PS810

Li Ion Single Cell Fuel Gauge

Hardware Features

- Highly accurate fuel gauge for single cell Li Ion applications
- Algorithms are implemented using an embedded PIC18 low-power microcontroller with 16-bit instruction set
- Reports current, voltage and temperature utilizing a programmable 8 to15-bit + sign, sigma-delta ADC
- Host communication accomplished through an industry standard SMBus interface or an alternative single pin serial interface
- I/O pins are available to provide functions such as digital GPIO, coin cell voltage measurement and thermistor input
- Integrated temperature sensor and regulator minimize external components
- Embedded fuel gauge algorithms and application specific parameters are stored in a 4K x 16 Flash memory
- 512 bytes of RAM are available for temporary storage of battery parameters

Software Features

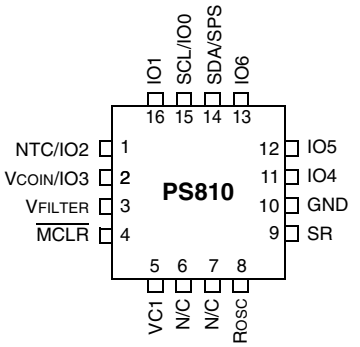
- Provides battery status, such as average time to empty, relative State-Of-Charge and battery State-Of-Health
- In-system offset calibration compensates for offset error in current measurement

Package Features

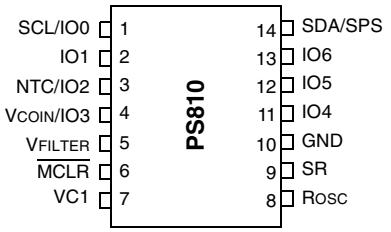
- 16-pin QFN package or 14-pin TSSOP package
- -20°C to +85°C operating temperature range

Pin Description

16-pin QFN (4 mm x 4 mm)



14-pin TSSOP



1.0 PRODUCT OVERVIEW

The PS810 is a fuel gauge for one-cell Li Ion or Li Polymer applications. The device provides the host and the system user with critical battery information, such as voltage, current, temperature, run time, State-Of-Charge and State-Of-Health. This information is available through an industry standard SMBus or an alternative Single Pin Serial interface. Advanced fuel gauge algorithms are stored in on-board Flash memory and executed by the industry recognized PIC18 microcontroller. These algorithms include compensation factors which optimize the performance of the battery for a specific application and operating environment. Compensation is included for the effects of temperature, discharge rate, charge rate and battery aging.

To provide precise measurements of current, voltage and temperature, the PS810 integrates a highly accurate 15-bit + sign, sigma-delta A/D converter. Based upon operating conditions, this programmable converter can be configured to measure specific battery parameters with a resolution of 8 to 15 bits + sign. Precision measurements combined with advanced algorithms provide accurate indications of capacity, run time, State-Of-Health and safety and charge/discharge conditions.

The ability to operate directly from a single Li Ion or Li Polymer cell minimizes the need for external components, such as a voltage regulator and voltage divider. To further limit external circuitry and enhance accuracy, the PS810 provides an integrated temperature sensor and oscillator.

