MICROCHIP

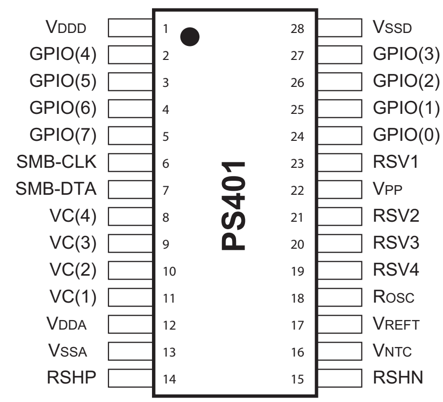
PS401

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 V_{CELL} 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



28-pin SSOP Package (0.209 mil)

Pin Summary

Pin Name	Type	Description
V_{DDD}, V_{SSD}	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
V_{DDA}, V_{SSA}	Supply	Voltage regulator output (internally connected to analog supply input); ground
RSHP, RSHN	I	Current sense resistor input
V_{NTC}	I	External thermistor input
V_{REFT}	O	Thermistor reference voltage
R_{OSC}	I	Internal oscillator bias resistor
RSV1-4	I	Reserved pins
V_{PP}	I	OTP programming voltage

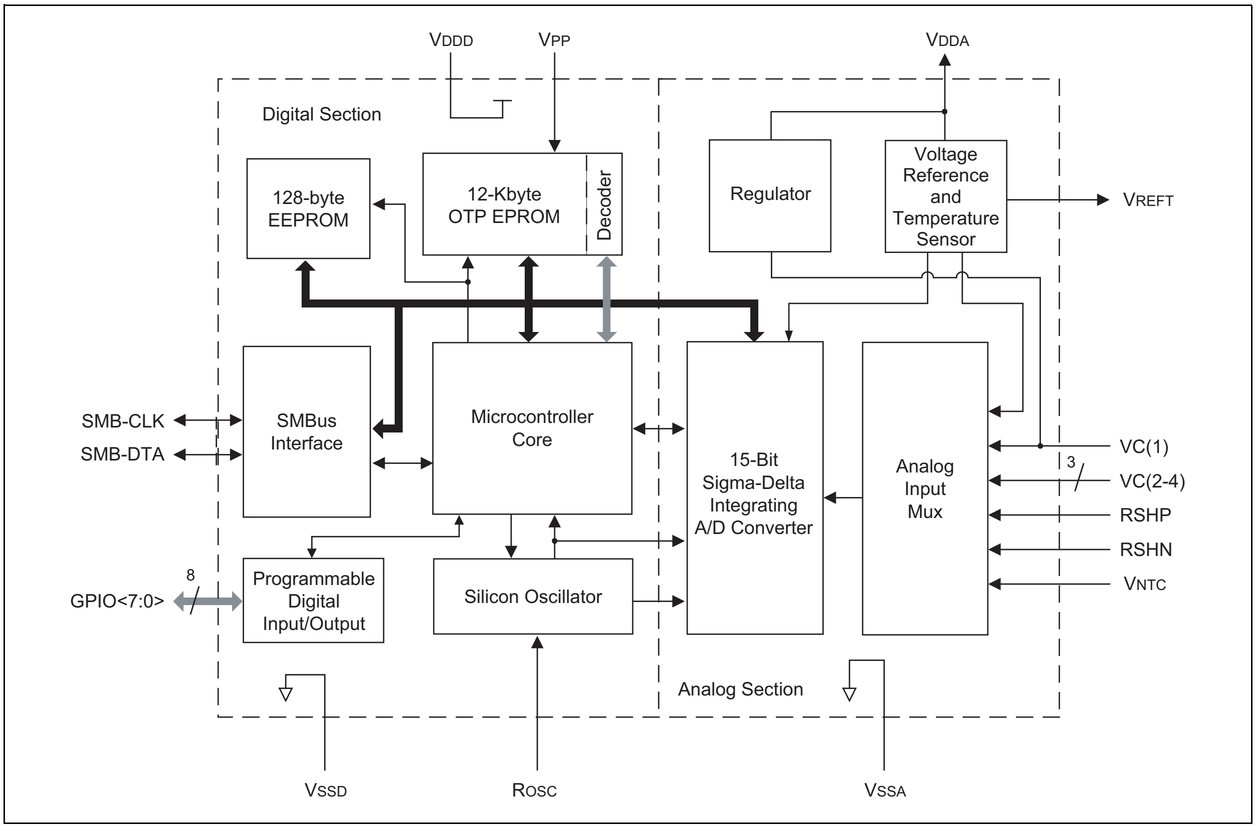
1.0 PRODUCT OVERVIEW

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 SBData 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.

