Advance Information

PS401 Accuron™

Single Chip Battery Manager

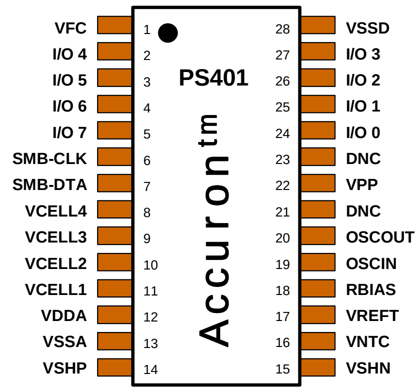
POWERSMART®

Smart Solutions for Battery Management

Features

- Single chip solution for rechargeable battery management
- Precise capacity reporting (within 1%) for all rechargeable chemistries using embedded PowerSmart patented algorithms
- User configurable and "learned" parameters stored in on-chip 128 x 8 EEPROM; fully field re-programmable via SMBus interface
- Integrating sigma-delta A/D converter accurately measures:
  - Charge / discharge current through VSHP, VSHN sense resistor inputs (15-bits)
  - High voltage (18V) battery cells directly connected to VCELL inputs (11-bits)
  - Temperature measurement from on-chip sensor or optional external thermistor (10-bits)
- Flexible, accurate, time base options:
  - On-chip oscillator
  - Optional external 32 KHz quartz crystal
- Eight individually programmable input / output pins that can be assigned as
  - Charge control I/O
  - Safety function I/O
  - SOC LED output drive pins
  - General purpose I/O
- Full SMBus v1.1 2-wire host interface
- SBData v1.1 compliant firmware in 12 Kbytes of customizable on-chip OTP

Pin Description



28-pin 0.209 mil SSOP Package

Pin Summary

Pin Name	Type	Description
VFC	I	Supply filter cap input
I/O 7-0	I/O	Programmable digital I/O
SMB-CLK, SMB-DTA	I/O	SMBus Interface
VCELL4-1	I	Cell voltage inputs
VDDA, VSSA	Supply	Analog supply voltage
VSHP, VSHN	I	Current sense resistor inputs
VNTC, VREFT	I	External thermistor inputs
ROSC	I	Internal oscillator bias resistor
OSCIN, OSCOUT	I , O	Optional crystal oscillator connection
DNC	NC	Do Not Connect
VPP	I	OTP program voltage
VSSD	Ground	Digital supply voltage ground

Product Overview

The PS401 is the first device in the new Accuron™ Family of single-chip IC's for rechargeable battery management. Within a fully integrated IC, the Accuron combines a proprietary microcontroller core together with monitoring / control algorithms and 3D cell models stored in 12 Kbytes of on-chip OTP EPROM, precision A/D, and mixed signal circuitry. On-chip EEPROM is provided for storage of user-customizable and "learned" battery parameters. An industry standard 2-wire SMBus interface supports host communication using standard SBData commands and status.

The PS401 can be configured to accommodate all rechargeable lithium battery chemistries including Li Ion graphite, Li Ion hard carbon, and Li Ion polymer with direct connection to 4 series cell configurations. Future Accuron versions will quickly be added to support NimH and Pb.

Additional integrated features include a high accuracy on-chip oscillator and temperature sensor. Eight general purpose pins support charge or safety control, SOC LED display, or user-programmable digital I/O.

As a result, the PS401 delivers the highest possible accuracy in monitoring and reporting of battery voltage, temperature, current, and capacity with a minimum of external components.

General Description

The PS401 is the first device in the fully integrated A c c u r o n™ family of rechargeable battery management IC's. Based upon an advanced 8-bit RISC microcontroller core, it supports a full complement of integrated resources including OTP EPROM for storage of the battery management algorithms and 3D cell models, nonvolatile EEPROM for storage of user programmable and learned parameters, as well as a highly accurate 15-bit integrating A/D converter.

The A c c u r o n performs precise measurements of current, voltage and temperature using the A/D with its auto-zero offset correction feature. Battery capacity is precisely calculated and reported from the V, I, and T measurements using proprietary algorithms and sophisticated 3-dimensional cell models.

Developed by battery chemists, the patented, self-learning 3D cell models contain over 250 parameters and compensate for self-discharge, temperature, and other factors. In addition, multiple capacity correction and error reducing functions are performed during charge/discharge cycles to enhance accuracy and improve fuel-gauge and charge control performance. As a result, battery capacity reporting and run-time predictions accurate with less than 1% error are readily achievable.