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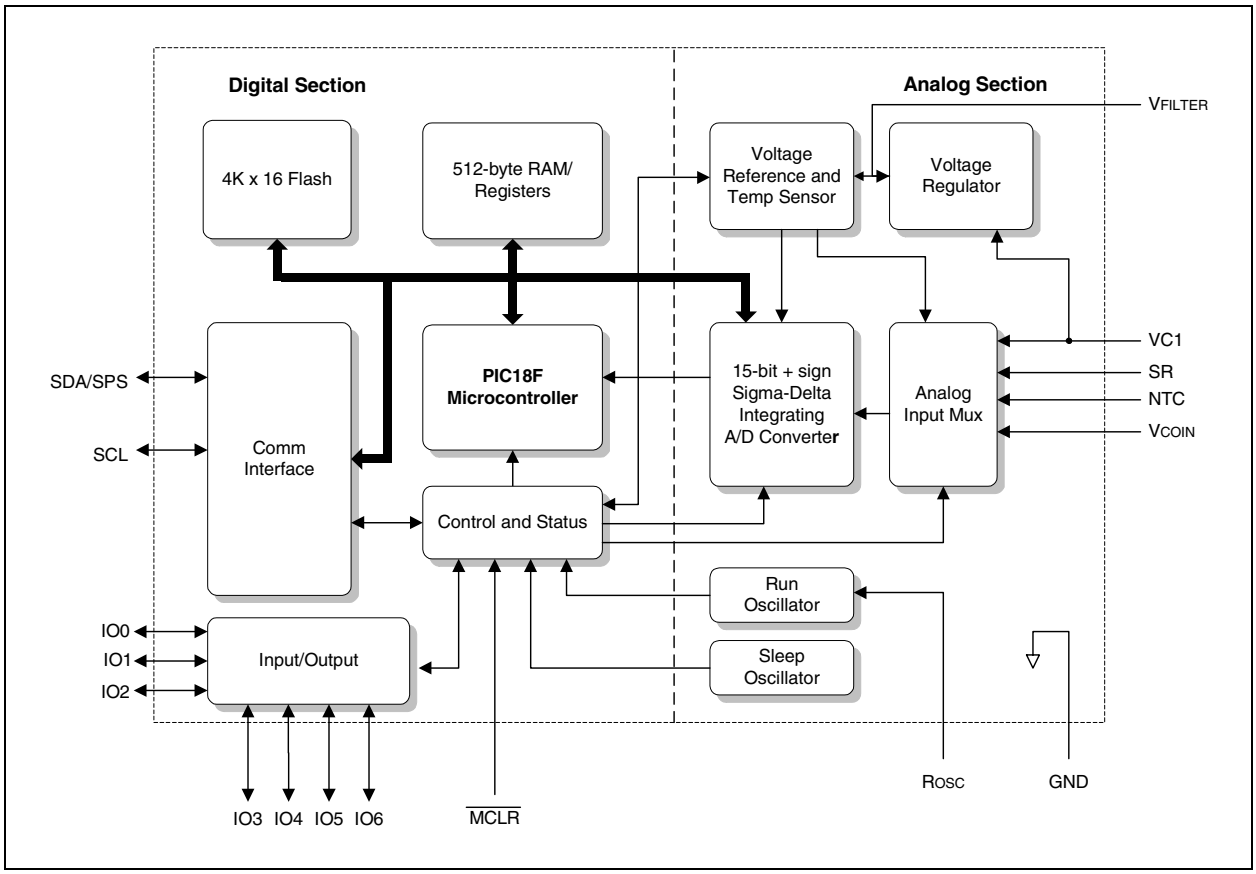
TABLE 1-1: PS810 QFN PIN SUMMARY

Pin#	Pin Name	Description
1	NTC/IO2	External NTC input or GPIO
2	VCOIN/IO3	Coin cell monitor input or GPIO
3	VFILTER	Power supply filter cap
4	$\overline{\text{MCLR}}$	Master Clear
5	VC1	Cell voltage input
6	N/C	No connect
7	N/C	No connect
8	ROSC	Oscillator bias resistor
9	SR	Sense resistor input
10	GND	Power supply ground
11	IO4	General purpose IO
12	IO5	General purpose IO
13	IO6	General purpose IO
14	SDA/SPS	SMBus data/one-wire serial line
15	SCL/IO0	SMBus clock or GPIO0
16	IO1	General purpose IO

TABLE 1-2: PS810 TSSOP PIN SUMMARY

Pin#	Pin Name	Description
1	SCL/IO0	SMBus clock or GPIO
2	IO1	General purpose IO
3	NTC/IO2	External NTC input or GPIO
4	VCOIN/IO3	Coin cell monitor input or GPIO
5	VFILTER	Power supply filter cap
6	$\overline{\text{MCLR}}$	Master Clear
7	VC1	Cell voltage input
8	ROSC	Oscillator bias resistor
9	SR	Sense resistor input
10	GND	Power supply ground
11	IO4	General purpose IO
12	IO5	General purpose IO
13	IO6	General purpose IO
14	SDA/SPS	SMBus data/one-wire serial line

