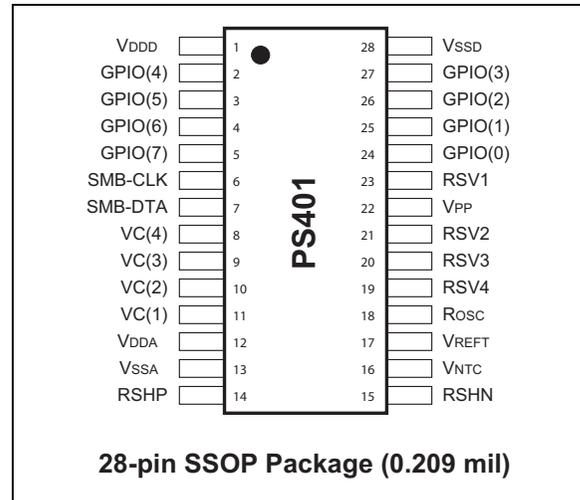


## Single Chip Battery Manager

### Features

- Single chip solution for rechargeable battery management
- Embedded Microchip patented Accuron™ technology provides precise capacity reporting (within 1%) for all rechargeable battery chemistries
- User configurable and "learned" parameters stored in on-chip 128 x 8 EEPROM; fully field reprogrammable via SMBus interface
- Integrating sigma-delta A/D converter accurately measures:
  - Current through sense resistor (15-bits)
  - High voltage (18V) battery cells directly connected to VCELL inputs (11-bits)
  - Temperature measurement from on-chip sensor or optional external thermistor (11-bits)
- Integrated precision silicon time base
- 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
- Microchip firmware in 12 Kbytes of customizable on-chip OTP EPROM

### Pin Description



### Pin Summary

Pin Name	Type	Description
VDD, VSSD	Supply	Digital supply voltage input, ground
GPIO(0..7)	I/O	Programmable digital I/O
SMB-CLK, SMB-DTA	I/O	SMBus Interface
VC(1..4)	I	Cell voltage inputs
VDDA, VSSA	Supply	Voltage regulator output (internally connected to analog supply input); ground
RSHP, RSHN	I	Current sense resistor input
VNTC	I	External thermistor input
VREFT	O	Thermistor reference voltage
ROSC	I	Internal oscillator bias resistor
RSV1-4	I	Reserved pins
VPP	I	OTP programming voltage

# PS401

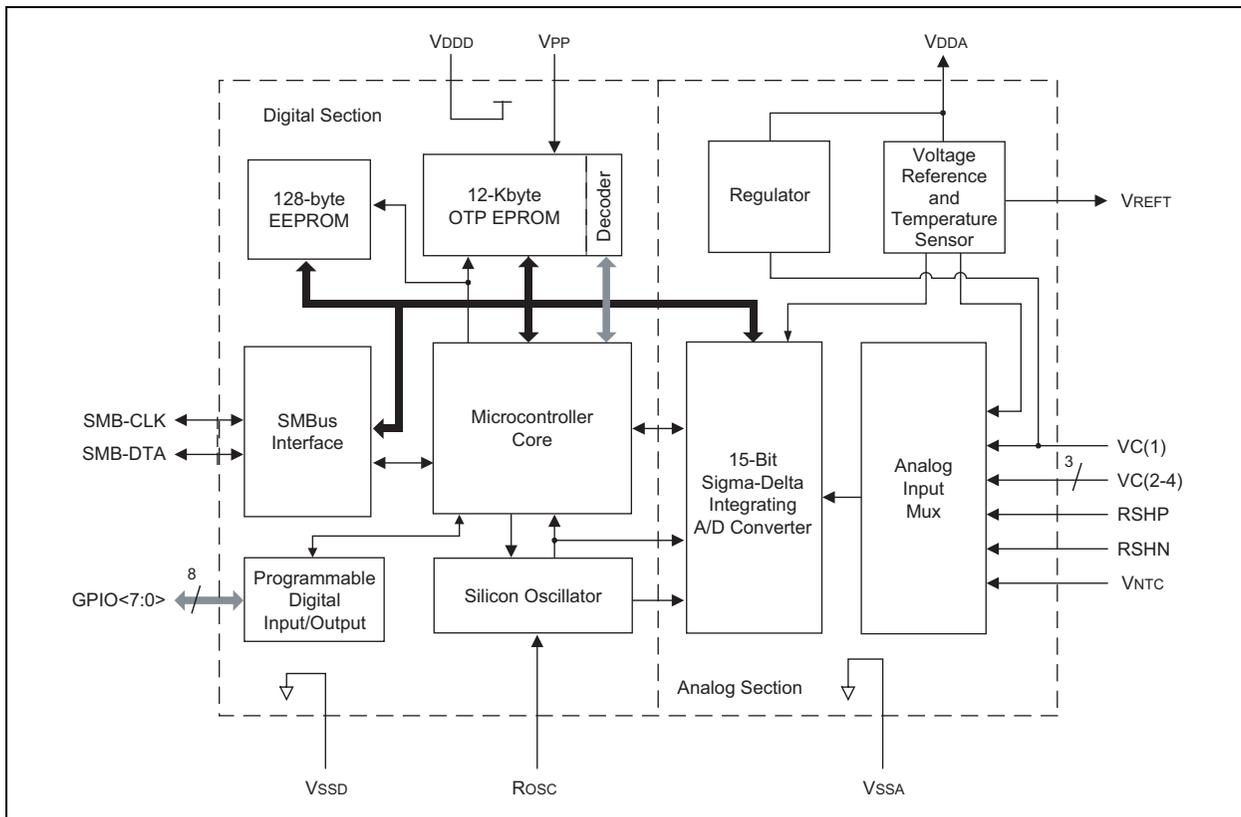
## 1.0 PRODUCT OVERVIEW

The PS401 is a fully integrated IC for battery management that combines a proprietary microcontroller core together with monitoring/control algorithms and 3D cell models stored in 12 Kbytes of on-chip OTP EPROM. Additional features include: precision 15-bit 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 v1.1 interface supports host communication using standard SBDData v1.1 commands and status.

Additional integrated features include an optional, 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.

Microchip's PS401 achieves the highest Smart Battery Data accuracy in a single IC, providing space and total system component cost savings for a wide variety of portable systems.

**FIGURE 1-1: PS401 INTERNAL BLOCK DIAGRAM**



## 1.1 Architectural Description

Figure 1-1 is an internal block diagram highlighting the major architectural elements described below.

## 1.2 Microcontroller/Memory

The PS401 incorporates an advanced, low power 8-bit RISC microcontroller core. Memory resources include 12 Kbytes of OTP EPROM for program/data storage, and 128 bytes of EEPROM for parameter storage.

## 1.3 A/D Converter

The PS401 performs precise measurements of current, voltage and temperature using a highly accurate 15-bit integrating sigma-delta A/D converter. The A/D can be calibrated to eliminate gain and offset errors and incorporates an auto-zero offset correction feature that can be performed while in the end system application.

## 1.4 Microchip Firmware/Battery Models

Contained within the 12-Kbyte OTP is Microchip developed battery management firmware that incorporates 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, accurate battery capacity reporting and run-time predictions 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 created without the need for silicon revisions.

The PS401 can be easily customized for a particular application's battery cell chemistry. Standard configuration files are provided by Microchip for a wide variety of popular rechargeable cells and battery pack configurations.

## 1.5 SMBus Interface/SBData Commands

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.

## 1.6 Accurate Integrated Time Base

The PS401 provides a highly accurate RC oscillator that provides accurate timing for self-discharge and capacity calculations and eliminates the need for an external crystal.

## 1.7 Temperature Sensing

An integrated temperature sensor is provided to minimize component count where the PS401 IC is located in close physical proximity to the battery cells being monitored. As an option, a connection is provided for an external thermistor that can be simultaneously monitored.

## 1.8 General Purpose I/O

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 Li Ion packs. Alternatively, they can be used as general purpose input/outputs.

# PS401

**TABLE 1-1: PS401 PIN DESCRIPTION**

Pin	Name	Description
1	VDDD	(Input) Filter capacitor input for digital supply voltage.
2	GPIO(4)	(Bidirectional) Programmable General Purpose Digital Input/Output pin (4).
3	GPIO(5)	(Bidirectional) Programmable General Purpose Digital Input/Output pin (5).
4	GPIO(6)	(Bidirectional) Programmable General Purpose Digital Input/Output pin (6).
5	GPIO(7)	(Bidirectional) Programmable General Purpose Digital Input/Output pin (7).
6	SMB-CLK	SMBus Clock pin connection.
7	SMB-DTA	SMBus Data pin connection.
8	VC(4)	(Input) Cell voltage input for the fourth highest voltage cell in a series string.
9	VC(3)	(Input) Cell voltage input for the third highest voltage cell in a series string.
10	VC(2)	(Input) Cell voltage input for the second highest voltage cell in a series string.
11	VC(1)	(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	RSHP	(Input) Current measurement A/D input from positive side of the current sense resistor.
15	RSHN	(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 3.65 kOhm 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 the voltage divider and connects to an external thermistor.
18	ROSC	External bias resistor.
19	RSV4	Reserved – Must be connected to ground.
20	RSV3	Reserved – Must be connected to ground.
21	RSV2	Reserved – Must be connected to VDDD.
22	VPP	(Input) Supply voltage input for OTP programming voltage.
23	RSV1	Reserved – Must be connected to VDDD.
24	GPIO(0)	(Bidirectional) Programmable General Purpose Digital Input/Output pin (0).
25	GPIO(1)	(Bidirectional) Programmable General Purpose Digital Input/Output pin (1).
26	GPIO(2)	(Bidirectional) Programmable General Purpose Digital Input/Output pin (2).
27	GPIO(3)	(Bidirectional) Programmable General Purpose Digital Input/Output pin (3).
28	VSSD	Digital ground reference point.

## 2.0 A/D OPERATION

The PS401 A/D converter measures voltage, current and temperature and integrates the current over time to measure state-of-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. Using an external sense resistor, current is monitored during both charge and discharge and is integrated over time using the on-chip oscillator as the time base. Temperature is measured from the on-chip temperature sensor or an optional external thermistor. Current and temperature are also calibrated for accuracy.

### 2.1 Current Measurement

The A/D input channels for current measurement are the RSHP and RSHN pins. The current is measured using an integrating method, which averages over time to get the current measurement and integrates over time to get a precise measurement value.

A 5 to 600 milli-Ohm sense resistor is connected to RSHP and RSHN as shown in the example schematic. The maximum input voltage at either RSHP or RSHN is +/-150 mV. The sense resistor should be properly sized to accommodate the lowest and highest expected charge and discharge currents, including suspend and/or standby currents.

Circuit traces from the sense resistor should be as short as practical without significant crossovers or feedthroughs. Failure to use a single ground reference point at the negative side of the sense resistor can significantly degrade current measurement accuracy.

The OTP EPROM value **NullCurr** represents the zero-zone current of the battery. This is provided as a calibration guard band for reading zero current. Currents below +/- **NullCurr** (in mA) limit are read as zero and not included in the capacity algorithm calculations. A typical value for **NullCurr** is 3 mA, so currents between -3 mA and +3 mA will be reported as zero and not included in the capacity calculations.

The equation for current measurement resolution and sense resistor selection is:

$$9.15 \text{ mV} / \text{RSENSE (milli-Ohms)} = \text{Current LSB}$$

(Minimum current measurement if > **NullCurr**)

$$\text{Current LSB} \times 16384 = \text{Maximum current measurement possible}$$

In-circuit calibration of the current is done using the SMBus interface at time of manufacture to obtain absolute accuracy in addition to high resolution. The current measurement equation is:

$$I(\text{ma}) = (I_{\text{A/D}} - \text{COCurr} - \text{COD}) * \text{CFCurr} / 16384$$

where:

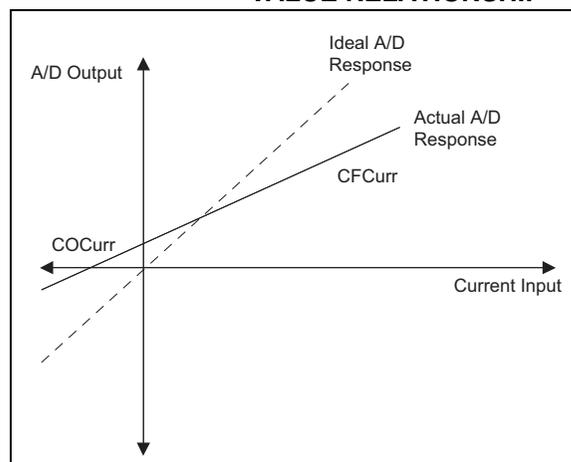
$I_{\text{A/D}}$  is the internal measurement.

**COCurr** is the "Correction Offset for Current" which compensates for any offset error in current measurement, stored in OTP EPROM.

**CFCurr** is the "Correction Factor for Current" which compensates for any variances in the actual sense resistance over varying currents, stored in OTP EPROM

Figure 2-1 shows the relationship of the **COCurr** and **CFCurr** values.

**FIGURE 2-1: COCurr AND CFCurr VALUE RELATIONSHIP**



### 2.2 Auto-Offset Compensation

Accuracy drift is prevented using an automatic auto-zero self-calibration method which 're-zeroes' the current measurement circuit every 30 seconds, when enabled. This feature can correct for drift in temperature during operation. The Auto-Offset Compensation circuit works internally by disconnecting the RSHP and RSHN inputs and internally shorting these inputs to measure the zero input offset. The EEPROM and calibration value COD is the true zero offset value of the particular IC. When an Auto-Offset Compensation measurement occurs (once per 30 seconds), the actual current measurement is skipped and the previous measurement for current is used for the next capacity calculation.

## 2.3 Voltage Measurements

The A/D input channels for cell and pack voltage measurements are the VC(1) to VC(4) pins. Measurements are taken each measurement period when the A/D is active. The maximum voltage at any VCELLX input pin is 19V absolute, but voltages above 18V are not suggested. The individual cell voltages are measured with an integration method to reduce any sudden spikes or fluctuations. The A/D uses an 11-bit Resolution mode for these measurements.

Only one cell voltage input is read per measurement period, therefore in multi-cell configurations, it may take multiple measurement periods to read all inputs. This could be further extended by the use of Run mode, where A/D measurements are not activated every measurement period, depending on the configuration of **SampleLimit** and **NSample** values. (See Section 3.0, Operational Modes for additional information.) For Li Ion, Li-based or even Lead-Acid applications, up to four (4) series cell voltages may be monitored individually. The highest voltage cell of the stack must be connected to VC(1).

For some applications, the actual cell stack arrangement can be altered accordingly. The PS401 voltage inputs pins (VCELLX pins) are capable of measuring up to 18V each. Therefore, cell arrangements can be combined and the corresponding cell voltage thresholds can be adjusted. For example, a 2-cell Li Ion pack could actually be connected as a single 7.2V cell instead of two 3.6V cells. The values for the cell voltages would all be doubled and only the VC(1) input pin would be used.

Each VCELLX input circuit contains an internal resistive divider to reduce the external voltage input to a range that the internal A/D circuit can accommodate (150 mV maximum). These dividers are set based on a cell voltage range of 4.5 Volts maximum.

The impedance at each VCELLX input is roughly 100 kOhms, but is only connected to ground (via the VSSA pins) when the actual voltage measurement is occurring. This corresponds to an insignificant amount of capacity drained through this circuit during the brief voltage measurement period.

### 2.3.1 IMPEDANCE COMPENSATION

Since accurate measurement of pack voltage and cell voltages are critical to performance, the voltage measurements can be compensated for any impedance in the power path that might affect the voltage measurements.

The first compensation point is the current sense resistor. This sense resistor affects the measured voltage of the lowest cell in a Li Ion configuration, since the ground reference point for the measurement is on the side of the current sense resistor farthest from the lowest cell.

The OTP EPROM value **PackResistance** is used to compensate for additional resistance that should be removed.

The equation for the compensation value (in ohms) is:

$$\text{PackResistance} = \text{Trace resistance} * 65535$$

(This is a 2-byte value so the largest value is 1 ohm.)