The proprietary algorithms and 3D cell models are contained within the 12-Kbyte on-chip one-time-programmable (OTP) EPROM. Firmware upgrades and customized versions can be rapidly performed without the need for silicon revisions.

The PS401 A c c u r o n can be easily customized for a particular application's battery cell chemistry. Standard configuration files are provided by PowerSmart for a wide variety of popular rechargeable cells and battery pack configurations.

Communication with the host is fully compliant with the industry standard Smart Battery System (SBS) Specification. 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 integrated firmware processes all the revised Smart Battery Data (SBData) V1.1 data values.

In addition to the on-chip memory and firmware resources the PS401 provides the option of an integrated accurate time base and temperature sensor.

The integrated time base is a highly accurate RC oscillator that provides accurate timing for self-discharge and capacity calculations and eliminates the need for an external crystal. However, for the highest possible accuracy, a direct connection for an external 32 KHz quartz crystal is also supported.

An integrated temperature sensor is provided that can eliminate the need for an external thermistor. In addition, a connection is provided for an external thermistor that can be simultaneously monitored.

Eight programmable digital input / output pins are provided by the PS401. These pins can be used as LED outputs to display State-Of-Charge (SOC), or for direct control of external charge circuitry, or to provide additional levels of safety in LiIon packs. Alternatively, they can be used as general purpose input / outputs.

With all of its sophisticated features, PowerSmart's PS401 A c c u r o n achieves the highest smart battery data accuracy in a complete battery management solution at an attractive cost. The A c c u r o n delivers both space and total system component cost savings for a wide variety of battery operated or battery backed systems.

Figure 1: PS401 Internal Block Diagram

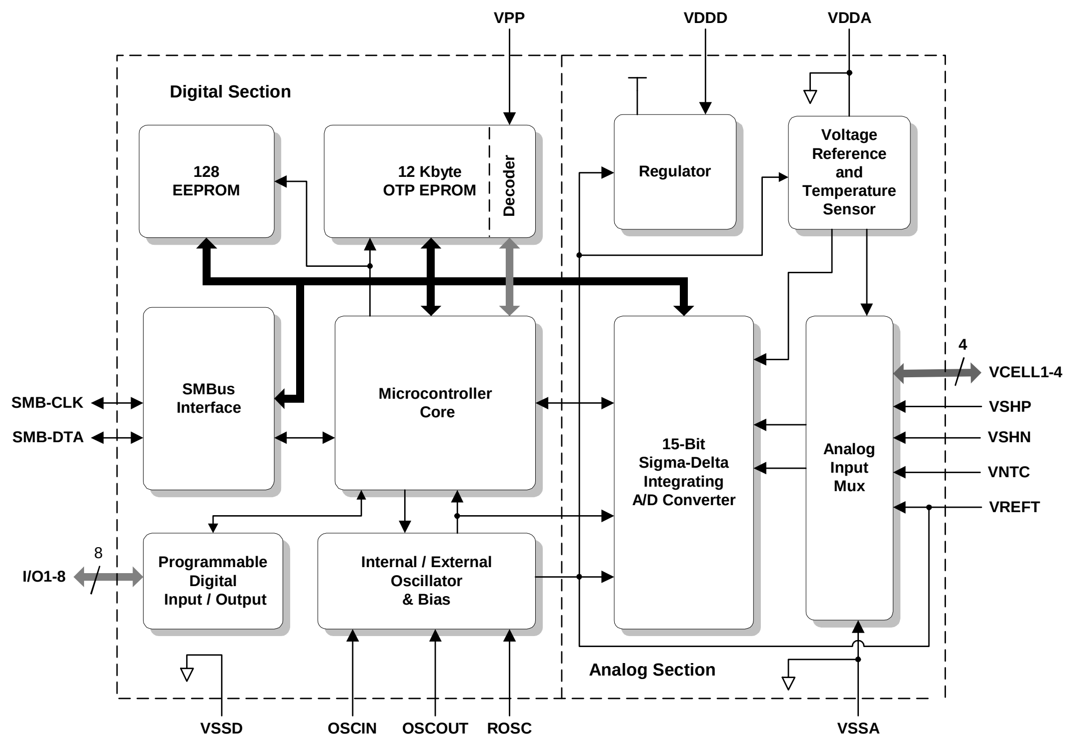
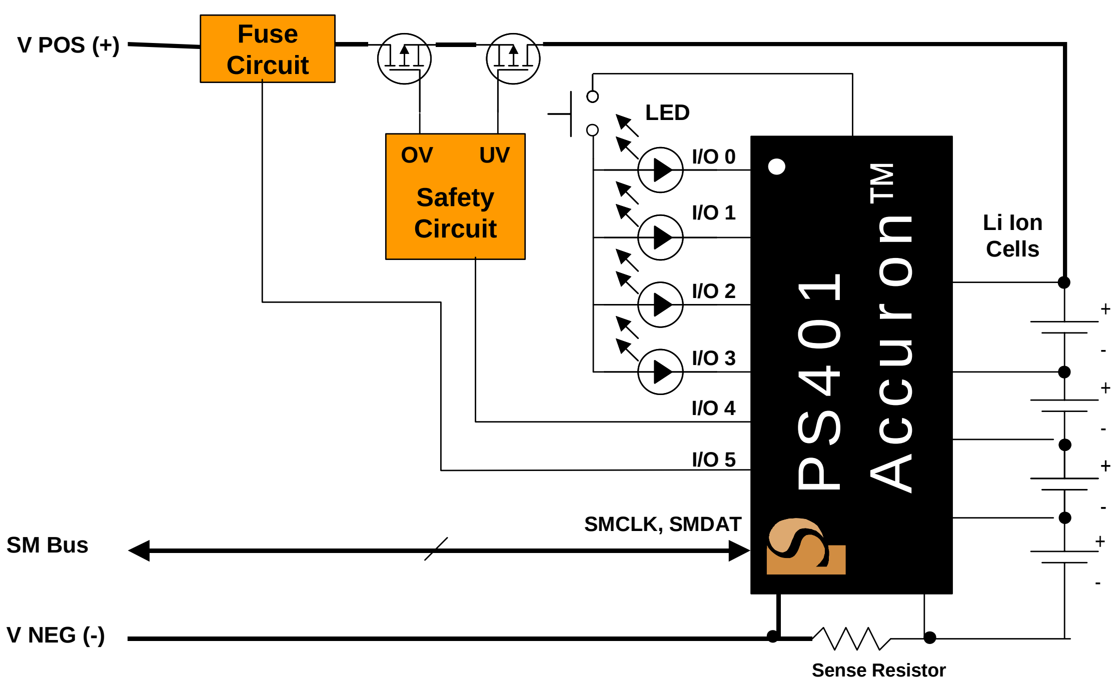