FIGURE 1-1: PS810 INTERNAL BLOCK DIAGRAM



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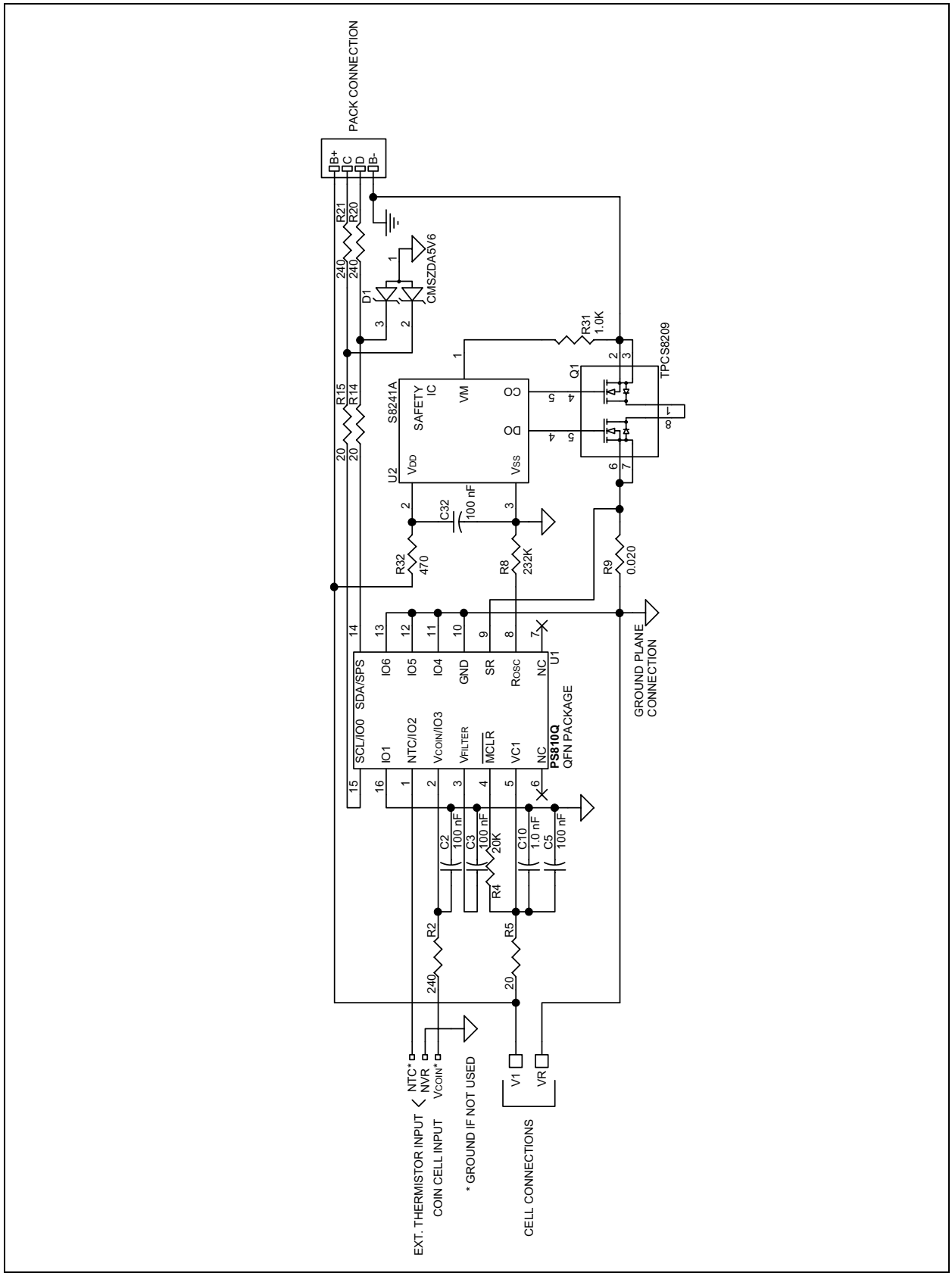
1.1 Schematic