This requires modification of overall voltage SBData function to compensate for pack resistance and shunt resistance of current sense resistor. Thus, the previous voltage equation is modified to:

$$\text{SBData Voltage value} = \text{VC}(1) + \frac{\text{Measured Current (mA)} * \text{PackResistance}}{65535}$$

Figure 2-2 illustrates the compensations provided by the **PackResistance** value. The heavy traces are the portions of the circuit represented by the resistance.

The voltage measurement equation is:

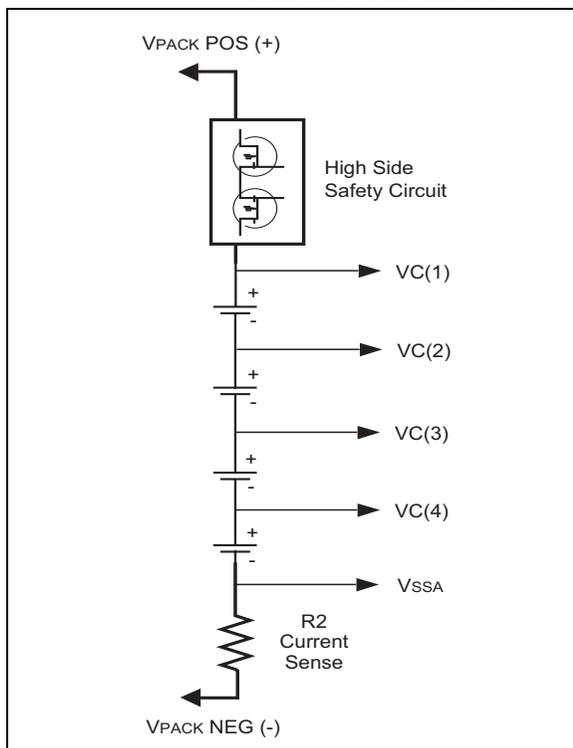
$$V \text{ (mV)} = (V_{\text{A/D}} - \text{COVPack}) * \text{CFVPack} / 2048$$

where:

V\_A/D is the internal measurement output.

**COVPack** is the "Correction Offset for Pack Voltage" which compensates for any offset error in voltage measurement (since the offset of the A/D is less than the voltage measurement resolution of +/- 16.5 mV, the COVPack value is typically zero).

**FIGURE 2-2: PACK RESISTANCE VALUE COMPENSATIONS**

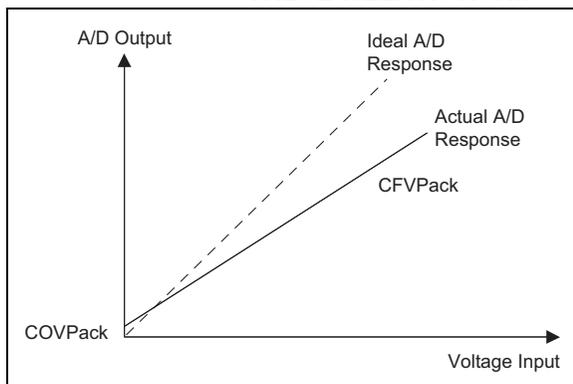


**CFVPack** is the "Correction Factor for Pack Voltage" which compensates for any variance in the actual A/D response versus an ideal A/D response over varying voltage inputs.

The **COVPack** and **CFVPack** are calibration constants that are stored in EEPROM.

Figure 2-3 shows the relationship of the **COVPack** and **CFVPack** values.

**FIGURE 2-3: COVPack AND CFVPack VALUE RELATIONSHIP**



In-circuit calibration of the voltage is done at the time of manufacture to obtain absolute accuracy in addition to high resolution. Accuracy of  $\pm 40$  mV at zero current and  $\pm 80$  mV during charge or discharge is possible. Individual cell voltage measurements can be accurate to within  $\pm 40$  mV.

The individual cell voltage inputs are also calibrated the same way the pack voltage is. There is one offset value **COVCell** for all individual cells and up to four different correction factors **CFVCell1** through **CFVCell4**, one for each cell input.

## 2.4 Temperature Measurements

The A/D receives input from the internal temperature sensor to measure the temperature. Optionally, an external thermistor can be connected to the VNTC pin which is also monitored by the A/D converter. An output reference voltage for use with an external thermistor is provided on the VREFT pin. The A/D uses an 11-bit Resolution mode for the temperature measurements.

A standard 10 kOhms at 25°C Negative-Temperature-Coefficient (NTC) device of the 103ETB type is suggested for the optional external thermistor. One leg of the NTC should be connected to the VREFT pin and the other to both the VNTC pin and a 3.65 kOhms resistor to analog ground (VSSA). The resistor forms the lower leg of a voltage divider circuit. To maintain high accuracy in temperature measurements, a 1% resistor should be used.

A lookup table is used to convert the voltage measurement seen at the VNTC pin to a temperature value. The external thermistor should be placed as close as possible to the battery cells and should be isolated from any other sources of heat that may affect its operation. An algorithm feature is activated to disable temperature readings for 30 seconds, following an LED switch activation (SWITCH pin is shorted to VDDD) to prevent false temperature readings due to LED heating.

Calibration of the temperature measurements involves a correction factor and an offset exactly like the current and voltage measurements. The internal temperature measurement makes use of correction factor **CFTempI** and offset **COTempI**, while the VNTC and VREFT pins for the optional external thermistor make use of correction factor **CFTempE** and offset **COTempE**.

## 3.0 OPERATIONAL MODES

The PS401 operates on a continuous cycle, as illustrated in Figure 3-1. The frequency of the cycles depends on the Power mode selected. There are three Power modes: Run, Sample and SLEEP. Each mode has specific entry and exit conditions as listed below.

### 3.1 Run Mode

Whether the PS401 is in Run mode or Sample mode depends on the magnitude of the current. The Run and Sample mode entry-exit threshold is calculated using the following EEPROM data values and formula:

$$\pm X \text{ mA} = \text{SampleLimit} \times \text{CFCurr} / 16384$$

**SampleLimit** is a programmable EEPROM value, and **CFCurr** is an EEPROM value set by calibration.

Entry to Run mode occurs when the current is more than  $\pm X$  mA for two consecutive measurements. Run mode may only be exited to Sample mode, not to SLEEP mode. Exit from Run mode to Sample mode occurs when the converted measured current is less than the  $\pm X$  mA threshold for two consecutive measurements.

Run mode is the highest power consuming mode. During Run mode, all measurements and calculations occur once per measurement period. Current, voltage and temperature measurements are each made sequentially during every measurement period. Only one cell voltage measurement occurs per measurement period. For Li-based applications, each cell input is measured in turn. For example, in 4-cell Li-based configurations, four measurement periods are required to read all cell input voltages.

### 3.2 Sample Mode

Entry to Sample mode occurs when the converted measured current is less than  $\pm$  **SampleLimit** (EE parameter) two consecutive measurements. Sample mode may be exited to either Run mode or SLEEP mode.

While in Sample mode, measurements of voltage, current and temperature occur only once per **NSample** counts of measurement periods, where **NSample** is a programmable EEPROM value. Calculations of state-of-charge, SMBus requests, etc. still continue at the normal Run mode rate, but measurements only occur once every measurement period  $\times$  **NSample**. The minimum value for **NSample** is two.

The purpose of Sample mode is to reduce power consumption during periods of inactivity (low rate charge or discharge.) Since the analog-to-digital converter is not active except every **NSample** counts of measurement periods, the overall power consumption is significantly reduced.

#### Configuration Example:

Measurement period is 500 ms  
**CFCurr** current calibration factor is 12500  
**SampleLimit** is set to 27  
**NSample** is set to 16

#### Result:

Run/Sample mode entry-exit threshold:  
 $27 \times 12500 / 16384 = \pm 20.6 \text{ mA}$

During Sample mode, measurements will occur every:

16 measurement periods of 500 mS = **every 8 seconds**

### 3.3 SLEEP Mode

Entry to SLEEP mode can only occur when the measured pack voltage at VC(1) input is below a preset limit set by the EEPROM value **SleepVPack** (in mV). SLEEP mode may be exited to Run mode, but only when one of the wake-up conditions is satisfied.

If the voltage measured at the VC(1) input is below the **SleepVPack** threshold, but the measured current is above the Sample mode threshold (which maintains Run mode), then SLEEP mode will NOT be entered. SLEEP mode can only be entered from Sample mode.

While in SLEEP mode, no measurements occur and no calculations are made. The fuel gauge display is not operational, no SMBus communications are recognized, and only a wake-up condition will permit an exit from SLEEP mode. SLEEP mode is one of the lowest power consuming modes and is used to conserve battery energy following a complete discharge.

When in the SLEEP mode (entry due to low voltage and Sample mode), there are four methods for waking up. They are voltage level, current level, SMBus activity and I/O pin activity. The EEPROM value, **WakeUp**, defines which wake-up functions are enabled, and also the voltage wake-up level. Table 3-1 indicates the appropriate setting. Note that the setting is independent of the number of cells or their configuration.

**TABLE 3-1: WakeUp**

Bit	Name	Function
6	WakeIO	Wake-up from I/O activity
5	WakeBus	Wake-up from SMBus activity
4	WakeCurr	Wake-up from Current
3	WakeVolt	Wake-up from Voltage
2:0	WakeLevel	Defines Wake Voltage Level

**TABLE 3-2: WakeUp VOLTAGE**

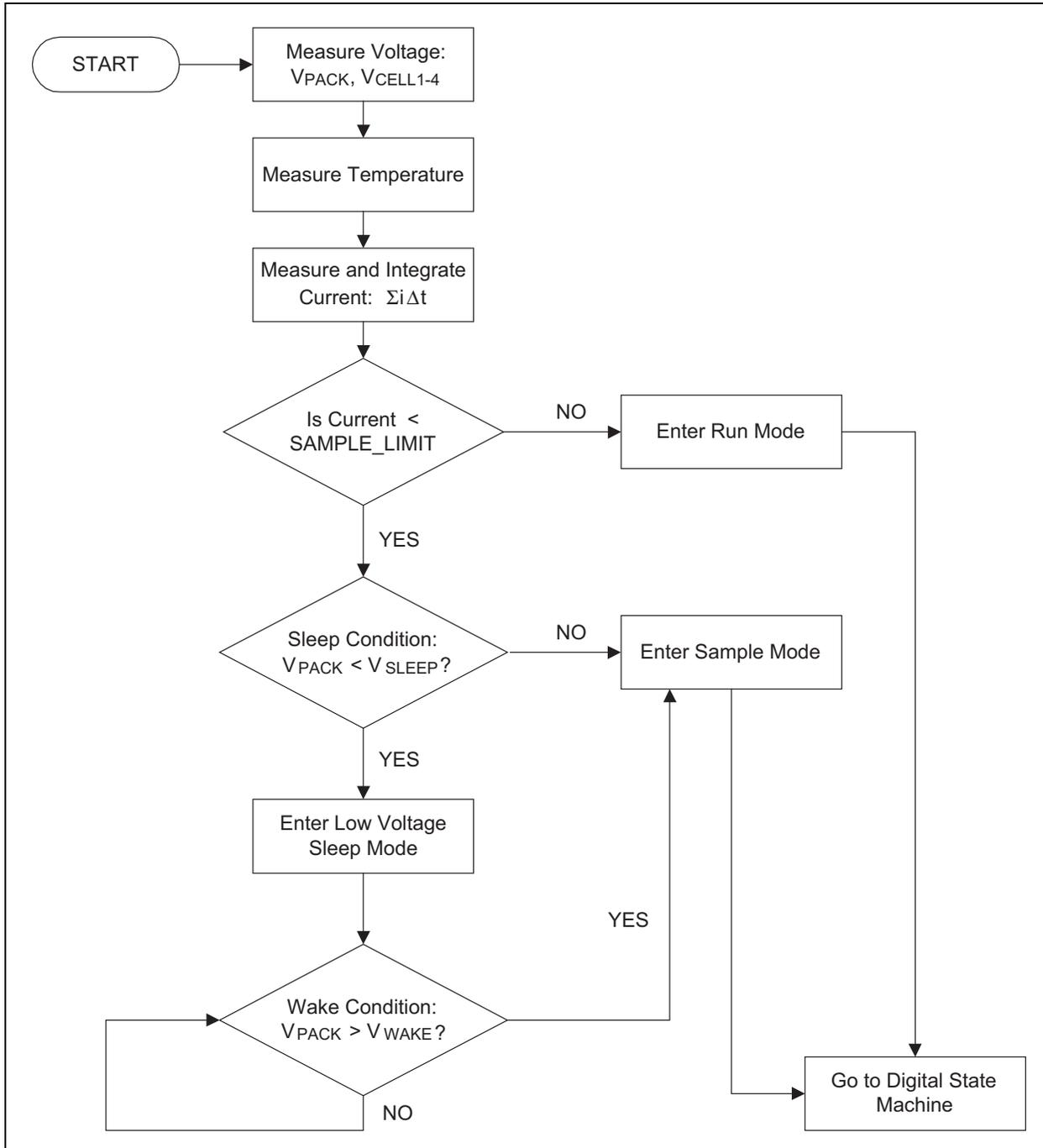
WakeUp (2:0)	Voltage	Purpose
000	6.4V	2 cells Li Ion
001	6.66V	6 cells NiMH
010	8.88V	8 cells NiMH
011	9.6V	3 cells Li Ion
100	9.99V	9 cells NiMH
101	11.1V	10 cells NiMH
110	12.8V	4 cells Li Ion
111	13.3V	12 cells NiMH

**TABLE 3-3: POWER OPERATIONAL MODE SUMMARY**

Mode	Entry	Exit	Notes
Run	Measured current > preset threshold (set by <b>SampleLimit</b> )	Measured current < preset threshold (set by <b>SampleLimit</b> )	Highest power consumption and accuracy for rapidly changing current.
Sample	Measured current < preset threshold (set by <b>SampleLimit</b> )	Measured current > preset threshold (set by <b>SampleLimit</b> )	Saves power for low, steady current consumption. Not as many measurements needed.
Low Voltage SLEEP	VC(1) < <b>SleepVPack</b> AND in Sample mode	<b>WakeUp</b> condition met	No measurements made when battery voltage is very low.

# PS401

FIGURE 3-1: PS401 OPERATIONAL CYCLE FLOW CHART



## 4.0 CAPACITY MONITORING

The PS401 internal CPU uses the voltage, current and temperature data from the A/D converter, along with parameters and cell models from the EEPROM and OTP EPROM, to determine the state of the battery and to process the SBData function instruction set.

By integrating measured current, monitoring voltages and temperature, adjusting for self-discharge and checking for end-of-charge and end-of-discharge conditions, the PS401 creates an accurate fuel gauge under all battery conditions.

### 4.1 Capacity Calculations

The PS401 calculates state-of-charge and fuel gauging functions using a 'coulomb counting' method, with additional inputs from battery voltage and temperature measurements. By continuously and accurately measuring all the current into and out of the battery cells, along with accurate three dimensional cell models, the PS401 is able to provide run-time accuracy with less than 1% error.

The capacity calculations consider two separate states: charge acceptance or capacity increasing (CI) and discharge or capacity decreasing (CD). The CI state only occurs when a charge current larger than OTP EPROM **NullCurr** value is measured. Otherwise, while at rest and/or while being discharged, the state is CD. Conditions must persist for at least **NChangeState** measurement periods for a valid state change between CD and CI. A minimum value of 2 is suggested for **NChangeState**.

Regardless of the CI or CD state, self-discharge is also calculated and subtracted from the integrated capacity values. Even when charging, there is still a self-discharge occurring in the battery.

To compensate for known system errors in the capacity calculations, a separate error term is also continuously calculated. This term is the basis for the SBData value of **MaxError**. Two error values are located in OTP EPROM. The **CurrError** value is the inherent error in current measurements and should be set based on the selection of a sense resistor and calibration results. The **SelfDischrgErr** value is the error in the parameter tables for self-discharge and depends on the accuracy of the cell chemistry model for self-discharge.