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 mV / RSENSE (milli-Ohms) = Current LSB (Minimum current measurement if > **NullCurr**)

Current LSB x 16384 = 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(ma) = (I_A/D – **COCurr** – **COD**) ***** **CFCurr** /16384

where:

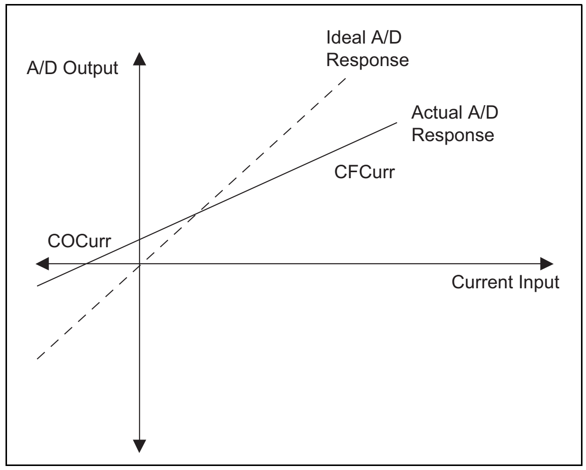
I_A/D is the internal measurement.

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:

PackResistance = 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:

SBData Voltage value = VC(1) + Measured Current (mA) * **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:

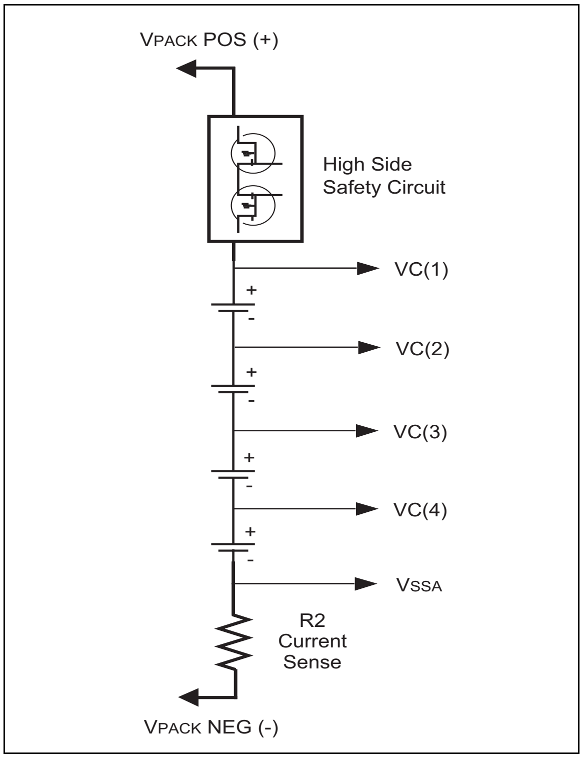
V (mV) = (V_A/D - **COVPack**) x **CFVPack** / 2048

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

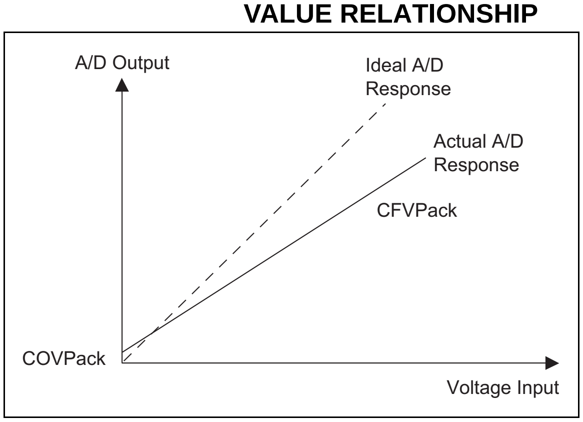


CFVPack is the "Correction Factor for Pack Voltage" which compensates for any variance in the actual A/D response versus an ideal A/D response over varying voltage inputs.

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 ±40 mV at zero current and ±80 mV during charge or discharge is possible. Individual cell voltage measurements can be accurate to within ±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 V_{NTC} pin which is also monitored by the A/D converter. An output reference voltage for use with an external thermistor is provided on the V_{REFT} 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 V_{REFT} pin and the other to both the V_{NTC} pin and a 3.65 kOhms resistor to analog ground (V_{SSA}). 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 V_{NTC} 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 V_{DDD}) 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 V_{NTC} and V_{REFT} 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:

+/- X mA = **SampleLimit x 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 +/- 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 +/- 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 +/- **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 x **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 x 12500 / 16384 = **+/- 20.6 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

