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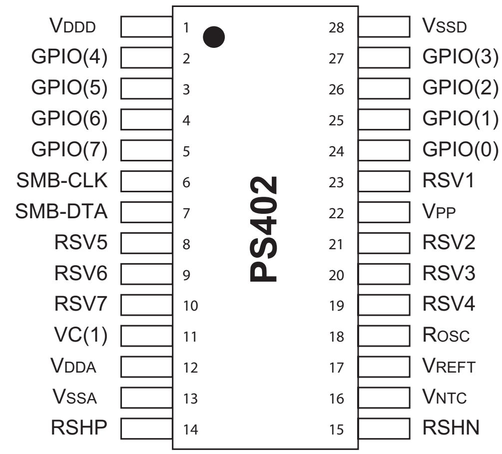
Single Chip Battery Manager – Nickel Chemistries

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

1.0 PRODUCT OVERVIEW

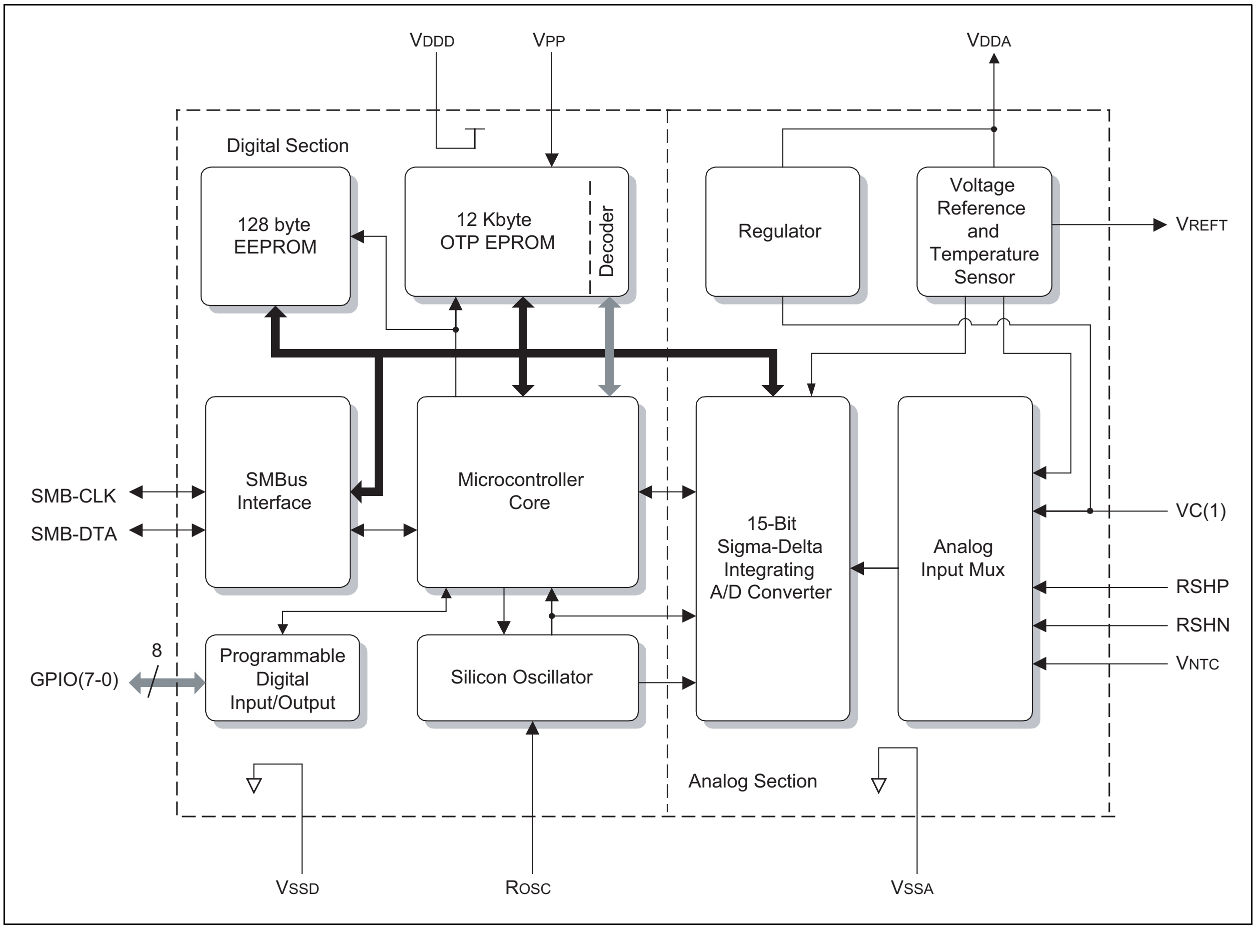
The PS402 is a fully integrated IC for battery management that combines a proprietary microcontroller core together with monitoring/control algorithms and 3D cell models stored in 12 Kbytes of on-chip OTP EPROM. Additional features include: precision 15-bit A/D and mixed signal circuitry. On-chip EEPROM 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.