FIGURE 1-2: PS810 APPLICATION SCHEMATIC – PS810-BASED BATTERY PACK



1.2 Bill of Materials

TABLE 1-3: PS810 BILL OF MATERIALS

ID	Part Number	Symbol	Description	Mftr.	Mftr. PN	Supplier	Supplier PN	Qty
1	04-826197 Rev. 1.1		Raw PCB, PS8110	Microchip	04-826197 Rev. 1.1	Microchip	04-826197 Rev. 1.1	1
2	CC-0402-10X7R25-1.0NF-01	C10	Capacitor, Ceramic, 1.0 nF, 25V, +/-10%, X7R dielectric, 0402	Panasonic	ECJ-0EB1E102K	Digikey	PCC102BQCT-ND	1
3	CC-0603-10X7R16-100NF-01	C2, C3, C5, C32	Capacitor, Ceramic, 100 nF, 16V, +/-10%, X7R dielectric, 0603	Panasonic	ECJ-1VB1C104K	Digikey	PCC1762CT-ND	4
4	DZ-SOT323-10D-CMSZDA5V6-01	D1	Dual Zener Diode, 5.6V, +/-10%, 200 mW, common anode, SOT-323	Central Semi. Diodes Inc.	CMSZDA5V6 AZ23C5V6W-7	Central Semi. Diodes Inc.	CMSZDA5V6 AZ23C5V6W-7	1
5	QM-TSSOP844-DN-TPCS8209-01	Q1	MOSFET, dual N-channel Enhancement mode, 20V, 5A, TSSOP-8/4.4 mm body width package	Toshiba	TPCS8209(TE12L)	Digikey	TPCS8209CT-ND	1
6	RF-0402-5-20-01 **(Note 1)**	R14, R15	Resistor, film, 0402, 5%, 20 ohms	Panasonic	ERJ-2GEJ200X	Digikey	P20JCT-ND	2
7	RF-0402-5-20K-01 **(Note 1)**	R4	Resistor, film, 0402, 5%, 20 kOhms	Panasonic	ERJ-2GEJ203X	Digikey	P20KJCT-ND	1
8	RF-0603-ITC25-221K-01 **(Note 1)**	R8	Resistor, film, 0603, 1%, 232 kOhms, 25 ppm TC	Susumu Co. Ltd.	RR0816P-2213-D-34D	Digikey	RR08P221KDCT-ND	1
9	RF-0603-5-1.0K-01 **(Note 1)**	R31	Resistor, film, 0603, 5%, 1.0 kOhms	Panasonic	ERJ-3GEYJ102V	Digikey	P1.0KGCT-ND	1
10	RF-0603-5-470-01 **(Note 1)**	R32	Resistor, film, 0603, 5%, 470 ohms	Panasonic	ERJ-3GEYJ471V	Digikey	P470GCT-ND	1
11	RF-0805-5-20-01 **(Note 1)**	R5	Resistor, film, 0805, 5%, 20 ohms	Panasonic	ERJ-6GEYJ200V	Digikey	P20ACT-ND	1
12	RF-0805-5-240-01 **(Note 1)**	R2, R20, R21	Resistor, film, 0805, 5%, 240 ohms	Panasonic	ERJ-6GEYJ241V	Digikey	P240ACT-ND	3
13	RF-1206-1-0.029-01 **(Note 1)**	R9	Resistor, metal strip, 1206, 1%, 0.020 ohms	Vishay	WSL1206-0.020-1%-R86	Vishay	WSL1206-0.020-1%-R86	1
14	UM-SOT235-4085-S8241ABPMCGBPT2-01	U2	IC, Battery Protection Circuit, Li Ion, 1-cell, -40°C to +85°C, SOT23-5 package	Seiko Instruments	S-8241ABPMC-GBP-T2 **(Note 2)**	Seiko Instruments	S-8241ABPMC-GBP-T2 **(Note 2)**	1
15	UM-QFN164X4-2085-PS810-01	U1	IC, Low-Voltage Fuel Gauge, -20°C to +85°C, QFN-16/ 4.0x4.0 mm package	Microchip	PS810	Microchip	PS810	1

Note 1: Resistor sizes shown are minimum recommended sizes for the application.

2: Other variants of the S-8241A series, with different trip points, are also available. Consult the S-8241A series data sheet.

