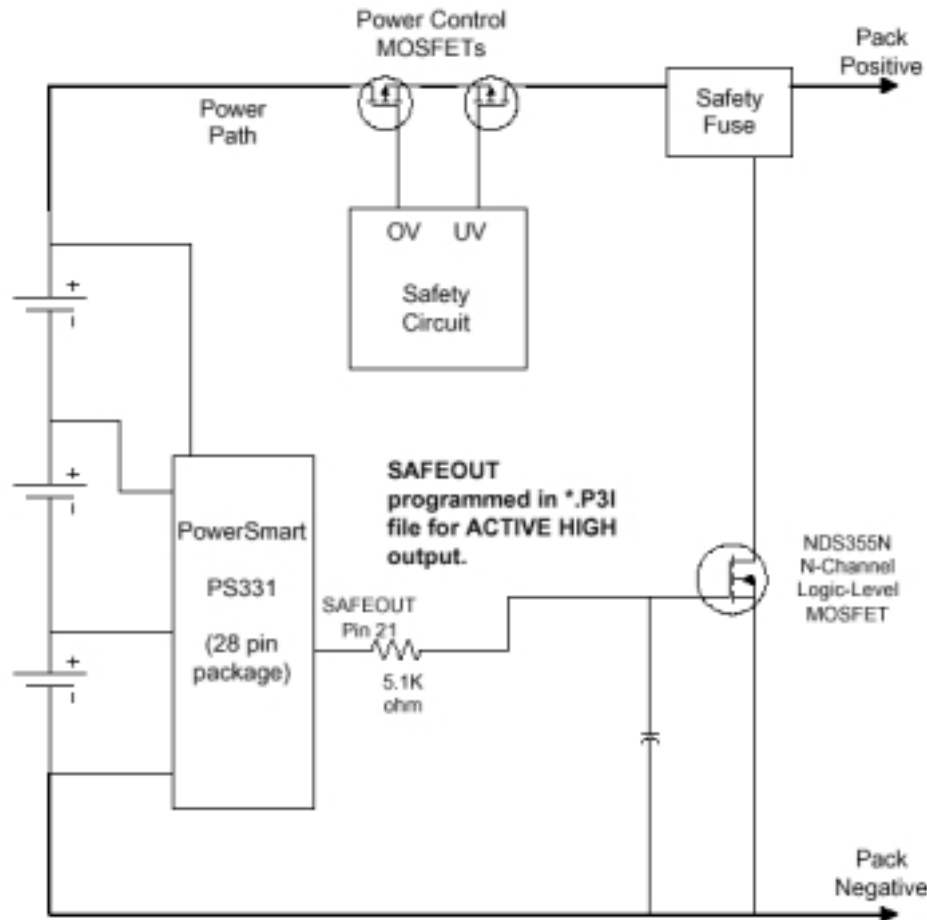
Figure 2: SAFEOUT Operational Flowchart

In the description below, VCELLx is the measurement of each cell voltage. Temperature is the SBData value for the measured pack temperature:

> If VCELLx > SAFETY_VOLT then SAFEOUT is activated

> If Temperature > SAFETY_TEMP then SAFEOUT is activated

> If VCELLx < SAFE_VOLT AND Temperature < AL_HI_TEMP then the SAFEOUT pin is reset

The limits are set in the appropriate *.P3I file for the external EEPROM. Examples are shown below:

```
SAFETY_VOLT        : 4300       ; Voltage which activates SAFEOUT pin (4.3V)
SAFE_VOLT          : 4150       ; Voltage required to reset SAFEOUT pin (4.15V)
SAFETY_TEMP        : 750        ; Temperature to activate SAFEOUT pin (55'C)
AL_HI_TEMP         : 700        ; HI_TEMP Alarm and reset SAFEOUT pin (50'C)
SAFE_STATE         : 8240       ; SAFEOUT pin output polarity (Active LO)
OR
SAFE_STATE         : 12320      ; SAFEOUT pin output polarity (Active HI)
```

PRELIMINARY

7. Discharge Capacity and Relearn

Discharge capacity is determined based on the end-of-discharge (EOD) voltage point. This voltage can be reached at different times based on the discharge rate. The discharge capacity parameter table values predict the point at which this EOD will be reached based on various discharge rates and environmental conditions.

The end-of-discharge voltage is specified in the external EEPROM value of U_EMPTY. When the voltage measured on the VPACK4 pin is below U_EMPTY for a duration of EOD_RECHECK x TWS periods, then a valid EOD has occurred.

When a valid EOD has been reached, the TERMINATE_DISCHARGE_ALARM bit (bit 11) in BatteryStatus will be set. An AlarmWarning with this bit set will be broadcast to the SMBus Host.

Typically, the REMAINING_TIME_ALARM and/or REMAINING_CAPACITY_ALARM bits will be set first, giving a user-defined early warning prior to the TERMINATE_DISCHARGE_ALARM.