The PS402 can be configured to accommodate all Nickel rechargeable battery chemistries, including Nickel Metal Hydride and Nickel Cadmium.

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 PS402 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: PS402 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 PS402 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 PS402 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 PS402 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 PS402 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 PS402 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 PS402. 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 battery packs. Alternatively, they can be used as general purpose input/outputs.

TABLE 1-1: PIN DESCRIPTIONS

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	RSV5	Reserved – Must be connected to ground.
9	RSV6	Reserved – Must be connected to ground.
10	RSV7	Reserved – Must be connected to ground.
11	VC(1)	(Input) Pack voltage input.
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 PS402 A/D converter measures voltage, current and temperature and integrates the current over time to measure State-Of-Charge. The voltage of the entire pack is monitored and the pack is 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/R_{SENSE} (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:

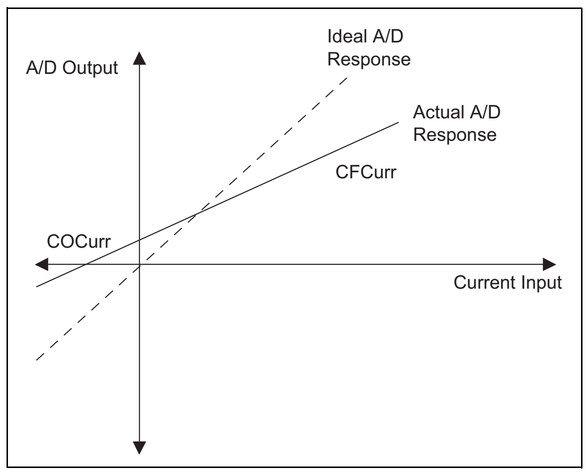
I_A/D is the internal measurement.

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 channel for pack voltage measurements is the VC(1) pin. Measurements are taken each measurement period when the A/D is active. The maximum voltage at the VC(1) input pin is 18.5V absolute, but voltages above 18V are not suggested. The pack voltage is measured with an integration method to reduce any sudden spikes or fluctuations. The A/D uses an 11-bit Resolution mode for these measurements.

The pack voltage input is read once per measurement period in Run mode. Voltage readings occur less frequently in Sample 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.)

2.3.1 IMPEDANCE COMPENSATION

Since accurate measurement of pack voltage is 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 since the ground reference point for the measurement is on the side of the current sense resistor.

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:

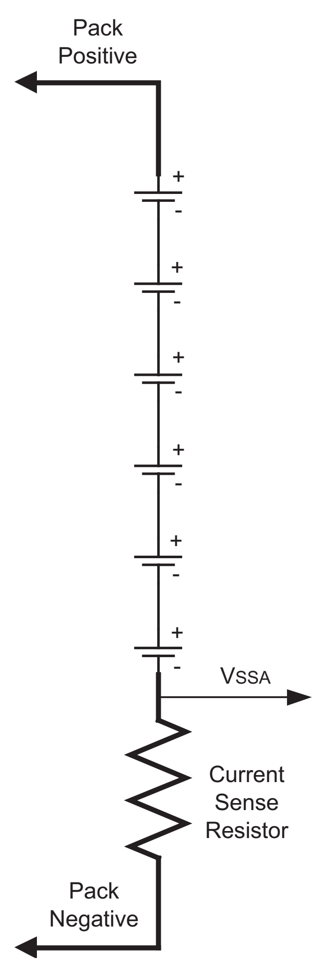
V (mV) = (V_A/D – **COVPack**) x **CFVPack**/2048

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

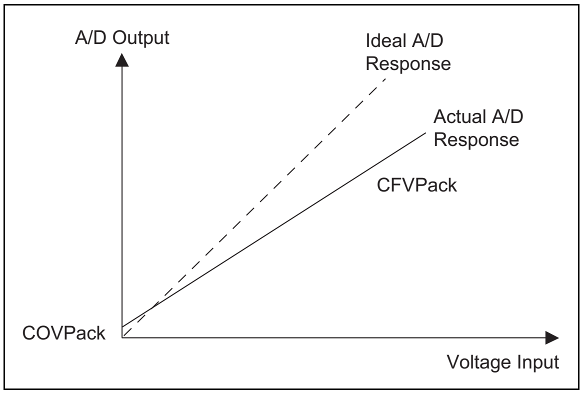


CFVPack is the "Correction Factor for Pack Voltage" which compensates for any variance in the actual A/D response versus an ideal A/D response over varying voltage inputs.