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2.0 ARCHITECTURAL OVERVIEW

The PS810 contains a complete analog “front-end” for battery monitoring as well as an embedded micro-controller, with supporting memory, for control, measurement accumulation, calculation and communications. Major functions within the PS810 include:

- Voltage Regulator
- Precision Time Base
- Temperature Sensor
- 4K x 16 Flash Memory
- 512-byte RAM Memory
- 15-bit plus sign Analog-to-Digital (A/D) Converter
- SMBus/I^{2}C™ or Single Pin Serial Communications Interface
- PIC18 Microcontroller

Figure 1-1 is a block diagram of the internal circuitry of the PS810. Figure 1-2 is a schematic diagram that depicts the PS810 in a typical single cell lithium ion application. The function of each of the blocks listed above is summarized in the following sections.

2.1 Internal Voltage Regulator

The PS810 incorporates an internal voltage regulator that supports 1-cell lithium pack configurations. The internal regulator draws power directly from the VC1 input. No other external components are required to regulate circuit voltage.

2.2 Precision Time Base

The integrated precision time base is a highly accurate RC oscillator that provides precise timing for the sigma-delta A/D and for the on-chip elapsed time counters without the need for an external crystal. This time base is trimmed during manufacturing to a nominal frequency of 512 kHz.

2.3 Temperature Sensor

An integrated temperature sensor is provided that can eliminate the need for an external thermistor. As an option, a connection is provided for an external thermistor for applications where the battery cell is physically separated from the PS810.

2.4 Flash Memory

4K x 16 of Flash memory is incorporated for storage of nonvolatile parameters, such as PowerSmart® 3D cell models, fuel gauge algorithms and application specific data.

2.5 RAM Memory

512 bytes of general purpose RAM memory is provided for storage of temporary parameters.

2.6 A/D Converter

The PS810 incorporates an integrating sigma-delta A/D converter together with an analog that has inputs for charge and discharge current, cell voltage, coin cell voltage, the on-chip temperature sensor and an off-chip thermistor. The converter can be programmed to perform a conversion with resolutions of 8 to 15 bits + sign, while utilizing either a single-ended +300 mV or a differential ±150 mV reference.

2.7 SMBus/I^{2}C™ or Single Pin Serial Communications Interface

This communications port for the PS810 is selectable as a 2-pin industry standard SMBus/I^{2}C or a single pin interface. All commands, status and data are read or written from the host system via this interface.

2.7.1 SMBus/I^{2}C

The two pin communication interface uses one clock pin and one data pin and is compatible with the industry standard System Management Bus (SMBus) and the Inter IC Communication Bus (I^{2}C).

2.7.2 SINGLE PIN SERIAL INTERFACE

The Single Pin Serial (SPS) interface consists of one pin only: the SDA/SPS pin (pin 14). This communication is an asynchronous return-to-one protocol. The timing of the driven low pulses defines the communication.

2.8 PIC18 Microcontroller

The PIC18 is a high-performance, CMOS, fully static 8-bit microcontroller. The PIC18 employs an advanced RISC architecture. This device has enhanced core features, such as 31 level deep stack and multiple internal and external interrupt sources. The separate instruction and data buses of the Harvard architecture allow a 16-bit wide instruction word with a separate 8-bit wide data bus. The two-stage instruction pipeline allows all instructions to execute in a single cycle, except for program branches, which require two cycles. A total of 75 instructions are available.

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NOTES:

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3.0 OPERATIONAL DESCRIPTION

3.1 A/D Operation

The PS810 A/D converter measures current, voltage and temperature and integrates the current over time to calculate State-Of-Charge. Cell voltage is measured with a direct connection to the battery cell without requiring an external voltage divider. 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. Voltage, current and temperature can be calibrated for accuracy over the operational range. The A/D converter performs sampling using a 32 kHz clock.

3.1.1 CURRENT MEASUREMENT

The A/D input channels for current measurement are the SR and GND pins. The voltage drop across the sense resistor is measured and converted mathematically into a current measurement. The current is also integrated over time to get the amount of charge entering or leaving the battery.

A sense resistor is connected to SR and GND. The maximum input voltage that can be measured at SR 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.

The parameter **NullCurr** represents the zero-zone current of the battery. This is provided as a calibration guardband 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, therefore, currents between -3 mA and +3 mA will be reported as zero and not included in the capacity calculations. This feature is provided so that electrical noise on the battery module current path is not interpreted as actual charge entering or leaving the battery.