To maintain accurate capacity prediction ability, the FULLCAPACITY value is re-learned on each discharge which has reached a valid EOD after a previous valid fully charged EOC. If a partial charge occurs before reaching a valid EOD, then no re-learn will occur. If the discharge rate at EOD is greater than the 'C-rate' adjusted value in HIGH_DISCHARGE then no re-learn will occur either.

When a valid EOD has been reached and the discharge is halted or slowed such that the voltage at VPACK4 has risen above U_EMPTY + EDV_HYST then the error calculations represented by the SBData value of MaxError will be cleared to zero. If appropriate, the re-learned value of FULLCAPACITY (and FullChargeCapacity) will also be updated at this time.

8. Electrical Characteristics

8.1. Absolute Maximum Ratings

Symbol	Description	Min	Max	Units
V_{ADD}-$V_{ASS1,2}$	Supply voltage - Analog section	2.5	7.0	V
V_{DDD}-V_{DSS}	Supply voltage - Digital section	2.5	7.0	V
V_{CELLx}	Voltage at any VCELLx pin	-0.5	20	V
V_{PIN}	Voltage directly at any pin (except VCELLx)	-0.5	7.0	V
T_{BIAS}	Temperature under bias	-25	85	°C
$T_{STORAGE}$	Storage temperature (package dependent)	-35	150	°C

Note: These are stress ratings only. Stress greater than the listed ratings may cause permanent damage to the device. Exposure to absolute maximum ratings for an extended period may affect device reliability. Functional operation is implied only at the listed Operating Conditions below.

8.2. DC Characteristics

(TA=-20°C to 85°C; VCC =3.3V ± 10%)

Symbol	Description	Min	Typ.	Max	Units	Notes
V_{ADD}	Supply voltage – Analog section	2.7	3.3	5.0	V	
V_{DDD}	Supply voltage – Digital section	2.7	3.3	5.0	V	
I_{DD}	Current consumption (See modes below)	8	270	600	μA	
	Run Mode	375	500	600	μA	1
	Sample Mode	190	250	375	μA	1,2
	Low-Voltage Sleep	8	12	15	μA	3
	Shelf Sleep	10	12	18	μA	3,4
V_{SENSE}	Sense resistor voltage input	-152		152	mV	
V_{REFT}	NTC Reference voltage output at V_{REFT} pin		150		mV	
LED0..4	Output voltage for 5 mA current output			0.5	V	
$V_{IN-CELL4}$	Voltage at VCELL4	-0.5		20	V	
I_{IN}	Input current at any VCELLx (only for V_{time})			200	μA	
SCL,SDA	Output voltage for 350 μA output current			35	mV	
$I_{PULLDOWN}$	Pull down current at SCL,SDA		0.5	1.0	μA	
I_{LO}, I_{HI}	Current at SCL,SDA			10.0	μA	
$V_{LO,IN}$	Input voltage for LOW at SCL,SDA	-0.5	0.4	0.6	V	
$V_{HI,IN}$	Input voltage for HIGH at SCL,SDA	1.4	2	5.5	V	
$V_{LO,OUT}$	Output voltage for LOW at SCL,SDA		0.2	0.4	V	
I_{SINK}	Device sink current	100		350	μA	

Notes:

1. During LED illumination, currents may peak at 10mA but average individual LED current is typically 5 mA (using low-current, high-brightness devices.)
2. Sample Mode power consumption is variable and dependent on threshold and timing settings for Sample Mode operation.
3. Power consumption in Low-Voltage Sleep and Shelf Sleep Modes are dependent on the pack voltage. Connecting the SWITCH pin to the VDDD or VADD pin for more than 0.5 second causes the IC to recover from Shelf-Sleep Mode.AC Characteristics.

8.3. AC Characteristics

(TA=-20°C to 85°C; VCC =3.3V ± 10%)

Symbol	Description	Min	Typical	Max	Units	Notes
f_{RC}	Internal RC oscillator frequency	410	465	530	kHz	
f_{XTAL}	External crystal frequency		32.768		kHz	
$f_{A/D}$	Internal A/D operating clock frequency		$f_{RC}/10$		kHz	
f_{CPU}	Internal CPU operating clock frequency		$f_{RC}/4$		kHz	
V_{time}	Voltage measurement time, 10 bit		$2^{11}/f_{A/D}$		ms	
T_{time}	Temperature measurement time, 10 bit		$2^{11}/f_{A/D}$		ms	
I_{time}	Current measurement time, 13 bit+sign		$2^{14}/f_{A/D}$		ms	
C_{SMB}	Bus capacitance @ 100 kHz			160	pF	

8.4. Characteristics – SMBus

(TA=-20°C to 85°C; VCC =3.3V ± 10%)