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.

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 look-up 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. End-Of-Charge temperature readings are disabled during LED displays, following a switch press, in order to minimize effects of LED self-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 PS402 operates on a continuous cycle, as illustrated in Figure 3-1. The frequency of the cycles depend 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 PS402 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.

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

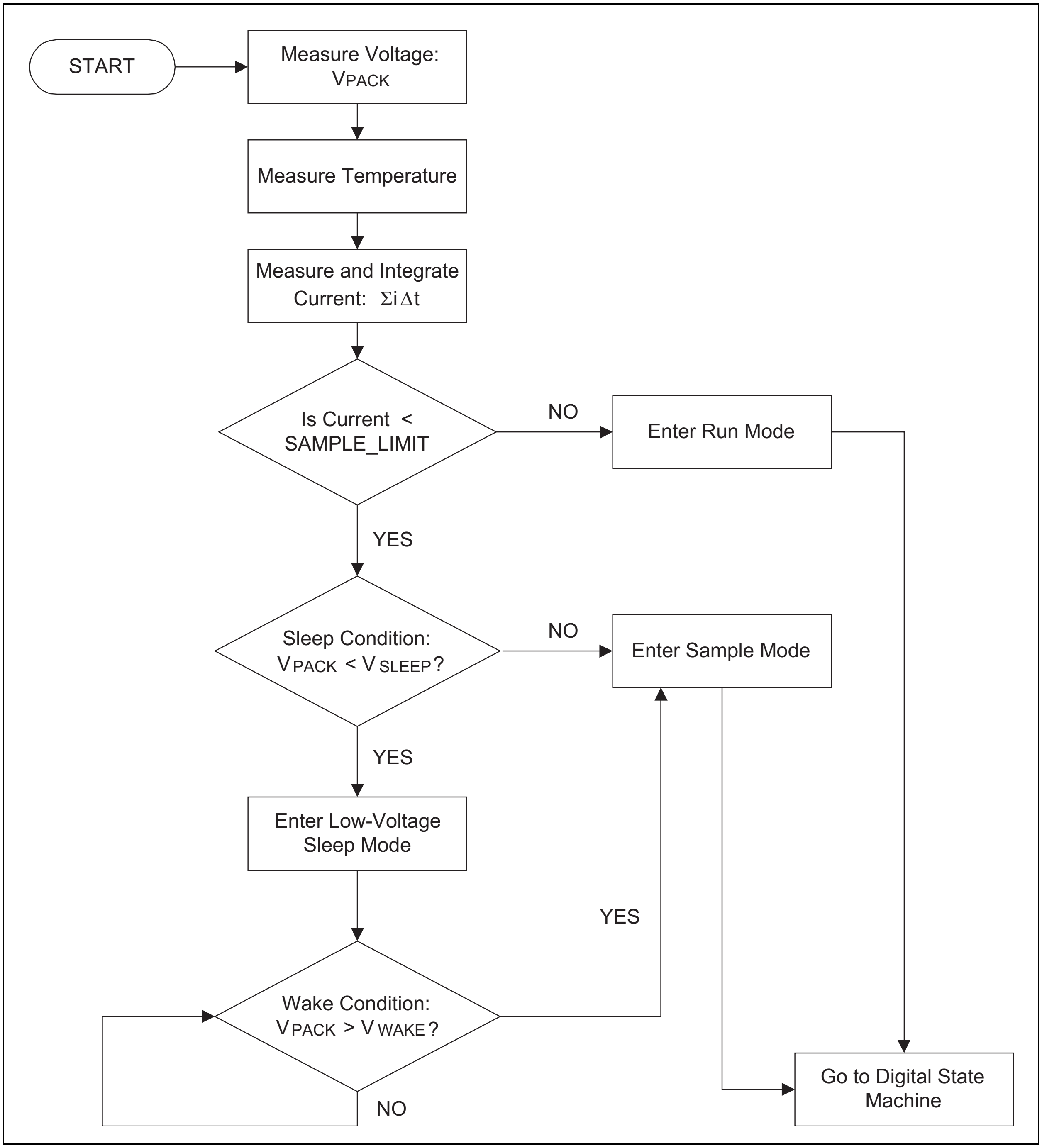
TABLE 3-2: WakeUp VOLTAGE

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: PS402-01XX OPERATIONAL CYCLE FLOW CHART



4.0 CAPACITY MONITORING

The PS402 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 PS402 creates an accurate fuel gauge under all battery conditions.