Since the PS401 electronics also drain current from the battery system, another OTP EPROM value allows even this minor drain to be included in the capacity calculations. The **PwrConsumption** value represents the drain of the IC and associated circuitry, including additional safety monitoring electronics, if present. A typical value of 77 represents the PS401's nominal power consumption of 300  $\mu$ A.

The total capacity added or subtracted from the battery (change in charge) per measurement period is expressed by the following formula:

$$\Delta\text{Charge} = \Sigma i\Delta t \text{ (the current integrated over time)}$$

- **CurrError** (Current Meas. Error)
- **PwrConsumption** \*  $\Delta t$  (PS401 IDD)
- % of Self-Discharge \* FCC
- **SelfDischrgErr** (Self-Disch. Error)

The error terms are always subtracted, even though they are +/- errors, so that the fuel gauge value will never be overestimated. Current draw of the PS401 and the self-discharge terms are also always subtracted. The SBData value **MaxError** is the total accumulated error as the gas gauge is running.

The battery current will be precisely measured and integrated at all times and for any current rate, in order to calculate total charge removed from or added to the battery. Based on lookup table access, the capacity is adjusted with self-discharging rates depending on actual capacity and temperature, and residual capacity corrections depending on the discharging current rate and temperature.

### 4.2 Discharge Termination and Capacity 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 voltage level at which this point occurs will also change depending on the temperature and discharge rate, since these factors affect the voltage curve and total capacity of the battery. The EOD voltage parameter table predicts the voltage point at which this EOD will be reached based on discharge rate and temperature.

The PS401 will monitor temperature and discharge rate continuously and update the EOD voltage in real-time. When the voltage measured on the cell is below **EOD voltage** for duration of **EODRecheck** x periods, a valid EOD has occurred.

When a valid EOD has been reached, the **TERMINATE\_DISCHARGE\_ALARM** bit (bit 11) in **BatteryStatus** will be set. This will cause an **AlarmWarning** condition with this bit set.

Additionally, the **REMAINING\_TIME\_ALARM** and/or **REMAINING\_CAPACITY\_ALARM** bits can be set first to give a user defined early warning prior to the **TERMINATE\_DISCHARGE\_ALARM**.

To maintain accurate capacity prediction ability, the **FullCapacity** value is relearned 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 relearn will occur. If the discharge rate at EOD is greater than the 'C-rate' adjusted value in **RelearnCurrLim**, then no relearn will occur.

When a valid EOD has been reached, then the error calculations represented by the SBData value of **MaxError** will be cleared to zero. If appropriate, the relearned value of **FullCapacity** (and **FullChargeCapacity**) will also be updated at this time.

## 4.3 EOD Voltage LookUp Table

### 4.3.1 SAVE TO DISK POINT

As the graph in Figure 4-1 shows, available capacity in the battery varies with temperature and discharge rate. Since the remaining capacity will vary, the save to disk point of a PC will also vary with temperature and discharge rate.

Knowing the discharge rate that occurs in the system during the save to disk process, and knowing the temperature can pinpoint the exact save to disk point that will always leave the perfect save to disk capacity. The PS401 uses this information to tailor the gas gauge to the system and the remaining capacity and RSOC fuel gauge function will always go to zero at the efficient save to disk point. Table 4-1 will use the voltage points at which this happens as the error correction and FULL CAPACITY relearn point. This will ensure a relearn point before save to disk occurs, and will correct any error in remaining capacity, also to ensure proper save to disk.

The shutdown point has to equal the capacity required to save to disk UNDER THE CONDITIONS OF SAVE TO DISK. That is, looking at the curve that represents the actual discharge C-rate that occurs during the system save to disk function, we must stop discharge and initiate save to disk when the system has used

capacity equal to that point on the save to disk C-rate curve. This is because, no matter what the C-rate is when the STD point is reached, the system will automatically switch to the C-rate curve that represents the actual current draw of the save to disk function. So it doesn't matter if the system is in high discharge, or low discharge, it will be in "save-to-disk" discharge conditions when save to disk begins, and there must be enough capacity left.

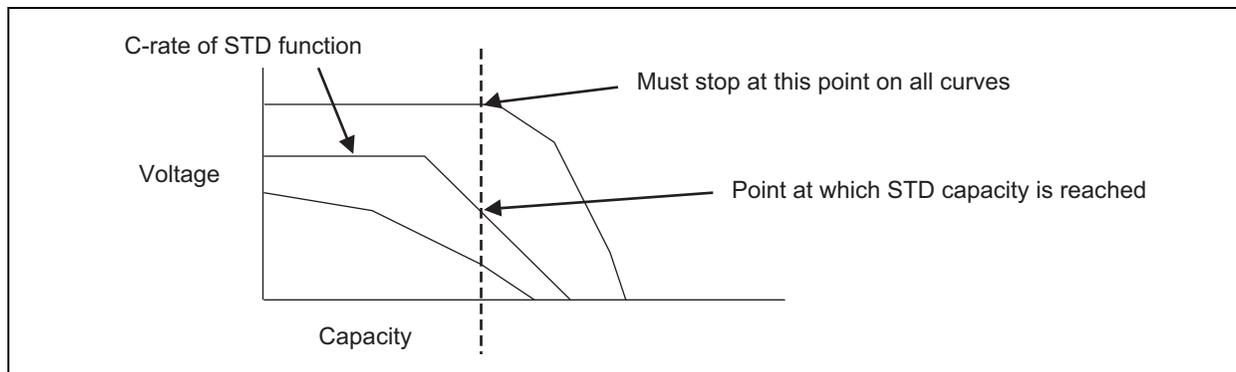
The graph in Figure 4-1 shows that the system will always shut down at the same capacity point regardless of C-rate conditions (since the C-rate of the save to disk procedure is a constant). Thus, we can automatically have an RSOC that is compensated for C-rate; it will go to zero when the capacity used is equal to the point at which STD occurs.

Ignoring the effects of temperature, we could mark the capacity used up to the shutdown point of the STD curve. All of the shutdown voltage points would then represent the same capacity, and RSOC would always become zero at this capacity, and FCC would always equal this capacity plus the residual capacity of the save to disk curve.

To compensate for temperature, we can look at the series of curves that represent the STD C-rate at different temperatures. The PS401 implementation is to measure the temperature and choose a scaled RSOC value that will go to zero at the save to disk point at this temperature, assuming the temperature does not change. If it does change, then an adjustment to RSOC will be needed to make it go to zero at STD point.

Taking temperature into consideration, the amount of capacity that can be used before save to disk is a constant as C-rate changes, but not constant as temperature changes. Thus, in the LUT, Table 4-1, the individual temperature columns will have voltage points that all represent the same capacity used, but the rows across temperature points (C-rate rows) will represent different capacity used.

**FIGURE 4-1: SAVE TO DISK POINT**



To compensate RSOC and RM, interpolation will be used and the compensation adjustment can happen in real-time to avoid sudden drops or jumps. Every time the temperature decreases by one degree, a new interpolated value will be subtracted from RSOC and RM. Every time the temperature increases by one degree, RSOC and RM will be held constant until discharged capacity equals the interpolated value that should have been added to RSOC and RM (to avoid capacity increases during discharge). With this

interpolation happening in real-time, there will be no big jumps or extended flat periods as we cross over boundaries in the LUT.

Table 4-1 is an example of the various voltage values that will signal the save to disk points as a function of temperature and discharge rate. Also shown is the amount of capacity used before "save to disk" that will be utilized to compensate RSOC.

Table 4-2 shows the actual names of the values in the OTP EPROM, Table 4-3 shows the value definitions:

**TABLE 4-1: V\_EOD LOOKUP TABLE**

	<-10°	<0°	<10°	<20°	<30°	<40°	<50°	<60°
< 0.2C	V1	V2	V3	-				
< 0.5C								
< 0.8C								
< 1.1C								
< 1.4C								
< 1.7C								
< 2.0C								
< 2.0C					-	V62	V63	V64
Capacity	20%	10%	5%	3%	0%	0%	0%	0%

**TABLE 4-2: VALUE NAMES IN THE OTP**

	TEOD(1)	TEOD(2)	TEOD(3)	TEOD(4)	TEOD(5)	TEOD(6)	TEOD(7)	TEOD(8)
CEOD(1)	Veod1(1)	Veod1(2)	Veod1(3)	Veod1(4)	Veod1(5)	Veod1(6)	Veod1(7)	Veod1(8)
CEOD(2)	Veod2(1)	Veod2(2)	Veod2(3)	Veod2(4)	Veod2(5)	Veod2(6)	Veod2(7)	Veod2(8)
CEOD(3)	Veod3(1)	Veod3(2)	Veod3(3)	Veod3(4)	Veod3(5)	Veod3(6)	Veod3(7)	Veod3(8)
CEOD(4)	Veod4(1)	Veod4(2)	Veod4(3)	Veod4(4)	Veod4(5)	Veod4(6)	Veod4(7)	Veod4(8)
CEOD(5)	Veod5(1)	Veod5(2)	Veod5(3)	Veod5(4)	Veod5(5)	Veod5(6)	Veod5(7)	Veod5(8)
CEOD(6)	Veod6(1)	Veod6(2)	Veod6(3)	Veod6(4)	Veod6(5)	Veod6(6)	Veod6(7)	Veod6(8)
CEOD(7)	Veod7(1)	Veod7(2)	Veod7(3)	Veod7(4)	Veod7(5)	Veod7(6)	Veod7(7)	Veod7(8)
CEOD(8)	Veod8(1)	Veod8(2)	Veod8(3)	Veod8(4)	Veod8(5)	Veod8(6)	Veod8(7)	Veod8(8)
	FCCP(1)	FCCP(2)	FCCP(3)	FCCP(4)	FCCP(5)	FCCP(6)	FCCP(7)	FCCP(8)

**TABLE 4-3: VALUE DEFINITIONS IN THE OTP EPROM**

<b>TEOD</b> 8 coded bytes	typ: 5,20,35,50,80,113,150,150	Range: 1-255 per byte
EOD Temperature boundaries, 8 increasing values of temperature coded as TEODx = (Tcelsius*10+200)/4		
<b>CEOD</b> 8 coded bytes	typ: 19,32,48,64,77,90,109,109	Range: 1-255
EOC C-rate boundaries, 8 increasing values of C-rates coded: CEODx = C-rate * (256/28/Rf), where Rf is the Rate Factor (RFactor) OTP EPROM parameter. For Rf = 7, CEODx = C-rate * 64. Thus, a value of 32 is one-half C, etc.		
<b>FCCP</b> coded %	typ: 50,25,12,8,0,0,0	Range: 1-255
Unusable residual capacity before save to disk, corresponding to temperature. 255 = 100%		
<b>VEOD</b> coded	typ: 75	Range: 1-255
End-of-discharge voltage, voltage = 2700 + 4 * VEOD. Cell voltage at which save to disk is signaled.		

## 5.0 CHARGE CONTROL

A SBS configuration normally allows the Smart Battery to broadcast the ChargingVoltage and ChargingCurrent values to the Smart Battery Charger (SMBus address 12 HEX) to 'control' when to start charge, stop charge, and when to signal a valid 'fully charged' condition. AlarmWarnings are also sent from the Smart Battery (SMBus address 16 HEX) to the Smart Battery Charger.

Alternately, the SMBus Host or a "Level 3" Smart Battery Charger may simply read the SBDData values for ChargingVoltage and ChargingCurrent from the Smart Battery directly. The Host or "Level 3" Smart Battery Charger is also required to read the SBDData value of BatteryStatus to obtain the appropriate alarm and status bit flags. When used in this configuration, the ChargingCurrent and ChargingVoltage broadcasts can be disabled from the Smart Battery by setting the CHARGER\_MODE (bit 14) in the BatteryMode register. The PS401 IC's support all of these functions. (Please refer to the SBS Smart Battery Charger Specification, for a definition of "Level 3" Smart Battery Charger.)

The ChargingCurrent and ChargingVoltage registers contain the maximum charging parameters desired by the particular chemistry, configuration and environmental conditions. The environmental conditions include the measured temperature and the measured cell or pack voltages.

For Li-based systems, ChargingVoltage is the product of the **EOCVolt** and **Cells** values from the EEPROM:

$$\text{ChargingVoltage} = \text{EOCVolt} \times \text{Cells}$$

The ChargingCurrent value is set to a maximum using the **ChrgCurr** value from the EEPROM. For lithium systems, both ChargingCurrent and ChargingVoltage values are maximums. When the current reaches **ChrgCurr** it will be held constant at this value. Then when the voltage reaches **ChrgVolt**, the current must be reduced so that the voltage will be constant and not exceed the maximum. This is accomplished by setting ChargingCurrent to **ChrgCurrOff**. For safety reasons, this current change also occurs when the temperature limits are exceeded. When temperature or voltage limits are exceeded, the value of ChargingCurrent changes to **ChrgCurrOff** value from the EEPROM. When a valid End-Of-Charge (EOC) condition is detected and a fully charged state is reached, the ChargingCurrent value is set equal to the **ChrgCurrOff** value.

When ChargingCurrent is set to the **ChrgCurrOff** value, no broadcasts of either ChargingCurrent or ChargingVoltage will occur unless a charge current greater than **NullCurr** is detected by the A/D measurements. Temperature limits are set using the **ChrgMaxTemp**, **DischrgMaxTemp** and **ChrgMinTemp** values from OTP EPROM. These values represent the temperate limits within which ChargingCurrent will be set to **ChrgCurr**. Temperatures outside these limits will cause ChargingCurrent to be set to **ChrgCurrOff**.

If ChargingCurrent is set to **ChrgCurrOff** and the measured temperature is greater than **DischrgMaxTemp** and less than **ChrgMaxTemp** and a charge current is measured which is significantly larger than the **ChrgCurrOff** value, then ChargingCurrent will be set to **ChrgCurr** unless a fully charged condition has already been reached.

If the CHARGER\_MODE bit in BatteryMode is cleared (enabling broadcasts of ChargingCurrent and ChargingVoltage) then these broadcasts will occur every **NChrgBroadcast** measurement cycles. Broadcasts only occur when ChargingCurrent is set to the **ChrgCurr** value and/or when the A/D converter measures a charge current greater than **NullCurr**.

The Smart Battery Data and Smart Battery Charger Specifications require that ChargingCurrent and ChargingVoltage broadcasts occur no faster than once per 5 seconds and no slower than once per 60 seconds when charging is occurring or desired. This requires that the **NChrgBroadcast** value must be set between 10 and 120. The SMBus Specification also requires that no broadcasts occur during the first 10 seconds after SMBus initialization. This, therefore, requires the **NSilent** value be set to 20 or higher.

### Configuration Example:

Measurement cycle is	500 msec
<b>NChrgBroadcast</b>	= 100 decimal
<b>NSilent</b>	= 24 decimal
<b>ChrgCurr</b>	= 2500 decimal
<b>ChrgCurrOff</b>	= 10 decimal
<b>ChrgMaxTemp</b>	= 650 decimal
<b>DischrgMaxTemp</b>	= 550 decimal
<b>ChrgMinTemp</b>	= 200 decimal

### Results:

ChargingCurrent and ChargingVoltage broadcasts:

**100 cycles of 500 msec = every 50 seconds**

Broadcast delay after SMBus initialization:

**24 cycles of 500 msec = 12 seconds**

ChargingCurrent if Temperature > 45°C: **10 mA**

ChargingCurrent if Temperature < 0°C: **10 mA**

ChargingCurrent if Temperature < 35°C and > 0°C: **2500 mA**

## 5.1 Full Charge Detection Methods

For a typical lithium ion constant-current/constant-voltage charge system, the PS401 will monitor the taper current that enters the battery once the battery has reached the final voltage level of the charger. Once the taper current falls to a certain level indicating that the battery is full, the End-Of-Charge (EOC) will be triggered. Different taper currents will be used for different temperatures. See the parameter explanation in the programming section for details.