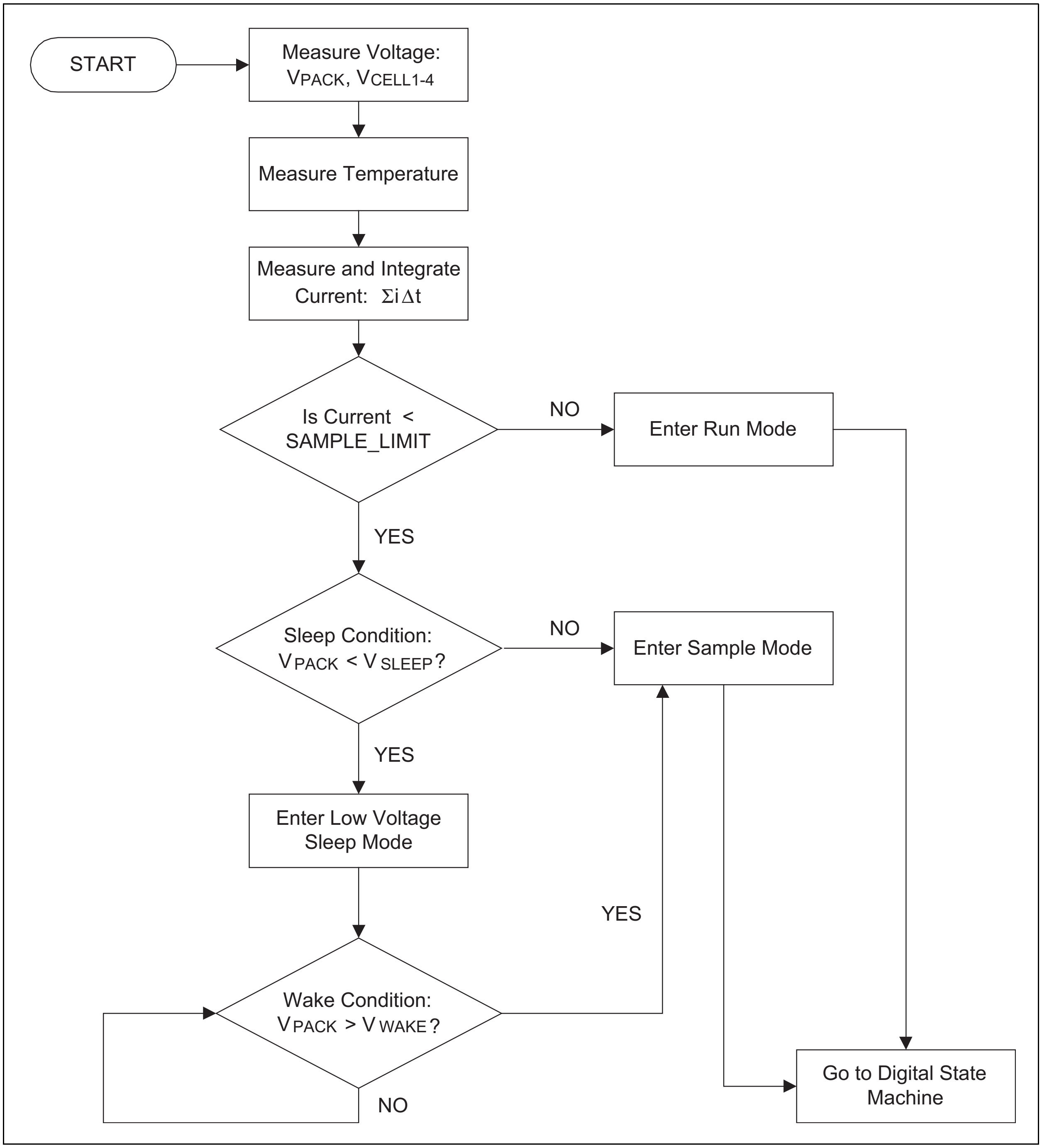
TABLE 3-2: WakeUp VOLTAGE

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

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 <u>MaxError</u>. 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 μA.

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

ΔCharge = $\Sigma i \Delta t$ (the current integrated over time)

- **CurrError** (Current Meas. Error)
- **PwrConsumption** * Δt (PS401 I_{DD})
- % 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 <u>MaxError</u> 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 <u>BatteryStatus</u> will be set. This will cause an <u>AlarmWarning</u> 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.