4.1 Capacity Calculations

The PS402 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 PS402 is able to provide run-time accuracy with less than 1% error.

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

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

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

Since the PS402 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 PS402 device’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 (PS402 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 PS402 and the self-discharge terms are also always subtracted. The SBData value MaxError is the total accumulated error as the gas gauge is running.

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

FIGURE 4-1: CHARGE INCREASING FLOW CHART

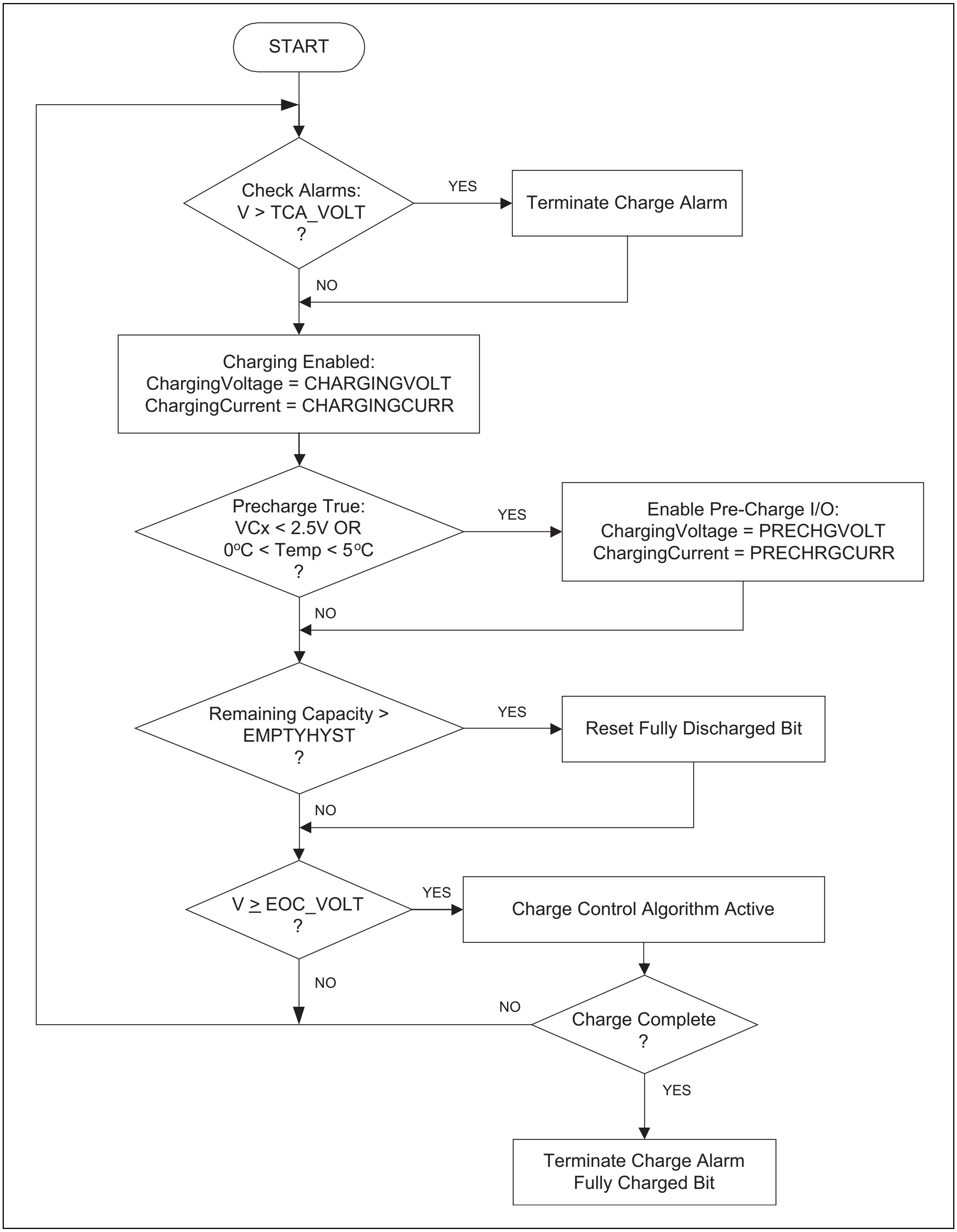
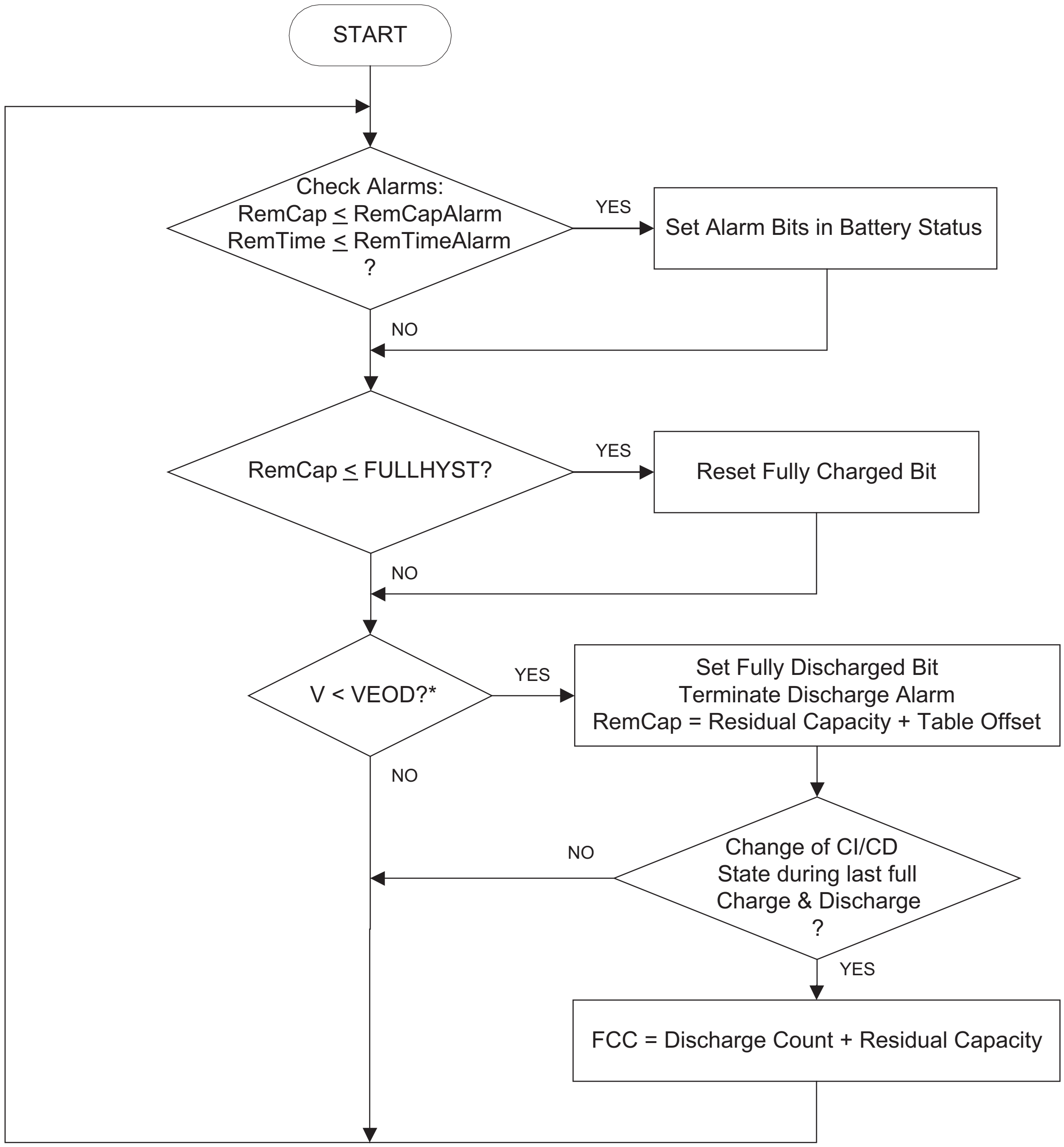
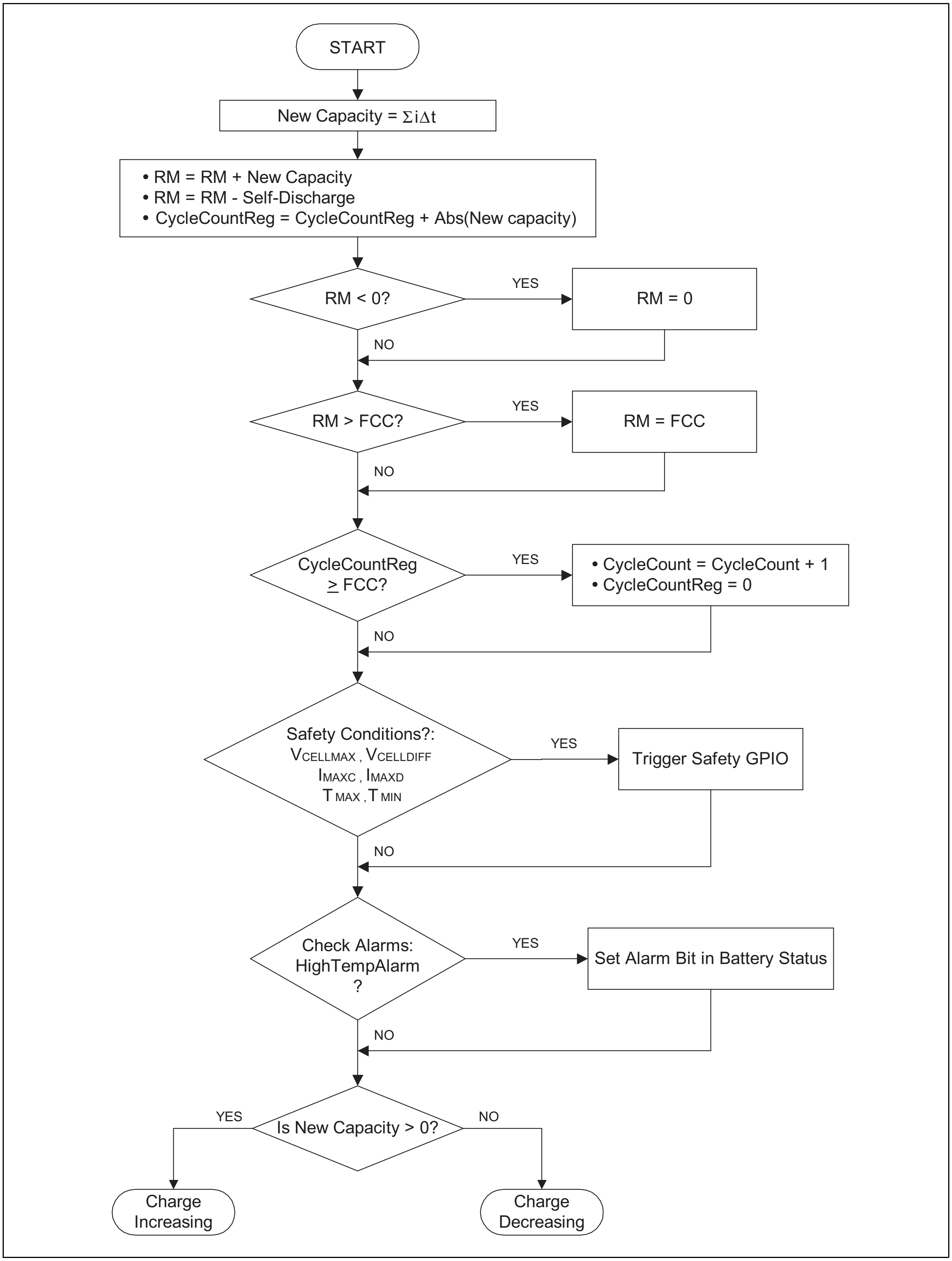