Figure 2: Simplified Application Block Diagram



Functional Description

Operational Modes

The PS401 Accuron has four modes of operation with varying power consumption: Run Mode, Sample Mode, Sleep Mode, and Shelf Sleep Mode. Run mode takes the most measurements and thus uses the most power. Sample mode takes measurements less often and uses less power. The PS401 enters sample mode when the battery current is less than a programmable threshold. The sampling frequency is also programmable. Sleep mode is entered when the battery voltage is less than a programmable level. During sleep mode, no measurements are taken in order to conserve the most energy when the battery is very low. Wake up from sleep mode can be programmed to occur at a voltage level, current level, or SMBus or I/O pin activity. Shelf Sleep mode is for storage of batteries and draws a no current. The PS401 must be taken out of Shelf Sleep mode by activating the SWITCH input before use.

Analog to Digital Converter Operation

The PS401 A/D converter measures voltage, current and temperature and integrates the current over time to measure charge. The voltage of all battery cells and the entire pack is monitored, and the pack and each cell input are individually calibrated for accuracy. Both charge and discharge currents are monitored and integrated over time using the on-chip oscillator or an optional external crystal. Temperature is measured from the on-chip temperature sensor or an optional external thermistor. Current and temperature are also calibrated for accuracy.

Charge Control

The PS401 can control charging using SMBus broadcasts of required charging current and charging voltage to the charger. The PS401 monitors cell voltage and charging current to determine the battery full end-of-charge (EOC) condition. Using the constant current followed by constant voltage tapering current method, EOC is determined by checking the taper current value after full voltage is reached. The full taper current value is dependent on temperature, so the PS401 uses the temperature reading to determine the actual taper current at which the battery is full.