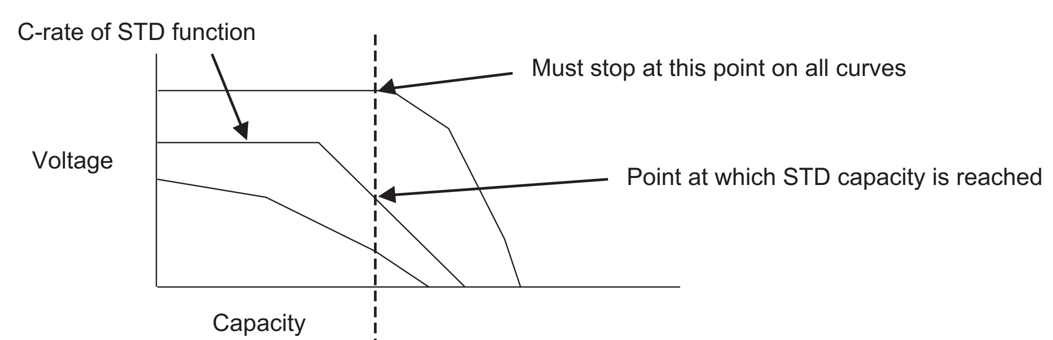
The graph in Figure 4-1 shows that the system will always shut down at the same capacity point regardless of C-rate conditions (since the C-rate of the save to disk procedure is a constant). Thus, we can automatically have an RSOC that is compensated for C-rate; it will go to zero when the capacity used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

TEOD 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		
CEOD 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.		
FCCP coded %	typ: 50,25,12,8,0,0,0	Range: 1-255
Unusable residual capacity before save to disk, corresponding to temperature. 255 = 100%		
VEOD 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 SBData values for ChargingVoltage and ChargingCurrent from the Smart Battery directly. The Host or "Level 3" Smart Battery Charger is also required to read the SBData 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:

ChargingVoltage = **EOCVolt** x **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

NChrgBroadcast	= 100 decimal
NSilent	= 24 decimal
ChrgCurr	= 2500 decimal
ChrgCurrOff	= 10 decimal
ChrgMaxTemp	= 650 decimal
DischrgMaxTemp	= 550 decimal
ChrgMinTemp	= 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 SBData 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.
- SBData 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.

HighTempAl: When the measured temperature is greater than **HighTempAl**, 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 > **SafetyMaxVCell**	Any cell voltage rises above **SafetyMaxVCell**
14	6	VCELLX < **SafetyMinVCell**	Any cell voltage falls below **SafetyMinVCell**
13	5	Vcell_Diff > **SafetyDiffVCell**	The difference between two cells is greater than **SafetyDiffVCell**
12	4	VPACK > **SafetyMaxVPack**	Pack voltage rises above **SafetyMaxVPack**
11	3	Temperature > **SafetyMaxTemp**	Temperature rises above **SafetyMaxTemp**
10	2	Temperature < **SafetyMinTemp**	Temperature falls below **SafetyMinTemp**
9	1	Charge Current > **SafetyIMaxC**	Charge current rises above **SafetyIMaxC**
8	0	Discharge Current > **SafetyIMaxD**	Charge current rises above **SafetyIMaxD**

TABLE 6-2: GPIO CHARGE CONDITIONS

OR Byte Bit	AND Byte Bit	Charge Condition	Description
15	7	VCELLX > **SafetyMaxVCell**	Any cell voltage rises above **SafetyMaxVCell**
14	6	Terminate Charge Alarm	Terminate Charge Alarm Active
13	5	Fully Charged Flag	Fully Charged Flag in Battery Status is set
12	4	**SOC** > **MaxSOC**	State-Of-Charge greater than MaxSOC
11	3	Temperature > **SafetyMaxTemp**	Temperature rises above **SafetyMaxTemp**
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** > **EOCVolt**	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.

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 **(Note 1)**	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 SBData 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

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

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

Temperature ( ) < ChrgMinTemp
ChargingCurrent ( ) = **ChrgCurrOff** ChargingVoltage ( ) = **ChrgVolt**

For all other temperature conditions:
ChargingCurrent ( ) = **ChrgCurr**
ChargingVoltage ( ) = **ChrgVolt**