FIGURE 4-2: CHARGE DECREASING FLOW CHART



*VEOD can be constant or can vary with temperature and discharage rate

FIGURE 4-3: DIGITAL CALCULATION FLOW CHART



The PS402 will monitor temperature and discharge rate continuously and update the EOD voltage in real-time. When the voltage measured on the cell is below **EOD voltage** for duration of **EODRecheck** x periods, a valid EOD has occurred.

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

Additionally, the REMAINING_TIME_ALARM and/or REMAINING_CAPACITY_ALARM bits can be set first to give a user defined early warning prior to the TERMINATE_DISCHARGE_ALARM.

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

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

4.3 EOD Voltage Look-up Table

4.3.1 SAVE TO DISK POINT

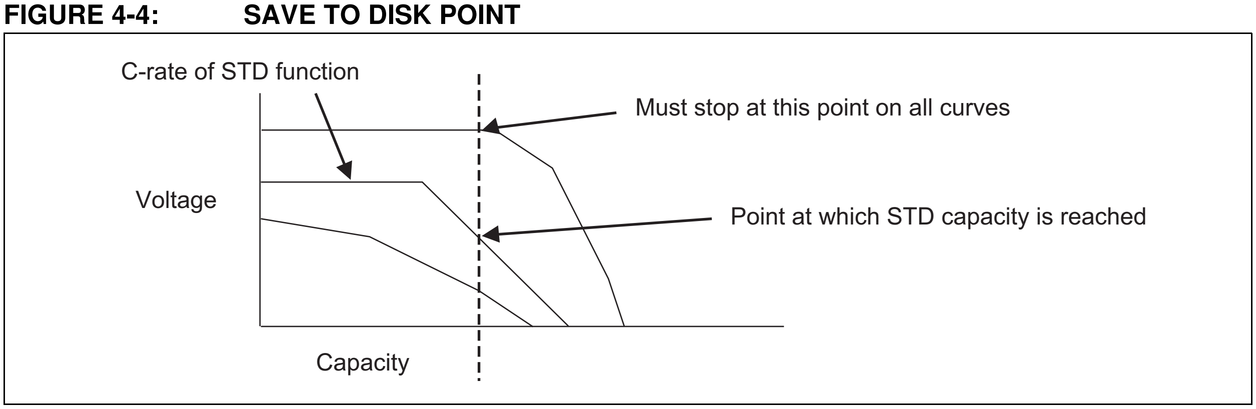
As the graph in Figure 4-4 shows, available capacity in the battery varies with temperature and discharge rate. Since the remaining capacity will vary, the save to disk point of a PC will also vary with temperature and discharge rate.

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 PS402 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 4-4 shows that the system will always shutdown 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.

FIGURE 4-4: SAVE TO DISK POINT



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 PS402 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.

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.

The 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 LOOK-UP 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 TEOD$_X$ = (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: CEOD$_X$ = C-rate * (256/28/R$_F$), where R$_F$ is the Rate Factor (R$_F$actor) OTP EPROM parameter. For R$_F$ = 7, CEOD$_X$ = 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 = 8000 + 4 * VEOD. Pack voltage at which save to disk is signaled.		

5.0 CHARGE CONTROL

The PS402 can control charging using SMBus broadcasts of required charging current and charging voltage to the charger. The PS402 monitors pack voltage and temperature to determine the battery full End-Of-Charge (EOC) condition. There are three possible fully charged EOC conditions that are monitored according to control parameters. These methods are designed to detect a fully charged battery over a range of operating temperatures and charge rates.

5.1 Temperature EOC

The rate of rise of the battery temperature is the first and primary full charge detection mechanism. This is a well known method used for Nickel-based chemistries and is commonly referenced as the “dT/dt” method (delta-Temperature over delta-time.) The rate of temperature rise over a finite period of time is continually monitored. A rapid increase at an inflection point is detected as End-Of-Charge point. This inflection point is usually seen just before a fully charged state so the resulting State-Of-Charge (SOC) Reset may be slightly less than 100%. Typically, a dT/dt rate of 1°C per minute can accurately detect the 95% full point when used with charging rates near the 1C or 1 hour rate. Although this method is active during any charge rate, it typically only occurs for charge rates of 0.8C or higher.

All of the control parameters regarding a temperature (dT/dt) EOC are available for customizing.

TABLE 5-1: dT/dt CONTROL PARAMETERS

Parameter	Description
DtEOCSOC (EE)	SOC Reset value when a dT/dt EOC condition occurs
NDtVSample (EE)	Delay between temperature samples
NDelayEOC (EE)	Time that EOC detection is delayed after Start-Of-Charge
EOCDeltaT (EE)	Minimum temperature change between two samples to cause EOC

5.2 Voltage Drop EOC

The second full charge detection mechanism looks for a negative voltage drop after reaching a peak. This is also an established method for Nickel-based chemistries and is termed the “-dV” method (negative delta-V). Just at the point of full charge, the voltage profile of the battery cells will start to drop from a peak value. This drop, if measured while the current remains stable, indicates a 100% full charge condition. Generally, a -10 mV per cell drop occurs. Charge rates above 0.5C are typically required to cause this method to be observed. This voltage drop method looks for a total pack voltage drop. If the charge current is stable and the voltage drops the programmed amount, a full charge EOC is signaled. All of the control parameters regarding a voltage drop (-dV) EOC are available for customizing.