When a valid fully charged EOC condition is detected, the following actions occur:

- The FULLY\_CHARGED status bit (bit 5) in the SBDData value of BatteryStatus is set to one to indicate a full condition. (This will remain set until RelativeStateOfCharge drops below the **ClrFullyChrg** value in OTP EPROM.)
- RelativeStateOfCharge is set to 100%.
- ChargingCurrent is set to **ChrgCurrOff** value.
- SBDData value for MaxError is cleared to zero percent (0%).
- The TERMINATE\_CHARGE\_ALARM bit (bit 14) is set in BatteryStatus and an AlarmWarning broadcast is sent to the SMBus Host and Smart Battery Charger addresses.
- The **OverChrg** value is incremented for any charge received above 100% after a valid fully charged EOC condition.
- Control flags for internal operations are set to indicate a valid full charge condition was achieved.
- Other BatteryStatus or AlarmWarning flag bits may also be set depending on the conditions causing the EOC.

## 5.2 Temperature Algorithms

The PS401 SMBus Smart Battery IC provides multiple temperature alarm set points and charging conditions. The following EEPROM and OTP EPROM parameters control how the temperature alarms and charging conditions operate.

**HighTempAI:** When the measured temperature is greater than **HighTempAI**, the Over\_Temp\_Alarm is set. If the battery is charging, then the Terminate\_Charge\_Alarm is also set.

**ChrgMinTemp, DischrgMaxTemp and ChrgMaxTemp:** If the measured temperature is less than ChrgMinTemp, the ChargingCurrent is set to ChrgCurrOff and the ChargingVoltage is set to ChrgVolt to communicate to the charger that the non-charging state of current and voltage should be given. When measured temperature is greater than ChrgMaxTemp and the system is charging, or greater than DischrgMaxTemp and the system is discharging, then ChargingCurrent is set to ChrgCurrOff and the ChargingVoltage is set to ChrgVoltOff also. Otherwise ChargingCurrent = ChrgCurr and ChargingVoltage = ChrgVolt.

## 6.0 GPIO CONFIGURATION

### 6.1 Safety Condition Programming

**GPIO0-GPIO7** are eight 16-bit OTP parameters that are programmed to configure the safety or charge condition desired for their associated pins. **GPIO5** and **GPIO6** must be programmed to configure the desired safety features described below.

There are 8 different functions that can be AND'ed and OR'd together for secondary safety. In **GPIO0-GPIO7**, the lower 8-bits are the AND bits and the upper 8-bits are the OR bits. The bits correspond to the secondary safety function as listed in Table 6-1.

The logic selected operates as follows:

#### AND byte

Desired trigger conditions are selected with a '1' in the control bit. All selected conditions must be true for a true "AND" condition. If no conditions are desired, 0FFh must be written to the byte.

#### OR byte

Desired trigger conditions are selected with a '1' in the control bit. Any selected condition which is true will cause a true "OR" condition. If no conditions are desired, 00h must be written to the byte. GPIOx pin activation results when all "AND" condition OR any "OR" condition is true.

#### Example:

If **\_AND** byte is set to 088h, and **\_OR** byte is set to 010h, then the OUTPUTx pin is active only if:

[ (VCELLX > VCELL\_MAX) AND (Temperature > TEMP\_MAX)] OR [VPACK > VPACK\_MAX]

**TABLE 6-1: GPIO SAFETY CONDITIONS**

OR Byte Bit	AND Byte Bit	Safety Condition	Description
15	7	VCELLX > <b>SafetyMaxVCell</b>	Any cell voltage rises above <b>SafetyMaxVCell</b>
14	6	VCELLX < <b>SafetyMinVCell</b>	Any cell voltage falls below <b>SafetyMinVCell</b>
13	5	Vcell_Diff > <b>SafetyDiffVCell</b>	The difference between two cells is greater than <b>SafetyDiffVCell</b>
12	4	VPACK > <b>SafetyMaxVPack</b>	Pack voltage rises above <b>SafetyMaxVPack</b>
11	3	Temperature > <b>SafetyMaxTemp</b>	Temperature rises above <b>SafetyMaxTemp</b>
10	2	Temperature < <b>SafetyMinTemp</b>	Temperature falls below <b>SafetyMinTemp</b>
9	1	Charge Current > <b>SafetyIMaxC</b>	Charge current rises above <b>SafetyIMaxC</b>
8	0	Discharge Current > <b>SafetyIMaxD</b>	Charge current rises above <b>SafetyIMaxD</b>

**TABLE 6-2: GPIO CHARGE CONDITIONS**

OR Byte Bit	AND Byte Bit	Charge Condition	Description
15	7	VCELLX > <b>SafetyMaxVCell</b>	Any cell voltage rises above <b>SafetyMaxVCell</b>
14	6	Terminate Charge Alarm	Terminate Charge Alarm Active
13	5	Fully Charged Flag	Fully Charged Flag in Battery Status is set
12	4	<b>SOC &gt; MaxSOC</b>	State-Of-Charge greater than MaxSOC
11	3	Temperature > <b>SafetyMaxTemp</b>	Temperature rises above <b>SafetyMaxTemp</b>
10	2	Precharge Condition True	PreCharge condition exists
9	1	Input Pin Activated	GPIO set up as switch is pressed or input active
8	0	VCELLX > <b>EOCVolt</b>	Any cell voltage rises above end of charge voltage

## 7.0 SMBus/SBData INTERFACE

The PS401 uses a two-pin System Management Bus (SMBus) protocol to communicate to the Host. One pin is the clock and one is the data. The SMBus port responds to all commands in the Smart Battery Data Specification (SBData). To receive information about the battery, the Host sends the appropriate commands to the SMBus port. Certain alarms, warnings and charging information may be sent to the Host by the PS401 automatically. The SMBus protocol is explained in this chapter. The SBData command set is summarized in Table 7-1.

The PS401 SMBus communications port is fully compliant with the System Management Bus Specification, Version 1.1 and supports all previous and new requirements, including bus time-outs (both slave and master), multi-master arbitration, collision detection/recovery and PEC (CRC-8) error checking. The SMBus port serves as a Slave for both read and write functions, as well as a Master for write word functions. SMBus slave protocols supported include Read Word, Write Word, Read Block and Write Block, all with or without PEC (CRC-8) error correction. Master mode supports Write Word protocols. The PS401 meets and exceeds the Smart Battery Data Specification, Version 1.1/1.1a requirements. The PS401 is compliant with System Management Bus Specification 1.0.

The PS401 fully implements the Smart Battery Data (SBData) Specification v1.1. The SBData Specification defines the interface and data reporting mechanism for an SBS compliant Smart Battery. It defines a consistent set of battery data to be used by a power management system to improve battery life and system run-time, while providing the user with accurate information. This is accomplished by incorporating fixed, measured, calculated and predicted values, along with charging and alarm messages, with a simple communications mechanism between a Host system, Smart Batteries and a Smart Charger.

The PS401 provides full implementation of the SBData set with complete execution of all the data functions, including sub-functions and control bits and flags, compliance to the accuracy and granularity associated with particular data values, and proper SMBus protocols and timing.

### 7.1 SBData Function Description

The following subsections document the detailed operation of all of the individual SBData commands.

#### 7.1.1 ManufacturerAccess (0x00)

Reports internal software version when read, opens EEPROM for programming when written with the password.

#### 7.1.2 RemainingCapacityAlarm (0x01)

Sets or reads the low capacity alarm value. Whenever the remaining capacity falls below the low capacity alarm value, the Smart Battery sends alarm warning messages to the SMBus Host with the REMAINING\_CAPACITY\_ALARM bit set. A low capacity alarm value of '0' disables this alarm.

#### 7.1.3 RemainingTimeAlarm (0x02)

Sets or reads the remaining time alarm value. Whenever the AverageTimeToEmpty falls below the remaining time value, the Smart Battery sends alarm warning messages to the SMBus Host with the REMAINING\_TIME\_ALARM bit set. A remaining time value of '0' disables this alarm.

#### 7.1.4 BatteryMode (0x03)

This function selects the various Battery Operational modes and reports the battery's capabilities, modes and condition.

##### Bit 0: INTERNAL\_CHARGE\_CONTROLLER

Bit set indicates that the battery pack contains its own internal charge controller. When the bit is set, this optional function is supported and the CHARGE\_CONTROLLER\_ENABLED bit will be activated.

##### Bit 1: PRIMARY\_BATTERY\_SUPPORT

Bit set indicates that the battery pack has the ability to act as either the primary or secondary battery in a system. When the bit is set, this optional function is supported and the PRIMARY\_BATTERY bit will be activated.

##### Bit 2-6: Reserved

##### Bit 7: CONDITION\_FLAG

Bit set indicates that the battery is requesting a conditioning cycle. This typically will consist of a full charge to full discharge back to full charge of the pack. The battery will clear this flag after it detects that a conditioning cycle has been completed.

##### Bit 8: CHARGE\_CONTROLLER\_ENABLED

Bit is set to enable the battery pack's internal charge controller. When this bit is cleared, the internal charge controller is disabled (default). This bit is active only when the INTERNAL\_CHARGE\_CONTROLLER bit is set.

##### Bit 9: PRIMARY\_BATTERY

Bit is set to enable a battery to operate as the primary battery in a system. When this bit is cleared, the battery operates in a secondary role (default). This bit is active only when the PRIMARY\_BATTERY\_SUPPORT bit is set.

# PS401

**TABLE 7-1: SMART BATTERY DATA FUNCTIONS**

SBData Function Name	Command Code	Access	Parameter Reference	Units
ManufacturerAccess-Write	0x00	R/W	PW1, PW2	Password Code
ManufacturerAccess-Read	0x00	R/W		SW Version Code
RemainingCapacityAlarm	0x01	R/W	RemCapAl	mAh or 10 mWh
RemainingTimeAlarm	0x02	R/W	RemTimeAl	Minutes
BatteryMode	0x03	R/W		Bit code
AtRate	0x04	Read		mAh or 10 mWh
AtRateTimeToFull	0x05	Read		Minutes
AtRateTimeToEmpty	0x06	Read		Minutes
AtRateOK	0x07	Read		Binary 0/1 (LSB)
Temperature	0x08	Read		0.1°K
Voltage	0x09	Read		mV
Current	0x0a	Read		mA
AverageCurrent	0x0b	Read		mA
MaxError	0x0c	Read		%
RelativeStateOfCharge	0x0d	Read		%
AbsoluteStateOfCharge	0x0e	Read		%
RemainingCapacity	0x0f	Read		mAh or 10 mWh
FullChargeCapacity	0x10	Read		mAh or 10 mWh
RunTimeToEmpty	0x11	Read		Minutes
AverageTimeToEmpty	0x12	Read		Minutes
AverageTimeToFull	0x13	Read		Minutes
ChargingCurrent	0x14	Read	ChrgCurr or ChrgCurrOff	mA
ChargingVoltage	0x15	Read	ChrgVolt or ChrgVoltOff	mV
BatteryStatus	0x16	Read	BatStatus	Bit code
CycleCount	0x17	Read	Cycles	Integer
DesignCapacity	0x18	Read	DesignCapacity	mAh or 10 mWh
DesignVoltage	0x19	Read	DesignVPack	mV
SpecificationInfo	0x1a	Read	SBDataVersion	Coded
ManufactureDate	0x1b	Read	Date	Coded
SerialNumber	0x1c	Read	SerialNumber	Not specified
FirmwareVersion ( <b>Note 1</b> )	0x1d	Read	Firmware Version	Coded
ManufacturerName	0x20	Read	MFGName	ASCII Text string
DeviceName	0x21	Read	DeviceName	ASCII Text string
DeviceChemistry	0x22	Read	Chemistry	ASCII Text string
ManufacturerData	0x23	Read	MFGData	HEX string
OptionalMfgFunction4	0x3c	Read	V1 cell voltage	mV
OptionalMfgFunction3	0x3d	Read	V2 cell voltage	mV
OptionalMfgFunction2	0x3e	Read	V3 cell voltage	mV
OptionalMfgFunction1	0x3f	Read	V4 cell voltage	mV
OptionalMfgFunction5	0x2f	Read	GPIO pin status	Bit coded data

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

**Bit 10-13:** Reserved

**Bit 14:** CHARGER\_MODE

Enables or disables the Smart Battery's transmission of ChargingCurrent and ChargingVoltage messages to the Smart Battery Charger. When set, the Smart Battery will NOT transmit ChargingCurrent and ChargingVoltage values to the charger. When cleared, the Smart Battery will transmit the ChargingCurrent and ChargingVoltage values to the charger when charging is desired.

**Bit 15:** CAPACITY\_MODE

Indicates if capacity information will be reported in mA/mAh or 10 mW/10 mWh. When set, the capacity information will be reported in 10 mW/10 mWh. When cleared, the capacity information will be reported in mA/mAh.

7.1.5 AtRate (0x04)

AtRate is a value of current or power that is used by three other functions: AtRateTimeToFull, AtRateTimeToEmpty and AtRateOK.

- AtRateTimeToFull returns the predicted time to full charge at the AtRate value of charge current.
- AtRateTimeToEmpty function returns the predicted operating time at the AtRate value of discharge current.
- AtRateOK function returns a Boolean value that predicts the battery's ability to supply the AtRate value of additional discharge current for 10 seconds.

7.1.6 AtRateTimeToFull (0x05)

Returns the predicted remaining time to fully charge the battery at the AtRate value (mA). The AtRateTimeToFull function is part of a two-function call set used to determine the predicted remaining charge time at the AtRate value in mA. It will be used immediately after the SMBus Host sets the AtRate value.

7.1.7 AtRateTimeToEmpty (0x06)

Returns the predicted remaining operating time if the battery is discharged at the AtRate value. The AtRateTimeToEmpty function is part of a two-function call set used to determine the remaining operating time at the AtRate value. It will be used immediately after the SMBus Host sets the AtRate value.

7.1.8 AtRateOK (0x07)

Returns a Boolean value that indicates whether or not the battery can deliver the AtRate value of additional energy for 10 seconds (Boolean). If the AtRate value is zero or positive, the AtRateOK function will ALWAYS return true. The AtRateOK function is part of a two-function call set used by power management systems to determine if the battery can safely supply enough energy for an additional load. It will be used immediately after the SMBus Host sets the AtRate value.

7.1.9 Temperature (0x08)

Returns the cell pack's internal temperature in units of 0.1°K.

7.1.10 Voltage (0x09)

Returns the pack voltage (mV).

7.1.11 Current (0x0a)

Returns the current being supplied (or accepted) through the battery's terminals (mA).

7.1.12 AverageCurrent (0x0b)

Returns a one-minute rolling average based on at least 60 samples of the current being supplied (or accepted) through the battery's terminals (mA).

7.1.13 MaxError (0x0c)

Returns the expected margin of error (%) in the state-of-charge calculation. For example, when MaxError returns 10% and RelativeStateOfCharge returns 50%, the RelativeStateOfCharge is actually between 50% and 60%. The MaxError of a battery is expected to increase until the Smart Battery identifies a condition that will give it higher confidence in its own accuracy. For example, when a Smart Battery senses that it has been fully charged from a fully discharged state, it may use that information to reset or partially reset MaxError. The Smart Battery can signal when MaxError has become too high by setting the CONDITION\_FLAG bit in BatteryMode.

7.1.14 RelativeStateOfCharge (0x0d)

Returns the predicted remaining battery capacity expressed as a percentage of FullChargeCapacity (%).

## 7.1.15 AbsoluteStateOfCharge (0x0e)

Returns the predicted remaining battery capacity expressed as a percentage of DesignCapacity (%). Note that AbsoluteStateOfCharge can return values greater than 100%.

## 7.1.16 RemainingCapacity (0x0f)

Returns the predicted remaining battery capacity. The RemainingCapacity value is expressed in either current (mAh) or power (10 mWh), depending on the setting of the BatteryMode's CAPACITY\_MODE bit.

## 7.1.17 FullChargeCapacity (0x10)

Returns the predicted pack capacity when it is fully charged. It is based on either current or power, depending on the setting of the BatteryMode's CAPACITY\_MODE bit.