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 BatteryStatus.
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 ChemistryLength. The Chemistry name can be programmed here and retrieved with the SBData DeviceChemistry command.
ChemNameLen	OTP	1	0	255	4	The length in bytes of the Chemistry String.
Date	EE	2	0	65535	0x2B7E	SBData value for ManufactureDate. The date of manufacture of the battery pack can be programmed here and retrieved with the SBData ManufactureDate command. Coding: Date = (Year-1980) x 512 + Month x 32 + Day
DesignCapacity	OTP	2	0	65535	4400	SBData value for DesignCapacity. This is the first capacity loaded into the Full Charge Capacity upon power-up.
DesignVPack	OTP	2	0	65535	14800	SBData value for DesignVoltage.
DeviceName	EE	8	–	–	–	SBData value for DeviceName. Can be any ASCII string. Length defined by DeviceNameLength. The battery circuit device name can be programmed here and retrieved with the SBData DeviceName command.
DevNameLen	OTP	1	0	255	7	The length in bytes of the DeviceName string.
DevNamePrefix	OTP	–	–	–	0	Device name prefix.
MFGData	EE	4	–	–	–	SBS string for ManufacturerData.
MFGName	EE	10	–	–	–	SBS string for ManufacturerName. Can be any ASCII string, typically the name of the battery pack manufacturer. Length of string is defined by MfgNameLength.
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 SerialNumber. The serial number of the battery pack can be programmed here and retrieved with the SBData SerialNumber 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 CycleCount. Cycles is updated to keep track of the total usage of the battery. Cycles 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, Cycles 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 InitialCap 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 LowCurrError will compensate the ERR term for low currents. LowCurrError 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	AtRate and other time-based calculations can be more accurate using a different formula for mWh. All calculations, except remaining capacity, will use mWhVolt for conversion. This approximates a straight line for the entire battery curve. mWhVolt 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.

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 NullCurr 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 > PowerVoltLimit, mWh = mAh * (V + PowerVolt) / 2. If V < PowerVoltLimit, mWh = mAh * (V + 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 FullChargeCapacity. 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 RelearnCurrLim. 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 FullCapacity. 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 RelearnLimit. The initial number of cycles where RelearnLimit is not active. FullCapacity 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'.

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 ChargeMaxTemp and the battery is charging, then ChargingCurrent is set to ChargingCurrOff and ChargingVoltage is set to ChargingVoltOff.
ChrgMinTemp	OTP	2	0	65535	200	Low temperature threshold, charging coded value = (Celsius*10+200). When charging, if the temperature is less than ChargeMinTemp, then ChargingCurrent is set to ChargingCurrOff and ChargingVoltage is set to ChargingVoltOff.
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, ClearFullyCharged 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 DischargeMaxTemp, then ChargingCurrent is set to ChargingCurrOff and ChargingVoltage is set to ChargingVoltOff.

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 **AvgCurrEOCThresh** threshold for a pass count equal to the EEPROM parameter value **ChrgCntrlTimr** (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 BatteryStatus 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.

TABLE 8-4: CHARGE CONTROL (CONTINUED)

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description
SOCErrorLimit	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 SOCThreshold, 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 StableCurr 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 GPIODirection 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 GPIOConfig 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.

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 LEDPermMin.
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 NLED * period. For NLED = 8, period = 0.5, the LEDs will stay on for 2 + 8 * .5 seconds, or 2 + 4 = 6 seconds.
NSafel	EE	1	0	255	60	Delay filter for all current safety conditions. The safety conditions must be valid for NSafel * 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 NSafeV * 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: 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: 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

TABLE 8-6: PS401 SETTINGS (CONTINUED)

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description
ConfigCAP	EE	1	0	255	11010000	Bit coded as follows: 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.
ConfigLED	EE	1	0	255	b10000010	Bit coded as follows: 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
EEError	EE	1	0	255	0	Incremented when write retries exceeds EERepeats.
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: Bit Function 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
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 NSample 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 PNModeDelay /2 periods before automatically returning to Normal mode. For PNModeDelay = 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/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] = SampleLimit x **CfCurr** / 16384

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	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. Wake-up: 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 Wake-up 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 8-7: SBData SETTINGS

Parameter Name	Loc.	# Bytes	Lower Limit	Upper Limit	Typical Value	Operational Description
BusConfig	EE	1	0	255	b00100001	Bit coded as follows: 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 AlarmWarning register, 0.1°C increments, Coded value = (Celsius*10+200). When the temperature exceeds HighTempAlarm, the OverTempAlarm becomes active. If charging, the TerminateChargeAlarm 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	SBData value for RemCapAl. The SBData specification requires a default of DesignCapacity/10 for this value. When the Remaining Capacity calculation reached the value of RemCapAl, the REMAINING_CAPACITY_ALARM bit will be set in the BatteryStatus register, and an alarm broadcast to the host will occur if alarm broadcasts are enabled.
RemTimeAl	EE	2	0	65535	10	SBData value for RemTimeAl. SBData requires a default of 10 minutes for this value. When the RunTimeToEmpty calculation reaches the value of RemTimeAl, the REMAINING_TIME_ALARM bit in BatteryStatus 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.