TABLE 5-2: -dV CONTROL PARAMETERS

Parameter	Description
DvCRate (EE)	Minimum C-rate required to enable -dV EOC
StableCurr (OTP)	Charge current stability factor to enable -dV EOC
NDtVSample (EE)	Delay between voltage samples
NDelayEOC (EE)	Time that EOC detection is delayed after Start-Of-Charge
EOCDeltaV (EE)	Minimum voltage drop between two samples to cause EOC

5.3 Fixed Overcharge EOC

When charging at low rates, neither of the previously mentioned full charge EOC conditions may occur. Since there are no signals from the battery temperature, voltage, or current to aid in determining a full charge a simple ‘count’ mechanism is used. By simply integrating the total charge that has entered the battery cells, a fixed amount of overcharge can signal a full charge EOC condition. For Nickel-based chemistries this varies between 20 and 50% of their rated capacity. Typically, at charge rates less than 0.4C neither the dT/dt or -dV EOC methods will occur. An accumulated charge of 120 to 150% of the last full charge capacity is a good indicator of full charge. This fixed amount of overcharge method is reliable for low rate charging or long term charging since it effectively serves as a charge timer as well. All of the control parameters regarding a fixed overcharge EOC are available for customizing.

TABLE 5-3: FIXED OVERCHARGE CONTROL PARAMETERS

Parameter	Description
EOCRateMax (EE)	Maximum C-rate required to enable overcharge EOC
StableCurr (OTP)	Charge current stability factor to enable -dV EOC
NDelayEOC (EE)	Time that EOC detection is delayed after Start-Of-Charge
SOCThreshold (OTP)	SOC to cause a valid overcharge EOC

5.4 Temperature Algorithms

The PS402 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**, charging is disabled. When the system is charging and the measured temperature is greater than **ChrgMaxTemp**, charging will be disabled. Similarly, when the system is discharging and the temperature is greater than **DischrgMaxTemp** discharging will be disabled.

If the ChrgMaxTemp threshold (typically 60°C) is exceeded, then charging will not be enabled until the pack temperature has dropped below 50°C.

6.0 GPIO CONFIGURATION

6.1 Safety Condition Programming

There are 5 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" conditions or any "OR" condition is true.

Example:

If _AND byte is set to 18h and _OR byte is set to 02h, then the OUTPUTx pin is active only if:

[(VPACK > SafetyMaxVPack) **AND** (Temperature > SafetyMaxTemp)] **OR** [Icharge > SafetyIMaxC]

6.2 Charge Control Programming

The PS402-01XX supports programming of charge control functions on the GPIO pins.

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 6-2:

TABLE 6-1: GPIO SAFETY CONDITIONS

OR Byte Bit	AND Byte Bit	Safety Condition	Description
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 CONTROL CONDITIONS

OR Byte Bit	AND Byte Bit	Charge Control Condition	Description
14	6	TerminateChargeAlarm active	TerminateChargeAlarm
13	5	Fully Charged bit set	Fully Charged bit set in BatteryStatus
12	4	SOC > **MaxSOC**	Overcharge – SOC rises above **MaxSOC**
11	3	Temperature > **SafetyMaxTemp**	Temperature rises above **SafetyMaxTemp**
10	2	Temperature < **PrechargeTemp**	**PrechargeCurr** is required
9	1	INPUT pin activated	GPIO pin is triggered
8	0	VPACK < **PrechargeVPack**	**PrechargeCurr** is required

7.0 SMBus/SBData INTERFACE

The PS402 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 PS402 automatically. The SMBus protocol is explained in this chapter. The SBData command set is summarized in Table 7-1.

The PS402 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 PS402 meets and exceeds the Smart Battery Data Specification, Version 1.1/1.1a requirements. The PS402 is compliant with System Management Bus Specification 1.0.

The PS402 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 PS402 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	Code
ManufacturerAccess-Read	0x00	R/W	Chip 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
FirmwareInfo (Note 1)	0x1d	Read	FW Version & PW1, PW2	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		
OptionalMfgFunction3	0x3d	Read		
OptionalMfgFunction2	0x3e	Read		
OptionalMfgFunction1	0x3f	Read		
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, AtRateTime-ToEmpty 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 AtRateTimeTo Full 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. Also, information broadcasting is disabled in the PS4XX-04XX.

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 PS402 does not implement this function.