## 7.1.18 RunTimeToEmpty (0x11)

Returns the predicted remaining battery life at the present rate of discharge (minutes). The RunTimeToEmpty value is calculated based on either current or power, depending on the setting of the BatteryMode's CAPACITY\_MODE bit. This is an important distinction because use of the wrong Calculation mode may result in inaccurate return values.

## 7.1.19 AverageTimeToEmpty (0x12)

Returns a one-minute rolling average of the predicted remaining battery life (minutes). The AverageTimeToEmpty value is calculated based on either current or power, depending on the setting of the BatteryMode's CAPACITY\_MODE bit. This is an important distinction because use of the wrong Calculation mode may result in inaccurate return values.

## 7.1.20 AverageTimeToFull (0x13)

Returns a one-minute rolling average of the predicted remaining time until the Smart Battery reaches full charge (minutes).

## 7.1.21 ChargingCurrent (0x14)

Sets the maximum charging current for the Smart Charger to charge the battery. This can be written to the Smart Charger from the Smart Battery, or requested by the Smart Charger from the battery.

## 7.1.22 ChargingVoltage (0x15)

Sets the maximum charging voltage for the Smart Charger to charge the battery. This can be written to the Smart Charger from the Smart Battery, or requested by the Smart Charger from the battery.

## 7.1.23 BatteryStatus (0x16)

Returns the Smart Battery's status word (flags). Some of the BatteryStatus flags, like REMAINING\_CAPACITY\_ALARM and REMAINING\_TIME\_ALARM, are calculated based on either current or power, depending on the setting of the BatteryMode's CAPACITY\_MODE bit. This is important because use of the wrong Calculation mode may result in an inaccurate alarm. The BatteryStatus function is used by the power management system to get alarm and status bits, as well as error codes from the Smart Battery. This is basically the same information returned by the SBDData AlarmWarning function, except that the AlarmWarning function sets the Error Code bits all high before sending the data.

### Battery Status Bits:

- bit 15:** OVER\_CHARGED\_ALARM
- bit 14:** TERMINATE\_CHARGE\_ALARM
- bit 13:** Reserved
- bit 12:** OVER\_TEMP\_ALARM
- bit 11:** TERMINATE\_DISCHARGE\_ALARM
- bit 10:** Reserved
- bit 9:** REMAINING\_CAPACITY\_ALARM
- bit 8:** REMAINING\_TIME\_ALARM
- bit 7:** INITIALIZED
- bit 6:** DISCHARGING
- bit 5:** FULLY\_CHARGED
- bit 4:** FULLY\_DISCHARGED

The Host system assumes responsibility for **detecting and responding** to Smart Battery alarms by reading the BatteryStatus to determine if any of the alarm bit flags are set. At a minimum, this requires the system to poll the Smart Battery BatteryStatus every 10 seconds at all times the SMBus is active.

## 7.1.24 CycleCount (0x17)

CycleCount is updated to keep track of the total usage of the battery. CycleCount is increased whenever an amount of charge has been delivered to, or removed from, the battery equivalent to the full capacity.

## 7.1.25 DesignCapacity (0x18)

Returns the theoretical capacity of a new pack. The DesignCapacity value is expressed in either current or power, depending on the setting of the BatteryMode's CAPACITY\_MODE bit.

## 7.1.26 DesignVoltage (0x19)

Returns the theoretical voltage of a new pack (mV).

## 7.1.27 SpecificationInfo (0x1a)

Returns the version number of the Smart Battery specification the battery pack supports.

## 7.1.28 ManufactureDate (0x1b)

This function returns the date the cell pack was manufactured in a packed integer. The date is packed in the following fashion: (year-1980) \* 512 + month \* 32 + day.

## 7.1.29 SerialNumber (0x1c)

This function is used to return a serial number. This number, when combined with the ManufacturerName, the DeviceName and the ManufactureDate will uniquely identify the battery.

## 7.1.30 ManufacturerName (0x20)

This function returns a character array containing the battery manufacturer's name.

## 7.1.31 DeviceName (0x21)

This function returns a character string that contains the battery's name.

## 7.1.32 DeviceChemistry (0x22)

This function returns a character string that contains the battery's chemistry. For example, if the DeviceChemistry function returns "NiMH," the battery pack would contain nickel metal hydride cells. The following is a partial list of chemistries and their expected abbreviations. These abbreviations are NOT case sensitive.

- Lead Acid: PbAc
- Lithium Ion: LION
- Nickel Cadmium: NiCd
- Nickel Metal Hydride: NiMH
- Nickel Zinc: NiZn
- Rechargeable Alkaline-Manganese: RAM
- Zinc Air: ZnAr

## 7.1.33 ManufacturerData (0x23)

This function allows access to the manufacturer data contained in the battery (data).

## 7.1.34 OptionalMfgFunction

The PS401 includes new SBData functions using the OptionalMfgFunction command codes. The command codes 3C HEX to 3F HEX report the individual cell voltages as measured by the analog-to-digital converter. These voltages are reported in mV and are calculated to include compensation for calibration and sense resistance voltage drops. Only one cell voltage is measured per measurement cycle (depending on Run or Sample mode operation.)

Rapid voltage changes will see some variation in voltages due to the delay of measurement. These voltage values may be used for cell balancing or other functions as the Host system may desire

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**TABLE 7-2: PS401 ALARMS AND STATUS SUMMARY**

Battery Status	Set Condition	Clear Condition
FULLY_CHARGED bit	Set at End-Of-Charge Condition: Charge FET Off AND Any VC(x) input > 4.175V AND IAVG < EOC_IAVG for ChrgCntrlTimer number of consecutive counts	RelativeStateOfCharge ( ) < ClearFullyCharged (default RSOC=80%)
OVER_CHARGED_ALARM bit	VCELLX > TCAVOLT (default 4.5V/Cell)	All VCELLX < TCAVOLT
TERMINATE_CHARGE_ALARM bit	VCELLX > TCAVOLT (default 4.5V/Cell) OR Charging Temperature ( ) > ChrgMaxTemp (default 60°C) OR Fully_Charged bit = 1	All VCELLX < TCAVOLT AND Temperature ( ) < ChrgRecTemp = AND Current ( ) = < 0
OVER_TEMP_ALARM bit	Temperature ( ) > HighTempAlarm (default 55°C)	Temperature ( ) < HighTempAlarm
TERMINATE_DISCHARGE_ALARM bit	Primary Method: VCELLX < VEOD1 (per Look Up Table) AND Above condition continues for NearEODRecheck time.  Secondary Method: VCELLX < VEOD2 (default 3.1V/Cell) AND Above condition continues for EODRecheck time.	Primary Method: All VCELLX > VEOD1 OR Current ( ) > 0  Secondary Method: All VCELLX > VEOD2 OR Current ( ) > 0
REMAINING_CAPACITY_ALARM bit	RemainingCapacity ( ) < RemainingCapacityAlarm ( )	RemainingCapacity ( ) > RemainingCapacityAlarm ( )
REMAINING_TIME_ALARM bit	AverageTimeToEmpty ( ) < RemainingTimeAlarm ( )	AverageTimeToEmpty ( ) > RemainingTimeAlarm ( )
FULLY_DISCHARGED bit	RemainingCapacity ( ) = 0	RelativeStateOfCharge ( ) > ClearFullyDischarged (default RSOC=20%)

**TABLE 7-3: TEMPERATURE, ChargingCurrent ( ) AND ChargingVoltage ( ) SUMMARY**

Temperature ( ) > HighTempAl (Default 60°C)	
CHARGING	DISCHARGING
TERMINATE_CHARGE_ALARM AND OVER_TEMP_ALARM	OVER_TEMP_ALARM
Cleared	Temperature ( ) < HighTempAl

Temperature ( ) > ChrgMaxTemp (Default 50°C)	Temperature ( ) > DischargeMaxTemp (Default 65°C)
CHARGING	DISCHARGING
<u>ChargingCurrent</u> ( ) = ChrgCurrOff <u>ChargingVoltage</u> ( ) = ChrgVoltageOff	

Temperature ( ) < ChrgMinTemp
<u>ChargingCurrent</u> ( ) = ChrgCurrOff <u>ChargingVoltage</u> ( ) = ChrgVolt

For all other temperature conditions:

ChargingCurrent ( ) = ChrgCurr

ChargingVoltage ( ) = ChrgVolt

# PS401

## 8.0 PARAMETER SETUP

This section documents all of the programmable parameters that are resident in either the OTP EPROM or EEPROM. It includes parameters that are common to the standard PS401 parameter set. The Parameter Set is organized into the following functional groups:

1. Pack Information
2. Capacity Calculations
3. EOD and FCC Relearn
4. Charge Control
5. GPIO
6. PS401 Settings
7. SBData Settings
8. Calibration

**TABLE 8-1: PACK INFORMATION**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description
BatStatus	EE	1	0	255	b01000000	SBData register for <u>BatteryStatus</u> .
Cells	EE	1	0	255	3	Number of cells in the battery pack.
Chemistry	OTP	8	–	–	LION	SBS data for Chemistry. Can be any ASCII string. Length defined by <u>ChemistryLength</u> . The Chemistry name can be programmed here and retrieved with the SBData <u>DeviceChemistry</u> command.
ChemNameLen	OTP	1	0	255	4	The length in bytes of the Chemistry String.
Date	EE	2	0	65535	0x2B7E	SBData value for <u>ManufactureDate</u> . The date of manufacture of the battery pack can be programmed here and retrieved with the SBData <u>ManufactureDate</u> command. Coding: Date = (Year-1980) x 512 + Month x 32 + Day
DesignCapacity	OTP	2	0	65535	4400	SBData value for <u>DesignCapacity</u> . This is the first capacity loaded into the Full Charge Capacity upon power-up.
DesignVPack	OTP	2	0	65535	14800	SBData value for <u>DesignVoltage</u> .
DeviceName	EE	8	–	–	–	SBData value for <u>DeviceName</u> . Can be any ASCII string. Length defined by <u>DeviceNameLength</u> . The battery circuit device name can be programmed here and retrieved with the SBData <u>DeviceName</u> command.
DevNameLen	OTP	1	0	255	7	The length in bytes of the <u>DeviceName</u> string.
DevNamePrefix	OTP	–	–	–	0	Device name prefix.
MFGData	EE	4	–	–	–	SBS string for <u>ManufacturerData</u> .
MFGName	EE	10	–	–	–	SBS string for <u>ManufacturerName</u> . Can be any ASCII string, typically the name of the battery pack manufacturer. Length of string is defined by <u>MfgNameLength</u> .
MFGNameLen	OTP	1	0	255	10	Name length of manufacturer name.
PackResistance	OTP	2	0	65535	3408	Resistance of pack.
PrefixLen	OTP	1	0	–	1	Length of DevNamePrefix String.
PW1	EE	2	0	65535	–	First password for the battery pack lock.
PW2	EE	2	0	65535	–	Second password for the battery pack lock.
SBDataVersion	EE	2	0	65535	33	Specification Info according to SBS Spec. 0011 refers to Smart Battery Specification version 1.1.
SerialNumber	EE	2	0	65535	–	SBData value for <u>SerialNumber</u> . The serial number of the battery pack can be programmed here and retrieved with the SBData <u>SerialNumber</u> command.

**TABLE 8-2: CAPACITY CALCULATIONS**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description
CurrError	OTP	1	0	255	0	Current measurement error. This is the error due to the accuracy of the A/D converter to measure and integrate the current, 255 = 100%.
Cycles	EE	2	0	65535	0	SBData register for <u>CycleCount</u> . <u>Cycles</u> is updated to keep track of the total usage of the battery. <u>Cycles</u> is increased whenever an amount of charge has been delivered to, or removed from the battery, equivalent to the full capacity. For a 4000 mAh battery, <u>Cycles</u> is increased every time 4000 mAh goes through the battery terminals in any direction.
InitialCap	EE	2	0	65535	2048	The Initial Capacity of the battery. When the PS401 is first powered up and initialized, before a learning cycle takes place to learn the full capacity, the full capacity will take the value programmed into <u>InitialCap</u> to compute relative state-of-charge percentage.
LowCurrError	OTP	1	0	255	0	Current offset for error calculation. Since the error of the A/D converter is proportional to the level of current it is measuring, the error term can be too low when the current is very low. For this reason, the <u>LowCurrError</u> will compensate the ERR term for low currents. <u>LowCurrError</u> milli-Amps are added to the current when factoring in the error. Thus, the error is: $ERROR = (current + LowCurrError) * CurrError$ .
mWhVolt	OTP	2	0	65535	32402	<u>AtRate</u> and other time-based calculations can be more accurate using a different formula for mWh. All calculations, except remaining capacity, will use <u>mWhVolt</u> for conversion. This approximates a straight line for the entire battery curve. <u>mWhVolt</u> is typically the full pack voltage plus the empty pack voltage, $V_{full} + V_{empty}$ .
NChangeState	OTP	1	0	255	8	State change delay filter. Delays the change between "charge increasing" state and "charge decreasing" state based on current direction. To avoid problems with current spikes in opposite directions, a delay filter is built-in to control when to change from charging status to discharging status. The current must change directions and stay in the new direction for $CST\_DELAY * period$ before the status is changed and capacity is increased or decreased as a result of the new current direction.

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**TABLE 8-2: CAPACITY CALCULATIONS (CONTINUED)**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description
NullCurr	OTP	1	0	255	3	A zero zone control is built into the PS401 so that any small inaccuracy doesn't actually drain the gas gauge, when in fact the current is zero. For this reason, current less than <u>NullCurr</u> mA in either direction will be measured as zero.
PowerCalcVolt	OTP	2	0	65535	9300	Used for power calculations early in the voltage curve, this is typically a mid-point voltage level that will approximate the flat part of the voltage curve as a straight line.
PowerEmptyVolt	EE	2	0	65535	15000	Voltage used for power calculation. This is the pack voltage when the pack is empty. Typically, this will be the cell empty voltage Vempty times the number of cells. This is used in the steep part of the voltage curve to approximate a straight line.
PowerVoltLimit	EE	2	0	65535	15602	Voltage for power calculations. VPOWER is cutoff voltage that decides which formula to use when converting mAh to mWh. If the battery voltage is V, then If $V > \text{PowerVoltLimit}$ , $\text{mWh} = \text{mAh} * (V + \text{PowerVolt}) / 2$ . If $V < \text{PowerVoltLimit}$ , $\text{mWh} = \text{mAh} * (V + \text{PowerEmptyVolt}) / 2$ .
PwrConsumption	OTP	2	0	65535	77	Current consumption of the battery module. This is the average current that the battery module typically draws from the battery (255 = 1 mA).
SelfdischrgErr	OTP	1	0	255	0	Self-discharge error. This is the error inherent in the ability of the self-discharge lookup tables to meet actual battery characteristics, 255 = 100%.