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: Bit Function 7 RCOSC 6 TEMP 5 CURRENT 4 VPACK 3 VCELL4 2 VCELL3 1 VCELL2 0 VCELL1 0 = Not Calibrated 1 = Calibrated
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.
CFTempI	EE	2	0	65535	23800	Correction Factor for Temperature. Adjusts the scaling of temperature measured from the internal temperature sensor. Calibration: New CF_TEMP = Old CF_TEMP x (Thermometer[°C] / SBData Temperature[°C]) Note: SBData Temperature 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. SBData Current[mA] = (I_A/D - CO_CURR - COD) x CF_CURR / 16384 Calibration: CF_CURR = ((Ammeter[mA] x 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. SBData Voltage[mV] = (V_A/D - CO_VOLT) x CF_VOLT / 2048 Calibration: New CF_VOLT = Old CF_VOLT x (Voltmeter[mV] / SBData Voltage[mV])
COVPack	EE	1	-128	127	0	Correction Offset for Voltage. Offset factor used for pack voltage reading.

9.0 ELECTRICAL CHARACTERISTICS

TABLE 9-1: ABSOLUTE MAXIMUM RATINGS

Symbol	Parameter	Min	Max	Units
V_{CX}	Voltage at any VC(x) pin	-0.5	18.5	V
V_{PIN}	Voltage directly at any pin (except V_{CELLX})	-0.5	7.0	V
T_{BIAS}	Temperature under bias	-20	85	°C
$T_{STORAGE}$	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 (T_A = -20°C TO +85°C; V_{REG} (INTERNAL) = +5.0V ±10%)

Symbol	Characteristic	Min	Typ	Max	Units	Condition
V_{SUPPLY}	Supply Voltage – Applied to VC(1)	5.6		18.0	V	
V_{DDA}	Supply Voltage – (Output from internal regulator on V_{DDA} pin)	4.5	5.0	5.5	V	**(Note 1)**
I_{DD}	Instantaneous Supply Current		375	400	µA	**(Note 2)**
I_{DDRUN}	Average Supply Current – Run mode		300	385	µA	A/D Active **(Note 2)**
I_{DDINS}	Inactive Supply Current – Sample mode		225	250	µA	A/D Inactive **(Note 2, 3)**
$I_{DDSLEEP}$	Average Supply Current – SLEEP mode		12	18	µA	SLEEP mode **(Note 2)**
I_{WAKE}	Wake-up Current Threshold from SLEEP mode – (Voltage across sense resistor)	2.50	3.75	5.00	mV	
V_{IL}	Input Low Voltage – GPIO(7-0)			0.2* V_{DDD}	V	
V_{IH}	Input High Voltage – GPIO(7-0)	0.8* V_{DDD}			V	
$I_{IL-IOPU}$	GPIO Input Low Current – Pull-up mode	-80	-110	-140	µA	
$I_{IH-IOPD}$	GPIO Input High Current – Pull-down mode	70	105	140	µA	
I_L	Leakage Current – GPIO pins programmed as outputs		1	2	µA	
V_{OL}	Output low voltage for GPIO(7-0)			0.4	V	I_{OL} = 0.5 mA
V_{OH-IO}	Output high voltage for GPIO(7-0) (non-LED mode)	2.0			V	I_{OH} = 100 µA
V_{OH-LED}	Output high voltage for GPIO(7-0) (LED mode)	2.0			V	I_{OH} = 10 mA **(Note 4)**
V_{SR}	Sense Resistor Input Voltage Range	-152		152	mV	
V_{NTC}	Thermistor Input Voltage Range	0		152	mV	
V_{REFT}	NTC Reference voltage output at V_{REFT} pin		150		mV	
V_{IL-SMB}	Input Low Voltage for SMBus pins	-0.5		0.8	V	
V_{IH-SMB}	Input High Voltage for SMBus pins	2.0		5.5	V	
V_{OL-SMB}	Output Low Voltage for SMBus pins			0.4	V	I_{PULLUP} = 350 µA
V_{OH-SMB}	Output High Voltage for SMBus pins	2.1		5.5	V	
$I_{PULLUP-SMB}$	Current through pullup resistor or current source for SMBus pins	100		350	µA	
$I_{LEAK-SMB}$	Input leakage current – SMBus pins			± 5	µA	

Note 1: V_{REG} is the on-chip regulator voltage. It is internally connected to analog supply voltage and is output on the V_{DDA} pin.
2: Does not include current consumption due to external loading on pins.
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 = (I_{DDRUN} + (n-1)*I_{DDINS})/n; where "n" is the programmed sample rate.
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 (T_A = -20°C TO +85°C; V_{REG} (INTERNAL) = +5.0V ±10%)