Symbol	Description	Min	Typical	Max	Units	Notes
f_{SMB}	Clock operating frequency	<1.0		100	kHz	
$f_{SMB-MASTR}$	Broadcast bit frequency (Note 1)	50	$f_{RC}/8$	68	kHz	1
t_{free}	Free time between START and STOP	4.7			µ s	
t_{SHLD}	Hold time after START condition	4.0			µ s	
$t_{RSSETUP}$	Setup time before repeated START	250			n s	
t_{PSETUP}	Setup time STOP condition	4.0			µs	
t_{HLD}	Data hold time	0			n s	
t_{SETUP}	Data setup time	250			n s	
$t_{LOW:SEXT}$	Message buffering time			24	m s	
$T_{TIMEOUT}$	Timeout period	25		35	m s	
t_{LOW}	Clock low period	4.7			µ s	
t_{HIGH}	Clock high period	4.0			µ s	
t_{HL}	Clock / data fall time			300	n s	
t_{LH}	Clock / data rise time			1000	n s	

Notes:

1. Used when broadcasting AlarmWarning, ChargingCurrent, and/or ChargingVoltage values to either a SMBus Host or a SMBus Smart Battery Charger. This is only used when the PS331 becomes a SMBus Master for these functions. The receiving (Slave) device may slow the transfer frequency. See *SMBus/I²C Tutorial in PowerSmart P3 Family Users Guide* for additional information.
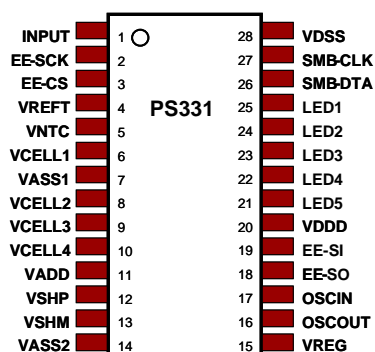
8.5. Granularity

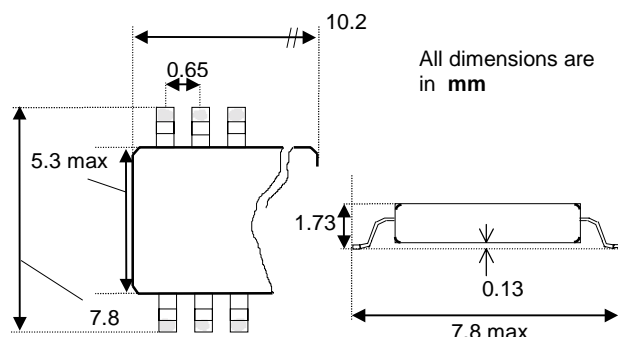(TA=-20°C to 85°C; VCC =3.3V ± 10%)

Symbol	Description	Min	Typical	Max	Units	Notes
$G_{ranularity}$	Voltage granularity, @Max = 17000 mV		16.5		mV/bit	
$T_{granularity}$	Temperature granularity, look up tables		0.1		°C/bit	
$I_{granularity}$	Current granularity, @ Rsense = 25 mOhms		0.8		mA/bit	

9. Mechanical Packaging Information

28 pin SSOP package

INPUT	1	28	VDSS
EE-SCK	2	27	SMB-CLK
EE-CS	3	26	SMB-DTA
VREFT	4	25	LED1
VNTC	5	24	LED2
VCELL1	6	23	LED3
VASS1	7	22	LED4
VCELL2	8	21	LED5
VCELL3	9	20	VDDD
VCELL4	10	19	EE-SI
VADD	11	18	EE-SO
VSHP	12	17	OSCIN
VSHM	13	16	OSCOUT
VASS2	14	15	VREG

PS331

Mechanical Dimensions

10.2

0.65

All dimensions are in **mm**

5.3 max

7.8

1.73

0.13

7.8 max

10. Quality Control

PowerSmart, Inc., has received ISO-9001 certification through TUV Rheinland of North America, based in Newtown, Conn. ISO-9001 certification indicates that PowerSmart has met strict international standards of quality control in manufacturing systems including product design, production, training, and inspection and testing. PowerSmart received certification for a quality system for the Design and Development of Battery Control Integrated Circuits, Software, Modules, Chargers, and Systems. PowerSmart, Inc., provides smart battery and charger electronics designed for use with all battery chemistries, bringing a new level of accuracy, reliability and customization not available before with other smart battery ICs.

11. Notice

PowerSmart products are not authorized for use as critical components of life support devices or systems. Seller disclaims any warranty or responsibility for such usage, which shall be at buyer's sole risk, notwithstanding any prior notice to seller of such usage or intended usage.

As used herein, "life support devices or systems" are devices or systems that are intended for implant into the body to support of sustain life, or to assist such an implant, and whose failure to perform in such function can be reasonably expected to result in significant injury to the user. A "critical component" is any component of a life support device or system whose failure to perform can reasonably be expected to cause or result in the failure of performance of a life support device or system or to adversely affect its safety or effectiveness.