**TABLE 8-3: EOD AND FCC RELEARN**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description
ADLNearEmpty	EE	1	0	255	6	SOC at which A/D switches to emphasize voltage over current measurement near EOD. EE value of 128 = 100%.
ADLNearFull	EE	1	0	255	122	SOC at which A/D switches to emphasize voltage over current measurement near EOC. EE value of 128 = 100%.
EOD1Cap	EE	2	0	65535	0	The capacity that remains in the battery at VEOD1. This is typically a small amount used to power a shutdown sequence for the system.
EODRecheck	OTP	1	0	255	6	Delay filter for the EOD condition. Number of checks before EOD trigger. The end of discharge conditions must remain for at least this number of periods before being considered true, to help filter out false empty conditions due to spikes.
FullCapacity	EE	2	0	65535	4150	Learned value of battery capacity. Used for SBData value of <u>FullChargeCapacity</u> . This is a learned parameter which is the equivalent of all charge counted from fully charged to fully discharged, including self-discharge and error terms. This is reset after a learning cycle and used for remaining capacity and relative state-of-charge calculations.
NearEODerrReset	OTP	2	0	65535	0	Near EOD error RESET.
NearEODRecheck	OTP	1	0	255	6	Number of periods of valid pack voltage measurements needed to trigger near EOD capacity RESET.
RelearnCurrLim	OTP	2	0	65535	6000	Value of measured current that prevents a capacity relearn from occurring when a terminate discharge alarm condition is reached at End-Of-Discharge (EOD). A learning cycle will happen when the battery discharges from fully charged all the way to fully discharged with no charging in between, and the discharge current never exceeds <u>RelearnCurrLim</u> . Example: 3000. A relearn will only occur if current does not exceed 3000 mA.
RelearnLimit	OTP	1	0	255	205	The maximum relearn limit. The maximum percentage that the FULL_CAPACITY can change after a learning cycle, where 255 = 100%.
RelearnMaxErr	OTP	2	0	65535	200	Maximum error for learning <u>FullCapacity</u> . The FULL_CAPACITY will not be learned after a learning cycle if the error is too great.
RelearnVCell	OTP	2	0	65535	200	(Unused)
RLCycles	OTP	1	0	255	2	The number of initial cycles without <u>RelearnLimit</u> . The initial number of cycles where <u>RelearnLimit</u> is not active. <u>FullCapacity</u> can vary more greatly with the first learning cycle, since the initial capacity may not be correct, thus this should be set to at least '2'.
VEOD1	EE	2	0	65535	3100	First end-of-discharge voltage point. At this point, capacity is set to S_CAP1, and FCC relearn takes place.
VEOD2	EE	2	0	65535	3000	Second and final end-of-discharge voltage point. At this point, remaining capacity is optionally set to '0'.

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**TABLE 8-4: CHARGE CONTROL**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description
ChrgCurr	EE	2	0	65535	3500	This is the full charging current that the battery requires during normal charging. It can be broadcasted to the charger or read from the PS401.
ChrgCurrOff	EE	2	0	65535	100	Trickle charging current. This is a small amount of current that the charger should deliver when full charging needs to be halted temporarily due to high temperature.
ChrgMaxTemp	OTP	2	0	65535	800	Temperature threshold when charging, coded value = (Celsius*10+200). When the temperature exceeds <u>ChargeMaxTemp</u> and the battery is charging, then <u>ChargingCurrent</u> is set to <u>ChargingCurrOff</u> and <u>ChargingVoltage</u> is set to <u>ChargingVoltOff</u> .
ChrgMinTemp	OTP	2	0	65535	200	Low temperature threshold, charging coded value = (Celsius*10+200). When charging, if the temperature is less than <u>ChargeMinTemp</u> , then <u>ChargingCurrent</u> is set to <u>ChargingCurrOff</u> and <u>ChargingVoltage</u> is set to <u>ChargingVoltOff</u> .
ChrgVolt	EE	2	0	65535	16800	This is the voltage required by the battery during normal charging.
ChrgVoltOff	EE	2	0	65535	16800	Voltage required when charging should be halted.
ClrFullyChrg	OTP	1	0	255	115	Reset FULLY_CHARGED bit at this level, 128 = 100%. Once the FULLY_CHARGED bit is set, taper or pulse current will not be monitored any more. When discharging begins, the FULLY_CHARGED bit must remain set until the cell voltages are below EOC_VOLT, so that a small current will not trigger a false end-of-charge trigger. Thus, <u>ClearFullyCharged</u> is set at about 90%. FULLY_CHARGED bit will be on until the battery has discharged to less than 90%.
ClrFullyDischrg	OTP	1	0	255	13	Reset FULLY_DISCHARGED bit, 128 = 100%. Once fully discharged bit is set, it will stay set until capacity rises above this value, typically 10%.
DishrgMaxTemp	OTP	2	0	65535	800	Temperature threshold when discharging Coded value = (Celsius*10+200). When discharging, if the temperature exceeds <u>DischargeMaxTemp</u> , then <u>ChargingCurrent</u> is set to <u>ChargingCurrOff</u> and <u>ChargingVoltage</u> is set to <u>ChargingVoltOff</u> .

**TABLE 8-4: CHARGE CONTROL (CONTINUED)**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description
EOCCurAvg	OTP	2	0	65535	200	EOC trigger for pulse charging. If the average current during charging with the CFET turned off has dropped below the <b>AvgCurrEOCThresh</b> threshold for a pass count equal to the EEPROM parameter value <b>ChrgCntrlTimr</b> (typically between 8 and 16) the End-Of-Charge state will be reached.
EOCRecheck	OTP	1	0	255	6	Delay filter for the EOC condition. Number of checks before EOC trigger. The end of charge conditions must remain for at least this number of periods before being considered true, to help filter out false full conditions due to spikes.
EOCVolt	EE	2	0	65535	4175	EOC trigger cell voltage. When any cell in the battery pack reaches this voltage, the end-of-charge determination will start monitoring the average current to determine when the battery is full. When the average current is in the proper range, and the cell voltage is greater than EOC_VOLT, then FULLY_CHARGED bit in <b>BatteryStatus</b> will be set, and terminate charge alarm will be active.
MaxSOC	EE	1	0	255	100	Maximum state-of-charge, 128 = 100%. This is the maximum state-of-charge that the battery fuel gauge should register. Typically set to 100% so that any overcharge is not displayed as a battery more than 100% full.
MaxTemp	EE	2	0	65535	750	Maximum temperature measured (including external and internal sensor). Coded value = (Celsius*10+200). This is where the PS401 keeps track of the highest temperature it has measured.
PrechargeCurr	OTP	2	0	65535	500	Precharge current required. Posted to SBData ChargingCurrent during precharge conditions.
PrechargeMax	OTP	2	0	65535	1000	Maximum precharge current allowed. When exceeded under precharge conditions, SBData ChargingCurrent is set to zero.
PrechargeTemp	OTP	2	0	65535	250	Precharge temperature, coded value = (Temp[°C] + 20) x 10. This is the temperature under which precharging should occur.
PrechargeVCell	OTP	2	0	65535	2500	Precharge cell voltage. This is the voltage under which precharging should occur.

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**TABLE 8-4: CHARGE CONTROL (CONTINUED)**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description
SOCErrLimit	EE	1	0	255	120	SOC range for error clamp to zero, 128 = 100%. When charging a Lithium battery using constant current, then taper current, the error term should be set to zero when the taper current gets too low, in order to allow for a full charge. This parameter will set the error term to zero when the state-of-charge reaches a high value, such as 92%.
SOCThreshold	OTP	1	0	255	154	Second EOC trigger based on state-of-charge, 128 = 100%. A second end-of-charge trigger is built into the PS401, such that if the state-of-charge exceeds a certain value, end-of-charge will be forced, even if the taper or pulse current was not detected. When state-of-charge reached <u>SOCThreshold</u> , then end-of-charge will trigger.
StableCurr	OTP	1	0	255	50	EOC trigger current deviation level. In order to prevent current spikes from causing a premature taper current trigger, the average current and the instantaneous current must be within <u>StableCurr</u> of each other for the end-of-charge to trigger on the taper current.
TaperCRate	OTP	6	0	255	50	Upper limit EOC taper current, based on temperature. $256/28/Rfactor = 1C$
TaperLow	OTP	1	0	255	10	Lower limit EOC taper current. $256/28/Rfactor = 1C$
TaperTemp	OTP	5	0	255	80	Temperature corresponding to TaperCRate byte.

**TABLE 8-5: GPIO**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description
GPIO0	OTP	2	0	65535	0x0001	GPIO0 condition definition. Low byte is AND function, high byte is OR function.
GPIO1	OTP	2	0	65535	0x0015	GPIO1 condition definition. Low byte is AND function, high byte is OR function.
GPIO2	OTP	2	0	65535	0x0029	GPIO2 condition definition. Low byte is AND function, high byte is OR function.
GPIO3	OTP	2	0	65535	0x003D	GPIO3 condition definition. Low byte is AND function, high byte is OR function.
GPIO4	OTP	2	0	65535	0x0051	GPIO4 condition definition. Low byte is AND function, high byte is OR function.
GPIO5	OTP	2	0	65535	0xAE00	GPIO5 condition definition. Low byte is AND function, high byte is OR function.
GPIO6	OTP	2	0	65535	0x0001	GPIO6 condition definition. Low byte is AND function, high byte is OR function.
GPIO7	OTP	2	0	65535	0x0000	GPIO7 condition definition. Low byte is AND function, high byte is OR function.
GPIOChgCtr	OTP	1	0	255	0b00000000	Defines a GPIO as based on the charge control conditions. A '1' sets charge control.
GPIOConfig	OTP	1	0	255	0b00000000	Defines function of the GPIO pins depending on the programming of each individual pin as an input or output via the <a href="#">GPIODirection</a> register: Input: 1 = Reacts to rising edge 0 = Reacts to falling edge Output: 1 = LED Output 0 = Standard CMOS Push-Pull
GPIODirection	OTP	1	0	255	0b11111111	Defines whether a GPIO set up as a conditional I/O in <a href="#">GPIOConfig</a> is an input or an output. A '1' bit means output, '0' means input.
GPIODisplay	OTP	1	0	255	0b00011111	Defines whether a GPIO set up as an LED should be used in the state-of-charge display when the "switch" is pushed. A '1' sets the GPIO to be state-of-charge display.
GPiOPolarity	OTP	1	0	255	0b11000000	The active polarity of the GPIOs can be programmed here. When an I/O is triggered, it can be programmed here to go either high or low, and the opposite state will be the default (not triggered). Set the appropriate bit to '1' for active being high level (LED on), and '0' for active being low level (LED off).
GPiOReset	OTP	1	0	255	b00000000	Defines the initial state of the GPIO at power-up or RESET. 1 = high (LED off), 0 = low
GPiOSafety	OTP	1	0	255	b01100000	Defines a GPIO as based on the safety conditions. A '1' sets safety control.
GPiOSwitch	OTP	1	0	255	b00000000	Defines GPIO state of charge display input switch. A '1' sets the switch condition.
LEDDutyCycle	EE	1	0	255	3	Duty cycle for LED display.

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**TABLE 8-5: GPIO (CONTINUED)**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description
LEDPermlMin	OTP	2	0	65535	100	Minimum charging current for permanent LED display. Since permanent LED display requires current draw from the battery, LEDs can be set to be on only while the battery is charging, with a minimum current of <u>LEDPermlMin</u> .
NLED	EE	1	0	255	6	Duration of LED display. When LEDs are set up to display state-of-charge information, they will be illuminated when the switch is pushed. They will stay illuminated for 2 seconds plus <u>NLED</u> * period. For <u>NLED</u> = 8, period = 0.5, the LEDs will stay on for 2 + 8 * .5 seconds, or 2 + 4 = 6 seconds.
NSafeI	EE	1	0	255	60	Delay filter for all current safety conditions. The safety conditions must be valid for <u>NSafeI</u> * period to avoid false triggers due to spikes or noise.
NSafeV	EE	1	0	255	10	Delay filter for all cell voltage safety conditions. The cell voltage based safety conditions must be valid for <u>NSafeV</u> * period to avoid false triggers due to spikes or noise.
ResetDiffVcell	OTP	2	0	65535	100	Maximum cell voltage difference reset condition.
ResetMaxTemp	OTP	2	0	65535	600	Maximum temperature reset condition.
ResetIMax	OTP	2	0	65535	500	Maximum current reset condition.
ResetMaxVcell	OTP	2	0	65535	4100	Maximum cell voltage reset condition.
ResetMaxVpack	OTP	2	0	65535	16800	Maximum pack voltage reset condition.
ResetMinTemp	OTP	2	0	65535	200	Minimum temperature reset condition.
ResetMinVcell	OTP	2	0	65535	2700	Minimum cell voltage reset condition.
ResetTCAVolt	OTP	2	0	65535	4100	Terminate Charge Alarm reset condition.
SafetyDiffVCell	OTP	2	0	65535	1000	Safety condition of maximum cell voltage difference.
SafetyIMaxC	OTP	2	0	65535	5500	Safety condition of maximum charging current.
SafetyIMaxD	OTP	2	0	65535	5500	Safety condition of maximum discharging current.
SafetyMaxTemp	OTP	2	0	65535	800	Safety condition of maximum temperature (Celsius*10+200).
SafetyMaxVCell	OTP	2	0	65535	4400	Safety condition of maximum cell voltage.
SafetyMaxVPack	OTP	2	0	65535	17600	Safety condition of maximum pack voltage.
SafetyMinTemp	OTP	2	0	65535	200	Safety condition of minimum temperature (Celsius*10+200).
SafetyMinVCell	OTP	2	0	65535	2700	Safety conditions of minimum cell voltage.

**TABLE 8-6: PS401 SETTINGS**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description																		
AutoOffset	EE	1	0	255	60	The frequency of the Auto Offset Calibration cycle.																		
BlockVersion	OTP	2	0	65535	3	OTP Block ID.																		
ComOffsetCurr	EE	1	0	255	7	Current offset for Wake-up current level.																		
ConfigEOC	EE	1	0	255	b00010000	Bit coded as follows: <table border="0"> <thead> <tr> <th>Bit</th> <th>Function</th> </tr> </thead> <tbody> <tr> <td>7</td> <td>(free)</td> </tr> <tr> <td>6</td> <td>(free)</td> </tr> <tr> <td>5</td> <td>Limit RemCap to FCC</td> </tr> <tr> <td>4</td> <td>Set overcharge alarm at EOC</td> </tr> <tr> <td>3</td> <td>Load capacity with FCC at EOC</td> </tr> <tr> <td>2</td> <td>Trigger EOC on SOC &gt; MaxSOC</td> </tr> <tr> <td>1</td> <td>Trigger EOC on average current</td> </tr> <tr> <td>0</td> <td>Trigger EOC on taper current</td> </tr> </tbody> </table>	Bit	Function	7	(free)	6	(free)	5	Limit RemCap to FCC	4	Set overcharge alarm at EOC	3	Load capacity with FCC at EOC	2	Trigger EOC on SOC > MaxSOC	1	Trigger EOC on average current	0	Trigger EOC on taper current
Bit	Function																							
7	(free)																							
6	(free)																							
5	Limit RemCap to FCC																							
4	Set overcharge alarm at EOC																							
3	Load capacity with FCC at EOC																							
2	Trigger EOC on SOC > MaxSOC																							
1	Trigger EOC on average current																							
0	Trigger EOC on taper current																							
ConfigEOD	EE	1	0	255	b01011000	Bit coded as follows: <table border="0"> <thead> <tr> <th>Bit</th> <th>Function</th> </tr> </thead> <tbody> <tr> <td>7</td> <td>Evaluate EOD1 on fixed voltage (else table)</td> </tr> <tr> <td>6</td> <td>Set fully discharged bit on EOD1</td> </tr> <tr> <td>5</td> <td>Set capacity to residual capacity value immediately upon VEOD1</td> </tr> <tr> <td>4</td> <td>Set Terminate Discharge Alarm on VEOD1 (default on VEOD2)</td> </tr> <tr> <td>3</td> <td>Learn FCC at VEOD1</td> </tr> <tr> <td>2</td> <td>TDA alarm at EOD2</td> </tr> <tr> <td>1</td> <td>Set capacity to zero at VEOD2</td> </tr> <tr> <td>0</td> <td>Do not allow capacity to drop below SCAP</td> </tr> </tbody> </table>	Bit	Function	7	Evaluate EOD1 on fixed voltage (else table)	6	Set fully discharged bit on EOD1	5	Set capacity to residual capacity value immediately upon VEOD1	4	Set Terminate Discharge Alarm on VEOD1 (default on VEOD2)	3	Learn FCC at VEOD1	2	TDA alarm at EOD2	1	Set capacity to zero at VEOD2	0	Do not allow capacity to drop below SCAP
Bit	Function																							
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6	Set fully discharged bit on EOD1																							
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4	Set Terminate Discharge Alarm on VEOD1 (default on VEOD2)																							
3	Learn FCC at VEOD1																							
2	TDA alarm at EOD2																							
1	Set capacity to zero at VEOD2																							
0	Do not allow capacity to drop below SCAP																							

# PS401

TABLE 8-6: PS401 SETTINGS (CONTINUED)