Symbol	Characteristic	Min	Typ	Max	Units	Condition
df_{RC}	Internal RC oscillator frequency	509	512	515	kHz	
$f_{A/D}$	Internal A/D operating clock		$f_{RC}/10$		ms	
t_{CONV}	A/D Conversion measurement time, n-bit+sign		$2^n/f_{A/D}$		ms	

TABLE 9-4: AC CHARACTERISTICS – SMBUS (T_A = -20°C TO +85°C; V_{REG} (INTERNAL) = +5.0V ±10%)

Symbol	Characteristic	Min	Typ	Max	Units	Condition
f_{SMB}	SMBus clock operating frequency	<1.0		100	kHz	Slave mode
$f_{SMB-MAS}$	SMBus clock operating frequency	50	$f_{RC}/8$	68	kHz	Master mode **(Note 1)**
t_{BUF}	Bus free time between START and STOP	4.7			µs	
t_{SHLD}	Bus Hold time after Repeated START	4.0			µs	
$t_{SU:STA}$	Setup time before Repeated START	4.7			µs	
$t_{SU:STOP}$	STOP setup time	4.0			µs	
t_{HLD}	Data hold time	300			ns	
t_{SETUP}	Data setup time	250			ns	
$t_{TIMEOUT}$	Clock low time-out period	25		35	ms	**(Note 2)**
t_{LOW}	Clock low period	4.7			µs	
t_{HIGH}	Clock high period	4.0		50	µs	**(Note 3)**
$t_{LOW:SEXT}$	Message buffering time			25	ms	**(Note 4)**
$t_{LOW:MEXT}$	Message buffering time			10	ms	**(Note 5)**
t_F	Clock/data fall time			300	ns	**(Note 6)**
t_R	Clock/data rise time			1000	ns	**(Note 6)**

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 $t_{TIMEOUT}$, Min of 25 ms. The PS401 will reset the communication no later than $t_{TIMEOUT}$, Max of 35 ms.

3: t_{HIGH} Max provides a simple method for devices to detect bus IDLE conditions.

4: $t_{LOW:SEXT}$ 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: $t_{LOW:MEXT}$ 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:
$t_R = (V_{IL_{MAX}} - 0.15)$ to $(V_{IH_{MIN}} + 0.15)$
$t_F = 0.9\ V_{DD}$ to $(V_{IL_{MAX}} - 0.15)$

TABLE 9-5: A/D CONVERTER CHARACTERISTICS (T_A = -20°C TO +85°C; V_{REG} (INTERNAL) = +5.0V ±10%)

Symbol	Characteristic	Min	Typ	Max	Units	Condition
AD_{RES}	A/D Converter Resolution	8		15	bits	**(Note 1)**
V_{ADIN}	A/D Converter Input Voltage Range (Internal)	-152		152	mV	Differential mode
		0		300	mV	Single-Ended mode
E_{VGAIN}	Supply Voltage Gain Error			0.100	%	
$E_{VOFFSET}$	Compensated Offset Error			0.100	%	
E_{TEMP}	Temperature Gain Error			0.100	%	
E_{INL}	Integrated Nonlinearity Error			0.004	%	

Note 1: Voltage is internal at A/D converter inputs. V_{SR} and V_{NTC} are measured directly. $V_C(x)$ 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