Discharge Termination and Full Capacity Learning

The PS401 uses advanced battery chemistry models to predict the capacity remaining in the battery, and when a discharge termination should occur. These models, in the form of “look up tables”, take into consideration the effects of temperature, discharge rate, age, and self-discharge to determine the capacity of the battery. The fuel gauge is constantly compensated in real time for these effects. In this manner the gauge is always accurate and no major corrections such as sudden drops in reported capacity will occur.

The voltage at which the discharge termination will occur is also compensated for these factors and will change in real time as the conditions change. The end of discharge (EOD) function can be tailored to individual systems also, to allow for extra capacity to remain in the battery to be used for shutdown procedures such as save to disk in a personal computer. For example if 100 mAH is needed for a save to disk function (3 amps for 2 minutes), then the voltage at which 100 mAH is left will constantly be computed even as temperature and discharge rate change. The fuel gauge function will always represent the capacity remaining until this point is reached. When this point is reached the Fully Discharged Flag will be signaled and the shutdown procedure can begin. There will be 100 mAH left in the battery no matter what the conditions were. And the fuel gauge will have ticked down to zero with no sudden drops due to constant compensation.

When the end of discharge point is reached, a relearn of the full capacity will occur if there was no partial charging between full and empty. This relearn occurs before the shutdown or save to disk procedure, thus guaranteeing the most accuracy.

Temperature Monitoring
Temperature is monitored using the internal sensor, or an optional external thermistor. The temperature is used to compensate the battery capacity. It is also used for charge control to stop charging if the temperature becomes to high. Additionally the secondary safety I/O pins can be set to trigger due to temperature.

Secondary Safety I/O

When set up as safety pins, the programmable I/O's can be set to trigger on any combination of the following conditions, which can be ANDed or OR'd together:

Condition	Equation
Cell Over Voltage	Vcell > Vcell_max
Cell Under Voltage	Vcell < Vcell_min
Cell Imbalance	Vcell_diff > Vcell_diff_max
Pack Over Voltage	Vcell_diff > Vcell_diff_max
Over Temperature	Temperature > Temp_max
Under Temperature	Temperature < Temp_min
Over Current Charging	Current > current_charge_max

When set up as charge control pins, the programmable I/O's can be set to trigger on any combination of the following conditions, which can be ANDed or OR'd together**:**

Condition	Equation
Cell Over Voltage	Vcell > Vcell_max
Terminate Charge Alarm	(active)
Fully Charged Flag	*(active)*
Overcharge	*SOC > MAX_SOC*
Over Temperature	Temperature > Temp_max
PRECHARGE	(condition true)
INPUT pin	(activated)
Cell Voltage greater than end-of-charge voltage	*Vcell > V_EOC*

SMBus
The PS401 has a dedicated system management bus (SMBus) port to communicate all Smart Battery Data (SBData) functions with no waiting or busy time. All of the Smart Battery Data functions are supported as shown in the chart below.

Table 1: PS401 Pin Description

PIN #	NAME	DESCRIPTION
1	VFC	(Input) Filter capacitor input for digital supply voltage.
2	I/O 4	(Bidirectional) Programmable Digital Input / Output pin (4)
3	I/O 5	(Bidirectional) Programmable Digital Input / Output pin (5)
4	I/O 6	(Bidirectional) Programmable Digital Input / Output pin (6)
5	I/O 7	(Bidirectional) Programmable Digital Input / Output pin (7)
6	SMB-CLK	SMBus Clock pin connection.
7	SMB-DTA	SMBus Data pin connection.
8	VCELL4	(Input) Cell voltage input for the fourth highest voltage cell in a series string.
9	VCELL3	(Input) Cell voltage input for the third highest voltage cell in a series string.
10	VCELL2	(Input) Cell voltage input for the second highest voltage cell in a series string.
11	VCELL1	(Input) Cell voltage input for the first or highest voltage cell in a series string.
12	VDDA	(Input) Analog supply voltage input.
13	VSSA	Analog ground reference point.
14	VSHP	(Input) Current measurement A/D input from positive side of the current sense resistor.
15	VSHN	(Input) Current measurement A/D input from negative side of the current sense resistor.
16	VNTC	(Input) A/D input for use with an external 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.
17	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.
18	ROSC	External bias resistor
19	OSCIN	(Input) Other oscillator connection . (See OSCOUT description.)
20	OSCOUT	(Output) Oscillator connection for an optional external low-power 32.768 kHz crystal which provides the best possible accuracy for timing in self-discharge and capacity calculations.
21	NC	No connection
22	VPP	(Input) Supply voltage input for OTP programming voltage.
23	NC	No connection
24	I/O 0	(Bidirectional) Programmable Digital Input / Output pin (8)
25	I/O 1	(Bidirectional) Programmable Digital Input / Output pin (1)
26	I/O 2	(Bidirectional) Programmable Digital Input / Output pin (2)
27	I/O 3	(Bidirectional) Programmable Digital Input / Output pin (3)
28	VSSD	Digital ground reference point.