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description																		
ConfigCAP	EE	1	0	255	11010000	<p>Bit coded as follows:</p> <table border="1"> <thead> <tr> <th>Bit</th> <th>Function</th> </tr> </thead> <tbody> <tr> <td>7</td> <td>Compensate RemCap – the displayed RemCap actually equals FCC minus capacity used minus residual capacity due to temperature. RemCap is compensated for temperature.</td> </tr> <tr> <td>6</td> <td>RemCap decrease only – when compensating, if temperature changed causing a decrease in residual capacity, do not let RemCap rise to reflect this. Instead hold it steady until discharge catches up. This occurs so user does not see capacity increase while discharging. (though usable capacity may increase if the temperature changes, user may be confused).</td> </tr> <tr> <td>5</td> <td>Use compensated FCC – to compute RSOC. Allows compensated RSOC to equal 100% at full charge.</td> </tr> <tr> <td>4</td> <td>Unused.</td> </tr> <tr> <td>3</td> <td>Report compensated FCC – the compensated FCC is reported in SBData to allow for externally calculated RSOC.</td> </tr> <tr> <td>2</td> <td>Set capacity to positive immediately upon charging – if discharged below zero, this allows capacity to count up immediately upon charging.</td> </tr> <tr> <td>1</td> <td>Learn Unconditionally – relearn FCC no matter what. Typically a max current and a max error limitation occur on relearn. This removes the limitations. Typically used for testing only.</td> </tr> <tr> <td>0</td> <td>Unused.</td> </tr> </tbody> </table>	Bit	Function	7	Compensate RemCap – the displayed RemCap actually equals FCC minus capacity used minus residual capacity due to temperature. RemCap is compensated for temperature.	6	RemCap decrease only – when compensating, if temperature changed causing a decrease in residual capacity, do not let RemCap rise to reflect this. Instead hold it steady until discharge catches up. This occurs so user does not see capacity increase while discharging. (though usable capacity may increase if the temperature changes, user may be confused).	5	Use compensated FCC – to compute RSOC. Allows compensated RSOC to equal 100% at full charge.	4	Unused.	3	Report compensated FCC – the compensated FCC is reported in SBData to allow for externally calculated RSOC.	2	Set capacity to positive immediately upon charging – if discharged below zero, this allows capacity to count up immediately upon charging.	1	Learn Unconditionally – relearn FCC no matter what. Typically a max current and a max error limitation occur on relearn. This removes the limitations. Typically used for testing only.	0	Unused.
Bit	Function																							
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0	Unused.																							
ConfigLED	EE	1	0	255	b10000010	<p>Bit coded as follows:</p> <table border="1"> <thead> <tr> <th>Bit</th> <th>Function</th> </tr> </thead> <tbody> <tr> <td>7</td> <td>Disable Master mode</td> </tr> <tr> <td>6</td> <td>(free)</td> </tr> <tr> <td>5</td> <td>(free)</td> </tr> <tr> <td>4</td> <td>LED display while charging</td> </tr> <tr> <td>3</td> <td>Display the most significant LED only</td> </tr> <tr> <td>2</td> <td>LED using Absolute SOC, else Relative SOC</td> </tr> <tr> <td>1</td> <td>Flash LEDs on remaining time or remaining cap alarm</td> </tr> <tr> <td>0</td> <td>Flash LEDs while charging</td> </tr> </tbody> </table>	Bit	Function	7	Disable Master mode	6	(free)	5	(free)	4	LED display while charging	3	Display the most significant LED only	2	LED using Absolute SOC, else Relative SOC	1	Flash LEDs on remaining time or remaining cap alarm	0	Flash LEDs while charging
Bit	Function																							
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2	LED using Absolute SOC, else Relative SOC																							
1	Flash LEDs on remaining time or remaining cap alarm																							
0	Flash LEDs while charging																							
EEError	EE	1	0	255	0	Incremented when write retries exceeds <u>EERepeats</u> .																		
EERepeats	EE	1	0	255	3	Maximum number of internal write retries.																		

**TABLE 8-6: PS401 SETTINGS (CONTINUED)**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description																		
EEversion	EE	1	0	255	1	EE version.																		
FLAGS1	EE	1	0	255	b00100110	Bit coded as follows: <table border="0"> <tr> <td><u>Bit</u></td> <td><u>Function</u></td> </tr> <tr> <td>7</td> <td>Enable precharge max current check</td> </tr> <tr> <td>6</td> <td>Hold Charge Current = 0 until next discharge</td> </tr> <tr> <td>5</td> <td>Int/Ext temp</td> </tr> <tr> <td>4</td> <td>Disable SLEEP in main IDLE mode</td> </tr> <tr> <td>3</td> <td>Require Run mode for low voltage SLEEP mode</td> </tr> <tr> <td>2</td> <td>Disable safety GPIO</td> </tr> <tr> <td>1</td> <td>Pack resistance enable</td> </tr> <tr> <td>0</td> <td>Enable Run mode detect</td> </tr> </table>	<u>Bit</u>	<u>Function</u>	7	Enable precharge max current check	6	Hold Charge Current = 0 until next discharge	5	Int/Ext temp	4	Disable SLEEP in main IDLE mode	3	Require Run mode for low voltage SLEEP mode	2	Disable safety GPIO	1	Pack resistance enable	0	Enable Run mode detect
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6	Hold Charge Current = 0 until next discharge																							
5	Int/Ext temp																							
4	Disable SLEEP in main IDLE mode																							
3	Require Run mode for low voltage SLEEP mode																							
2	Disable safety GPIO																							
1	Pack resistance enable																							
0	Enable Run mode detect																							
LUTSelection	EE	1	0	255	b00000000	b00xxxxxx = LUT 0 b01xxxxxx = LUT 1 b10xxxxxx = LUT 2 b11xxxxxx = LUT 3 bits 5-0 are unused																		
NSample	EE	1	0	255	10	Frequency of ADC activity in Sample mode. The A/D converter will make measurements every <u>NSample</u> periods while in Sample mode. In Run mode, new measurements are taken every period.																		
OSCTrim	EE	1	0	255	125	RC oscillator trimming.																		
PNModeDelay	EE	1	0	255	10	Time slot for Programming mode. When the PS401 is put into Programming mode to program the EEPROM through the SMBus, it will stay in Programming mode for <u>PNModeDelay</u> / 2 periods before automatically returning to Normal mode. For <u>PNModeDelay</u> = 16, period = 0.5, the PS401 will stay in Programming mode for 8 seconds. EEPROM programming must be finished in this amount of time.																		
ProgLock	EE	2	0	65535		Code for EEPROM programming function. Determines successful EEPROM update. Internal P4 code only.																		
PTRActualData	EE	2	0	65535	0x1721	OTP starting address of current data block.																		
RFactor	OTP	1	0	255	7	C-Rate scaling. $R_F = 28 / \text{max C-Rate}$ . This is used to scale all C-rate values, such as taper current values and lookup table C-rates. For a maximum allowable C-rate of 4C in these values, set $R_F$ to $28 / 4 = 7$ . By changing $R_F$ you can scale all C-rate values in lookup tables and other parameters for use with higher current systems, without changing all the other values.																		
SampleLimit	EE	1	0	255	15	Value used to determine the current threshold for entry/exit for Sample and Run modes: Threshold [mA] = <u>SampleLimit</u> x <b>CfCurr</b> / 16384																		

# PS401

**TABLE 8-6: PS401 SETTINGS (CONTINUED)**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description																																													
SleepVPack	EE	2	0	65535	8800	The pack voltage at which the PS401 will enter Low Voltage SLEEP mode.																																													
WakeUp	EE	1	0	255	b00001011	<p>When in the Low Voltage SLEEP mode (entry due to low voltage and Sample mode), there are four methods for waking up. They are voltage level, current level, SMBus activity and I/O pin activity. This value defines which wake-up functions are enabled, and also the voltage wake-up level. The table below indicates the appropriate setting. Note that the setting is independent of the number of cells or their configuration.</p> <p>Wake-up:</p> <table border="1"> <thead> <tr> <th>Bit</th> <th>Name</th> <th>Function</th> </tr> </thead> <tbody> <tr> <td>6</td> <td>Wake_IO</td> <td>Wake-up from I/O activity</td> </tr> <tr> <td>5</td> <td>Wake_Bus</td> <td>Wake-up from SMBus activity</td> </tr> <tr> <td>4</td> <td>Wake_Curr</td> <td>Wake-up from Current</td> </tr> <tr> <td>3</td> <td>Wake_Volt</td> <td>Wake-up from Voltage</td> </tr> <tr> <td>2:0</td> <td>Wake_Level</td> <td>Defines Wake Voltage Level</td> </tr> </tbody> </table> <p>Wake-up Voltage:</p> <table border="1"> <thead> <tr> <th>WakeUp (2:0)</th> <th>Voltage</th> <th>Purpose</th> </tr> </thead> <tbody> <tr> <td>000</td> <td>6.4V</td> <td>2 cells Li Ion</td> </tr> <tr> <td>001</td> <td>6.66V</td> <td>6 cells NiMH</td> </tr> <tr> <td>010</td> <td>8.88V</td> <td>8 cells NiMH</td> </tr> <tr> <td>011</td> <td>9.6V</td> <td>3 cells Li Ion</td> </tr> <tr> <td>100</td> <td>9.99V</td> <td>9 cells NiMH</td> </tr> <tr> <td>101</td> <td>11.1V</td> <td>10 cells NiMH</td> </tr> <tr> <td>110</td> <td>12.8V</td> <td>4 cells Li Ion</td> </tr> <tr> <td>111</td> <td>13.3V</td> <td>12 cells NiMH</td> </tr> </tbody> </table>	Bit	Name	Function	6	Wake_IO	Wake-up from I/O activity	5	Wake_Bus	Wake-up from SMBus activity	4	Wake_Curr	Wake-up from Current	3	Wake_Volt	Wake-up from Voltage	2:0	Wake_Level	Defines Wake Voltage Level	WakeUp (2:0)	Voltage	Purpose	000	6.4V	2 cells Li Ion	001	6.66V	6 cells NiMH	010	8.88V	8 cells NiMH	011	9.6V	3 cells Li Ion	100	9.99V	9 cells NiMH	101	11.1V	10 cells NiMH	110	12.8V	4 cells Li Ion	111	13.3V	12 cells NiMH
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110	12.8V	4 cells Li Ion																																																	
111	13.3V	12 cells NiMH																																																	

**TABLE 8-7: SBDData SETTINGS**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description												
BusConfig	EE	1	0	255	b00100001	Bit coded as follows: <table border="1"> <thead> <tr> <th>Bit</th> <th>Function</th> </tr> </thead> <tbody> <tr> <td>7</td> <td>V2.0 arbitration</td> </tr> <tr> <td>6</td> <td>Master wr w/CRC</td> </tr> <tr> <td>5</td> <td>PEC on</td> </tr> <tr> <td>4</td> <td>Baud rate control</td> </tr> <tr> <td>2-0</td> <td>Baud rate 2-0</td> </tr> </tbody> </table>	Bit	Function	7	V2.0 arbitration	6	Master wr w/CRC	5	PEC on	4	Baud rate control	2-0	Baud rate 2-0
Bit	Function																	
7	V2.0 arbitration																	
6	Master wr w/CRC																	
5	PEC on																	
4	Baud rate control																	
2-0	Baud rate 2-0																	
HighTempAl	EE	2	0	65535	750	Over Temp alarm threshold bit in <u>AlarmWarning</u> register, 0.1°C increments, Coded value = (Celsius*10+200). When the temperature exceeds <u>HighTempAlarm</u> , the <u>OverTempAlarm</u> becomes active. If charging, the <u>TerminateChargeAlarm</u> also becomes active.												
NChrgBroadcast	EE	1	0	255	20	Frequency of charging condition broadcasts.												
NSilent	EE	1	0	255	10	Bus-on silence period for messages.												
RemCapAl	EE	2	0	65535	440	SBDData value for <u>RemCapAl</u> . The SBDData specification requires a default of <u>DesignCapacity</u> /10 for this value. When the Remaining Capacity calculation reached the value of <u>RemCapAl</u> , the REMAINING_CAPACITY_ALARM bit will be set in the <u>BatteryStatus</u> register, and an alarm broadcast to the host will occur if alarm broadcasts are enabled.												
RemTimeAl	EE	2	0	65535	10	SBDData value for <u>RemTimeAl</u> . SBDData requires a default of 10 minutes for this value. When the <u>RunTimeToEmpty</u> calculation reaches the value of <u>RemTimeAl</u> , the REMAINING_TIME_ALARM bit in <u>BatteryStatus</u> will be set.												
SMBusAddr	EE	1	0	255	0x16	SMBus address of the battery.												
TCAVolt	EE	2	0	65535	4500	Cell voltage when the battery sends TERMINATE_CHARGE_ALARM. This is a voltage higher than end-of-charge voltage that will trigger a terminate charge alarm in case EOC is not responded to by the charger.												

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**TABLE 8-8: CALIBRATION**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description																		
CalStatus	EE	1	0	255	b11111111	Bit coded as follows: <table border="1"> <thead> <tr> <th>Bit</th> <th>Function</th> </tr> </thead> <tbody> <tr> <td>7</td> <td>RCOSC</td> </tr> <tr> <td>6</td> <td>TEMP</td> </tr> <tr> <td>5</td> <td>CURRENT</td> </tr> <tr> <td>4</td> <td>VPACK</td> </tr> <tr> <td>3</td> <td>VCELL4</td> </tr> <tr> <td>2</td> <td>VCELL3</td> </tr> <tr> <td>1</td> <td>VCELL2</td> </tr> <tr> <td>0</td> <td>VCELL1</td> </tr> </tbody> </table> 0 = Not Calibrated 1 = Calibrated	Bit	Function	7	RCOSC	6	TEMP	5	CURRENT	4	VPACK	3	VCELL4	2	VCELL3	1	VCELL2	0	VCELL1
Bit	Function																							
7	RCOSC																							
6	TEMP																							
5	CURRENT																							
4	VPACK																							
3	VCELL4																							
2	VCELL3																							
1	VCELL2																							
0	VCELL1																							
CFCurr	EE	2	0	65535	6844	Correction Factor for Current. Adjusts the scaling of the sense resistor current measurements. Used to calibrate the measurement of current at the RSHP and RSHN input pins. This is set for the size of the current sense resistor.																		
CFTempE	EE	2	0	65535	1300	Correction Factor for Temperature. Adjusts the scaling of temperature measured across an external thermistor at the VNTC input pin.																		
CFTempl	EE	2	0	65535	23800	Correction Factor for Temperature. Adjusts the scaling of temperature measured from the internal temperature sensor. Calibration: $\text{New CF\_TEMP} = \text{Old CF\_TEMP} \times (\text{Thermometer}[\text{°C}] / \text{SBData Temperature}[\text{°C}])$ Note: SBData <u>Temperature</u> is reported in 0.1°K normally. It must be converted to °C for this equation.																		
CFVCell1	EE	2	0	65535	22325	Calibration Correction Factor for VCELL1. Used to calibrate the measurement of individual cell voltage between the VCELL1-4 input pins.																		
CFVCell2	EE	2	0	65535	22393	Calibration Correction Factor for VCELL2. Used to calibrate the measurement of individual cell voltage between the VCELL1-4 input pins.																		
CFVCell3	EE	2	0	65535	22420	Calibration Correction Factor for VCELL3. Used to calibrate the measurement of individual cell voltage between the VCELL1-4 input pins.																		
CFVCell4	EE	2	0	65535	22470	Calibration Correction Factor for VCELL4. Used to calibrate the measurement of individual cell voltage between the VCELL1-4 input pins.																		