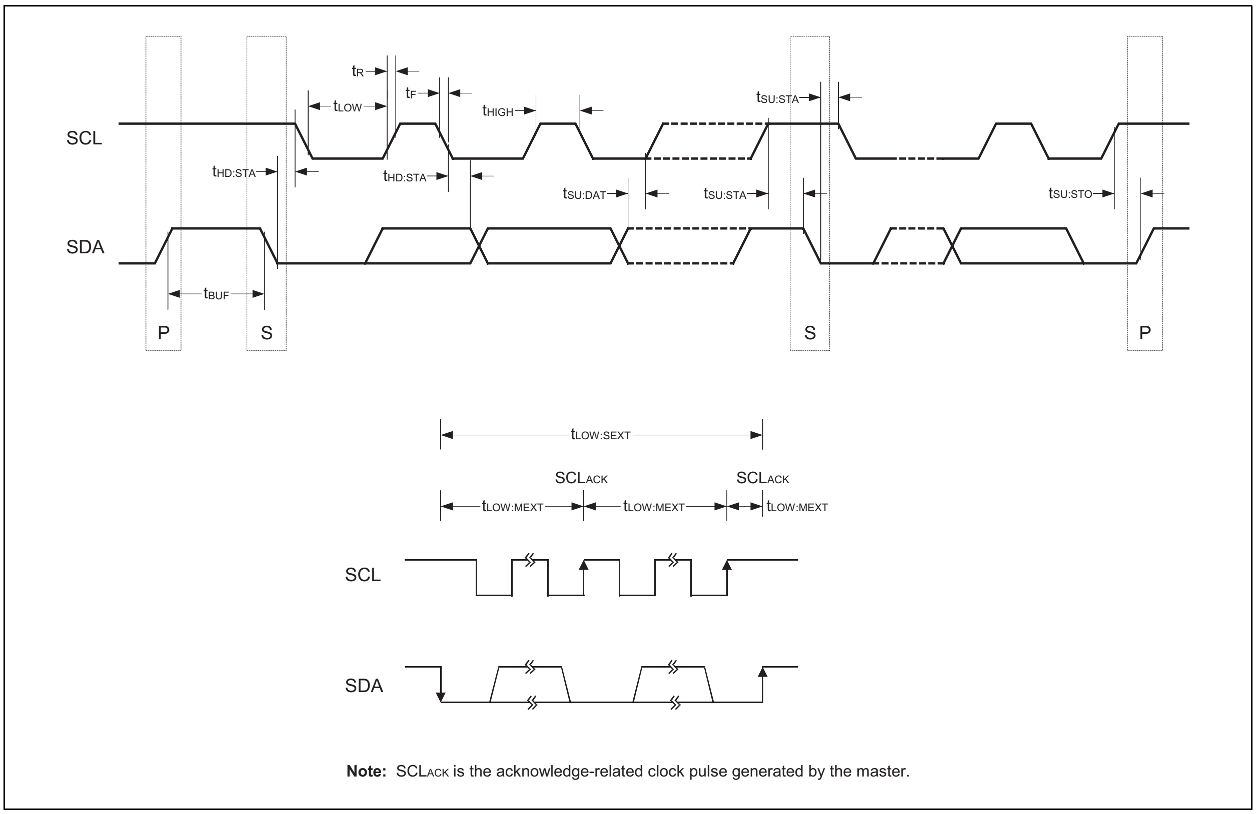
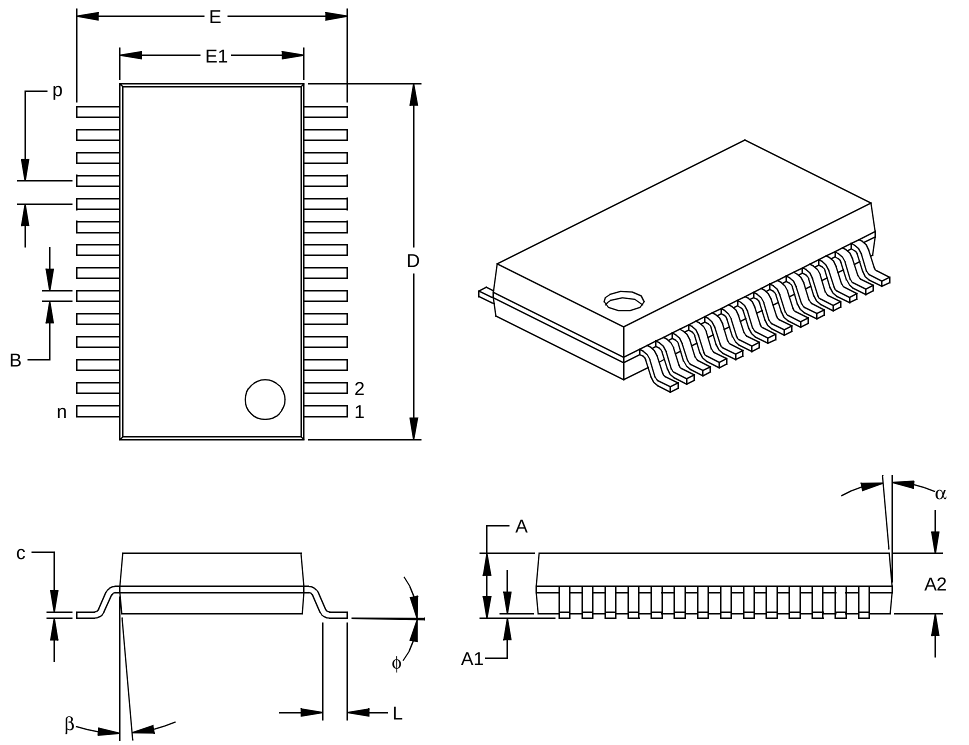


TABLE 9-6: SILICON TIME BASE CHARACTERISTICS (T_A = -20°C TO +85°C; V_{REG} (INTERNAL) = +5.0V ± 10%)

Symbol	Characteristic	Min	Typ	Max	Units	Condition
E_{TIME}	Silicon time base error			0.25	%	Bias Resistor R_{OSC} tolerance = 1% T_L = ± 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

NOTES:

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