Table 2: SBS Smart Battery Data Functions

SBData Function Name	Command Code	Access	Reference (if external)	Units	Notes
ManufacturerAccess()-Write	0x00	R/W	PW1, PW2	Code	
ManufacturerAccess()-Read	0x00	R/W	CHIP_VERSION	Code	1
RemainingCapacityAlarm()	0x01	R/W	AL_REM_CAP (default)	mAh or 10 mWh	2
RemainingTimeAlarm()	0x02	R/W	AL_REM_TIME (default)	Minutes	2
BatteryMode()	0x03	R/W	Internal RAM	Bit code	
AtRate()	0x04	Read	Internal RAM	mAh or 10 mWh	
AtRateTimeToFull()	0x05	Read	Calculated when requested	Minutes	
AtRateTimeToEmpty()	0x06	Read	Calculated when requested	Minutes	
AtRateOK()	0x07	Read	Calculated when requested	binary 0/1 (LSB)	
Temperature()	0x08	Read	Measured; maintained in RAM	0.1°K	
Voltage()	0x09	Read	Measured; maintained in RAM	mV	
Current()	0x0a	Read	Measured; maintained in RAM	mA	
AverageCurrent()	0x0b	Read	Calculated internally	mA	
MaxError()	0x0c	Read	Internal RAM	%	
RelativeStateOfCharge()	0x0d	Read	Internal RAM	%	
AbsoluteStateOfCharge()	0x0e	Read	Internal RAM	%	
RemainingCapacity()	0x0f	Read	Internal RAM	mAh or 10 mWh	
FullChargeCapacity()	0x10	Read	FULLCAPACITY (FCC)	mAh or 10 mWh	
RunTimeToEmpty()	0x11	Read	Calculated when requested	Minutes	
AverageTimeToEmpty()	0x12	Read	Calculated when requested	Minutes	
AverageTimeToFull()	0x13	Read	Calculated when requested	Minutes	
ChargingCurrent()	0x14	Read	CHARGING_CURR or TRICKLE_CHARGE	mA	3, 4
ChargingVoltage()	0x15	Read	CHARGING_VOLT or CHARGINGV_OFF	mV	3, 4
BatteryStatus()	0x16	Read	AL_STATUS	Bit code	4
CycleCount()	0x17	Read	CYCLES	Integer	
DesignCapacity()	0x18	Read	DESIGN_CAPACITY	mAh or 10 mWh	
DesignVoltage()	0x19	Read	NOM_VOLTAGE	mV	
SpecificationInfo()	0x1a	Read	SPEC_INFO	Coded	
ManufactureDate()	0x1b	Read	DATE	Coded	
SerialNumber()	0x1c	Read	SERIAL_NUMBER	not specified	
ManufaturerName()	0x20	Read	MANUFACTURER	ASCII Text	
DeviceName()	0x21	Read	DEVICE_NAME	ASCII Text	
DeviceChemistry()	0x22	Read	CHEMISTRY	ASCII Text	
ManufacturerData()	0x23	Read	(Various)	Hex string	5
OptionalMfgFunction4()	0x3c	Read	V1 cell voltage	mV	6
OptionalMfgFunction3()	0x3d	Read	V2 cell voltage	mV	6
OptionalMfgFunction2()	0x3e	Read	V3 cell voltage	mV	6
OptionalMfgFunction1()	0x3f	Read	V4 cell voltage	mV	6
OptionalMfgFunction5()	0x2f	Read	OUTPUTx pin status	bit-coded data	

Notes:

Note 1: Reports internal software version when read, opens EEPROM (and selected other values) for programming when written.

Note 2: Default values are listed. SBData allows these to be overwritten at any time by the SMBus Host or other SMBus device. All capacity defaults in EEPROM are in mA or mAH unless otherwise noted.

Note 3: ChargingCurrent and ChargingVoltage values may vary due to changes in measured conditions (such as temperature or cell voltage.)

Note 4: These values are also broadcast when required (unless disabled.)