**TABLE 8-8: CALIBRATION (CONTINUED)**

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description
CFVPack	EE	2	0	65535	20045	Correction Factor for Pack Voltage. Adjusts the scaling of the pack voltage measurements. Used to calibrate the measurement of pack voltage between VCELL4 input pin and ground.
COCurr	EE	1	-128	127	-12	Correction Offset for Current. This is the value the A/D reads when zero current is flowing through the sense resistor.
COD	EE	1	-128	127	-12	Correction Offset Deviation - Offset value for the auto-zero calibration of the current readings. $SBDData\ Current[mA] = (I\_A/D - CO\_CURR - COD) \times CF\_CURR / 16384$ Calibration: $CF\_CURR = ((Ammeter[mA] \times 16384) - 8192) / (Current - I\_A/D\ at\ OCV)$
COTempE	EE	1	-128	127	-2	Correction Offset for Temperature. Offset = 0 used for temperature measurement using internal temperature sensor.
COTempI	EE	2	-32768	32767	-11375	Correction Offset for Temperature. Offset = 0 used for temperature measurement using internal temperature sensor.
COVCell	EE	1	-128	127	0	Correction Offset for Cell Voltage. Offset factor used for individual cell voltage readings. $SBDData\ Voltage[mV] = (V\_A/D - CO\_VOLT) \times CF\_VOLT / 2048$ Calibration: $New\ CF\_VOLT = Old\ CF\_VOLT \times (Voltmeter[mV] / SBDData\ Voltage[mV])$
COVPack	EE	1	-128	127	0	Correction Offset for Voltage. Offset factor used for pack voltage reading.

# PS401

## 9.0 ELECTRICAL CHARACTERISTICS

**TABLE 9-1: ABSOLUTE MAXIMUM RATINGS**

Symbol	Parameter	Min	Max	Units
VCX	Voltage at any VC(x) pin	-0.5	18.5	V
VPIN	Voltage directly at any pin (except VCELLX)	-0.5	7.0	V
TBIAS	Temperature under bias	-20	85	°C
TSTORAGE	Storage temperature (package dependent)	-35	125	°C

**Note 1:** 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.

**TABLE 9-2: DC CHARACTERISTICS (TA = -20°C TO +85°C; VREG (INTERNAL) = +5.0V ±10%)**

Symbol	Characteristic	Min	Typ	Max	Units	Condition
VSUPPLY	Supply Voltage – Applied to VC(1)	5.6		18.0	V	
VDDA	Supply Voltage – (Output from internal regulator on VDDA pin)	4.5	5.0	5.5	V	(Note 1)
IDD	Instantaneous Supply Current		375	400	µA	(Note 2)
IDDRUN	Average Supply Current – Run mode		300	385	µA	A/D Active (Note 2)
IDDINS	Inactive Supply Current – Sample mode		225	250	µA	A/D Inactive (Note 2, 3)
IDDSLEEP	Average Supply Current – SLEEP mode		12	18	µA	SLEEP mode (Note 2)
IWAKE	Wake-up Current Threshold from SLEEP mode – (Voltage across sense resistor)	2.50	3.75	5.00	mV	
VIL	Input Low Voltage – GPIO(7-0)			0.2* VDD	V	
VIH	Input High Voltage – GPIO(7-0)	0.8* VDD			V	
IIL-IOPU	GPIO Input Low Current – Pull-up mode	-80	-110	-140	µA	
IIH-IOPD	GPIO Input High Current – Pull-down mode	70	105	140	µA	
IL	Leakage Current – GPIO pins programmed as outputs		1	2	µA	
VOL	Output low voltage for GPIO(7-0)			0.4	V	IO <sub>L</sub> = 0.5 mA
VOH-IO	Output high voltage for GPIO(7-0) (non-LED mode)	2.0			V	IO <sub>H</sub> = 100 µA
VOH-LED	Output high voltage for GPIO(7-0) (LED mode)	2.0			V	IO <sub>H</sub> = 10 mA (Note 4)
VSR	Sense Resistor Input Voltage Range	-152		152	mV	
VNTC	Thermistor Input Voltage Range	0		152	mV	
VREFT	NTC Reference voltage output at VREFT pin		150		mV	
VIL-SMB	Input Low Voltage for SMBus pins	-0.5		0.8	V	
VIH-SMB	Input High Voltage for SMBus pins	2.0		5.5	V	
VOL-SMB	Output Low Voltage for SMBus pins			0.4	V	IPULLUP = 350 µA
VOH-SMB	Output High Voltage for SMBus pins	2.1		5.5	V	
IPULLUP-SMB	Current through pullup resistor or current source for SMBus pins	100		350	µA	
I <sub>LEAK-SMB</sub>	Input leakage current – SMBus pins			± 5	µA	

- Note 1:** VREG is the on-chip regulator voltage. It is internally connected to analog supply voltage and is output on the VDDA pin.  
**Note 2:** Does not include current consumption due to external loading on pins.  
**Note 3:** Sample mode current is specified during an A/D inactive cycle. Sample mode average current can be calculated using the formula: Average Sample mode Supply Current = (IDDRUN + (n-1)\*IDDINS)/n; where "n" is the programmed sample rate.  
**Note 4:** During LED illumination, currents may peak at 10mA but average individual LED current is typically 5 mA (using low current, high brightness devices.)

**TABLE 9-3: AC CHARACTERISTICS (TA = -20°C TO +85°C; VREG (INTERNAL) = +5.0V ±10%)**

Symbol	Characteristic	Min	Typ	Max	Units	Condition
dfRC	Internal RC oscillator frequency	509	512	515	kHz	
fA/D	Internal A/D operating clock		fRC/10		ms	
tCONV	A/D Conversion measurement time, n-bit+sign		2 <sup>n</sup> /fA/D		ms	

**TABLE 9-4: AC CHARACTERISTICS – SMBUS (TA = -20°C TO +85°C; VREG (INTERNAL) = +5.0V ±10%)**

Symbol	Characteristic	Min	Typ	Max	Units	Condition
fSMB	SMBus clock operating frequency	<1.0		100	kHz	Slave mode
fSMB-MAS	SMBus clock operating frequency	50	fRC/8	68	kHz	Master mode ( <b>Note 1</b> )
tBUF	Bus free time between START and STOP	4.7			µs	
tSHLD	Bus Hold time after Repeated START	4.0			µs	
tSU:STA	Setup time before Repeated START	4.7			µs	
tSU:STOP	STOP setup time	4.0			µs	
tHLD	Data hold time	300			ns	
tSETUP	Data setup time	250			ns	
tTIMEOUT	Clock low time-out period	25		35	ms	( <b>Note 2</b> )
tLOW	Clock low period	4.7			µs	
tHIGH	Clock high period	4.0		50	µs	( <b>Note 3</b> )
tLOW:SEXT	Message buffering time			25	ms	( <b>Note 4</b> )
tLOW:MEXT	Message buffering time			10	ms	( <b>Note 5</b> )
tF	Clock/data fall time			300	ns	( <b>Note 6</b> )
tR	Clock/data rise time			1000	ns	( <b>Note 6</b> )

- Note 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 PS401 becomes a SMBus Master for these functions. The receiving (Slave) device may slow the transfer frequency.
- 2:** The PS401 will timeout when the cumulative message time defined from Start-to-Ack, Ack-to-Ack or Ack-to-Stop exceeds the value of tTIMEOUT, Min of 25 ms. The PS401 will reset the communication no later than tTIMEOUT, Max of 35 ms.
- 3:** tHIGH Max provides a simple method for devices to detect bus IDLE conditions.
- 4:** tLOW:SEXT is the cumulative time a slave device is allowed to extend the clock cycles in one message from the initial start to the stop.
- 5:** tLOW:MEXT is the cumulative time a master device is allowed to extend its clock cycles within each byte of a message as defined from Start-to-Ack, Ack-to-Ack or Ack-to-Stop.
- 6:** Rise and fall time is defined as follows:  
 $tR = (V_{IL_{MAX}} - 0.15) \text{ to } (V_{IH_{MIN}} + 0.15)$   
 $tF = 0.9 V_{DD} \text{ to } (V_{IL_{MAX}} - 0.15)$

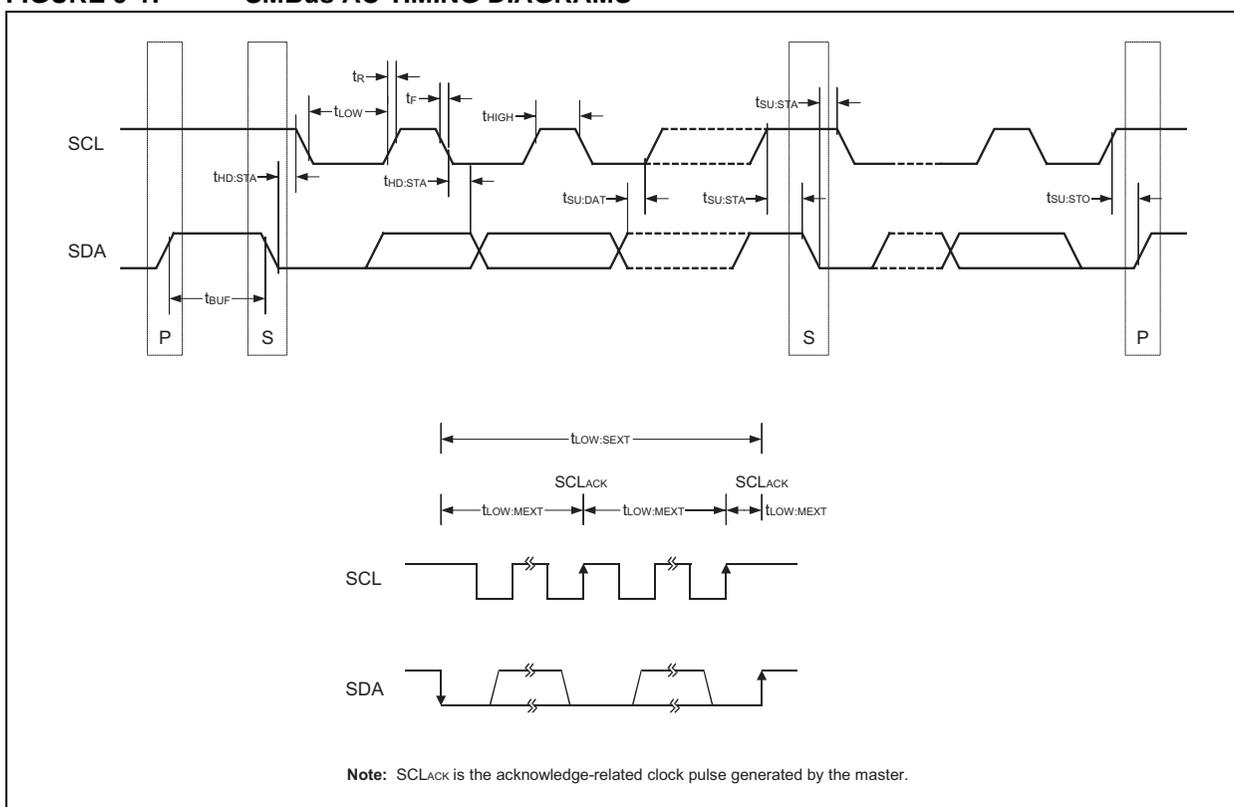
# PS401

**TABLE 9-5: A/D CONVERTER CHARACTERISTICS (TA = -20°C TO +85°C; VREG (INTERNAL) = +5.0V ±10%)**

Symbol	Characteristic	Min	Typ	Max	Units	Condition
ADRES	A/D Converter Resolution	8		15	bits	(Note 1)
VADIN	A/D Converter Input Voltage Range (Internal)	-152		152	mV	Differential mode
		0		300	mV	Single-Ended mode
EVGAIN	Supply Voltage Gain Error			0.100	%	
EVOFFSET	Compensated Offset Error			0.100	%	
ETEMP	Temperature Gain Error			0.100	%	
EINL	Integrated Nonlinearity Error			0.004	%	

**Note 1:** Voltage is internal at A/D converter inputs. VSR and VNTC are measured directly. VC(x) inputs are measured using internal level-translation circuitry that scales the input voltage range appropriately for the converter.

**FIGURE 9-1: SMBus AC TIMING DIAGRAMS**

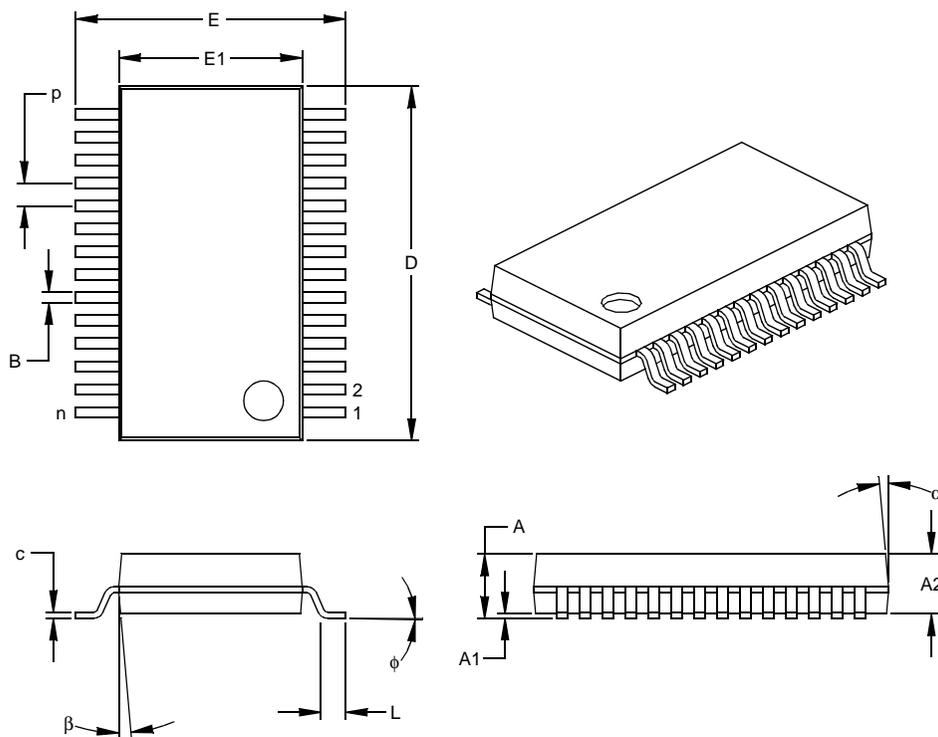


**TABLE 9-6: SILICON TIME BASE CHARACTERISTICS (TA = -20°C TO +85°C; VREG (INTERNAL) = +5.0V ± 10%)**

Symbol	Characteristic	Min	Typ	Max	Units	Condition
ETIME	Silicon time base error			0.25	%	Bias Resistor ROSC tolerance = 1% TL = ± 100 PPM

## 10.0 PACKAGING INFORMATION

28-Lead Plastic Shrink Small Outline (SS) – 209 mil, 5.30 mm (SSOP)



		Units	INCHES			MILLIMETERS*		
Dimension Limits			MIN	NOM	MAX	MIN	NOM	MAX
Number of Pins	n			28			28	
Pitch	p			.026			0.65	
Overall Height	A		.068	.073	.078	1.73	1.85	1.98
Molded Package Thickness	A2		.064	.068	.072	1.63	1.73	1.83
Standoff §	A1		.002	.006	.010	0.05	0.15	0.25
Overall Width	E		.299	.309	.319	7.59	7.85	8.10
Molded Package Width	E1		.201	.207	.212	5.11	5.25	5.38
Overall Length	D		.396	.402	.407	10.06	10.20	10.34
Foot Length	L		.022	.030	.037	0.56	0.75	0.94
Lead Thickness	c		.004	.007	.010	0.10	0.18	0.25
Foot Angle	φ		0	4	8	0.00	101.60	203.20
Lead Width	B		.010	.013	.015	0.25	0.32	0.38
Mold Draft Angle Top	α		0	5	10	0	5	10
Mold Draft Angle Bottom	β		0	5	10	0	5	10

\* Controlling Parameter  
 § Significant Characteristic

Notes:

Dimensions D and E1 do not include mold flash or protrusions. Mold flash or protrusions shall not exceed .010" (0.254mm) per side.

JEDEC Equivalent: MS-150

Drawing No. C04-073

# PS401

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NOTES:

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03/25/03