Note 5: ManufacturerData contains additional programming options and stores additional history parameters including maximum temperature experienced and total overcharge accumulated.

Note 6: The OptionalMfgFunction1-4 data functions are implemented by the P4 to return the individual cell voltages

Electrical Characteristics

Absolute Maximum Ratings

Symbol	Description	Min	Max	Units
V_{CELLx}	Voltage at any VCELLx pin	-0.5	18.0	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.

DC Characteristics

(TA=-20°C to 85°C; VCC(internal) = 5.0V ± 10%)

Symbol	Description	Min	Typ.	Max	Units	Notes
I_{DD}	Current consumption (See modes below)			350	µA	
V_{SENSE}	Sense resistor voltage input (VSHP, VSHN)	-150		150	mV	
V_{REFT}	NTC Reference voltage output at VREFT pin		150		mV	
I/O1-8	Output voltage for 5 mA current output (LED output drive)			0.5	V	1
$V_{IN-CELL4}$	Voltage at VCELL4	5.4		18.0	V	
I_{IN}	Input current at any VCELLx (only for V_{time})			200	µA	
$V_{SMB-CLK}$, $V_{SMB-DTA}$	Output voltage for 350 µA output current on SMBus pins			35	mV	
$I_{PULLDOWN}$	Pull down current at SMB-CLK, SMB-DTA		0.5	1.0	µA	
I_{LO}, I_{HI}	Current at S SMB-CLK, SMB-DTA			10.0	µA	
$V_{LO,IN}$	Input voltage for LOW at SMB-CLK, SMB-DTA	-0.5	0.4	0.6	V	
$V_{HI,IN}$	Input voltage for HIGH at SMB-CLK, SMB-DTA	1.4	2	5.5	V	
$V_{LO,OUT}$	Output voltage for LOW at SMB-CLK, SMB-DTA		0.2	0.4	V	
I_{SINK}	Device sink current (SMB-CLK, SMB-DTA)	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.)

AC Characteristics

(TA=-20°C to 85°C; VCC(internal) = 5.0V ± 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, 11 bit		$2^{12}/f_{A/D}$		ms	
T_{time}	Temperature measurement time, 11 bit		$2^{12}/f_{A/D}$		ms	
I_{time}	Current measurement time, 14-bit+sign		$2^{15}/f_{A/D}$		ms	

AC Characteristics – SMBus

(TA=-20°C to 85°C; VCC(internal) = 5.0V ± 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	
C_{SMB}	Bus capacitance @ 100 kHz			160	pF	

Notes:

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 PS401 becomes a SMBus Master for these functions. The receiving (Slave) device may slow the transfer frequency. See *SMBus/I^{2}C Tutorial* in P4 User's Guide for additional information.

A/D Converter

(TA=-20°C to 85°C; VCC(internal) = 5.0V ± 10%)

Symbol	Description	Min	Typical	Max	Units	Notes
V_{RES}	Voltage resolution @ full scale = 18000 mV		8.9		mV/bit	
T_{RES}	Temperature resolution (on-chip thermistor)		0.25		°C/bit	
I_{RES}	Current resolution, @ Rsense = 25 mOhms		0.4		mA/bit	

Accuracy

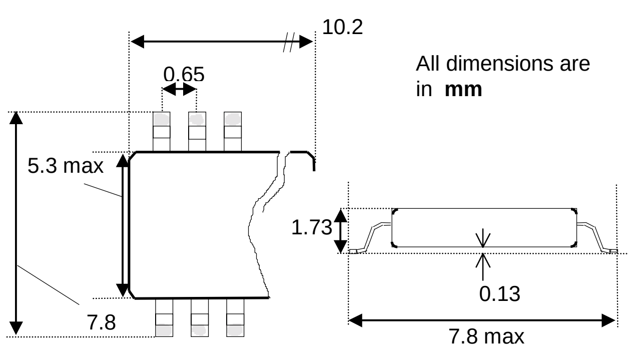
(TA=-20°C to 85°C; VCC(internal) = 5.0V ± 10%)

Symbol	Description	Min	Typ	Max	Units	Notes
Vaccuracy	A/D Accuracy for VCELL inputs	±22.0			mV	1
$T_{granularity}$	Temperature granularity, look up tables		0.1		°C/bit	

Notes:

1. Accuracy specified following pack and individual cell calibration.

Mechanical Packaging Information



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.

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.