3.1.1.1 Sense Resistor Selection and Current Measurement Range

The current resolution is based on the smallest amount of voltage the A/D converter can measure across the sense resistor. Since this measurement uses 13 bits (plus sign) and the reference used is the internal 150 mV reference, the smallest voltage across the sense resistor that can be measured is:

EQUATION 3-1:

$$150\ mV/(2\ ^\wedge\ 13 - 1) = 150\ mV/32767 = 18.3\ \mu V$$

Thus, the smallest current that can be measured is:

$$18.3\ \mu V/R_{SENSE}\ (m\Omega)$$

The largest current that can be measured is:

$$150\ mV/R_{SENSE}\ (m\Omega)$$

Example: a 20 milliohm sense resistor will measure from:

$$18.3\ \mu V/20\ m\Omega = 0.915\ mA$$

(though will be recorded as zero if < **NullCurr**)

up to:

$$150\ mV/20\ m\Omega = 7.5\ Amps$$

3.1.1.2 Current Calibration

In-circuit calibration of the current is done using the communication interface (SMBus/I^2C or SPS) at time of manufacture to obtain optimal accuracy. A correction is calculated and stored for both offset and slope.

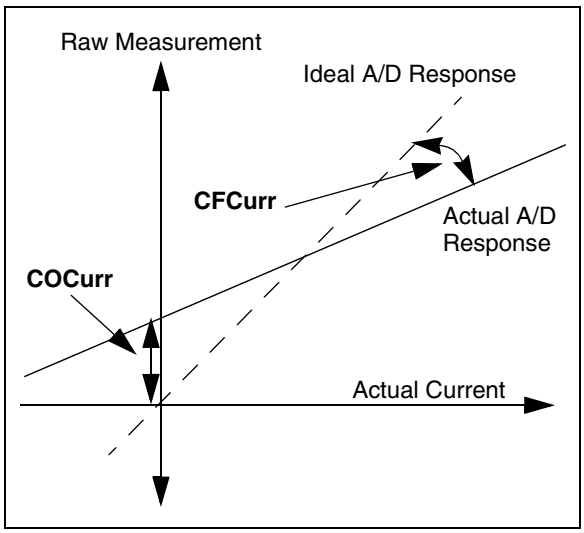
COD is a constant that is measured at calibration time and contains the offset due to external PCB components.

CFCurr is the “Correction Factor for Current” which compensates the A/D gain and any variances in the actual sense resistance over varying currents. It is multiplied against the raw A/D measurement.

COCurr is the “Correction Offset for Current” which is updated in real time by the A/D shorting the inputs and comparing any result to zero. This is added to **COD** and compensates for any offset that varies over time, such as temperature dependent offsets.

Figure 3-1 shows the relationship of the **COCurr** and **CFCurr** values.

FIGURE 3-1: COCurr AND CFCurr VALUE RELATIONSHIP



3.1.2 AUTO-OFFSET COMPENSATION

Accuracy drift is prevented using an automatic auto-zero self-calibration method which zeros the current measurement circuit periodically at a programmable rate. This feature can correct for drift in temperature during operation. The Auto-Offset Compensation circuit works internally by disconnecting the RS input and internally shorting it to GND to measure the zero input offset. Furthermore, the calibration factor, **COD**, contains the offset factor external to the IC, offset due to the circuit board, system, etc. **COD** is added to the internal offset calculated by the auto-offset cycle to determine the full offset, **COCurr**.

3.1.3 VOLTAGE MEASUREMENTS

The A/D input channel for cell voltage measurement is the VC1 pin. Measurements are taken each measurement period when the A/D is active. The maximum voltage at the VC1 pin is 5.5V, but voltages above 4.5V are not suggested since this will saturate the A/D. The cell voltage is measured with an integration method to reduce any sudden spikes or fluctuations. The A/D uses a default of 11-bit plus sign resolution for these measurements.

The VC1 input circuit contains an internal resistive divider to reduce the external voltage input to a range that the internal A/D circuit can accommodate (300 mV maximum). The divider is 15 to 1 based on a maximum cell voltage of 4.5 volts. The voltage divider is only connected to ground when the actual voltage measurement is occurring.

CFVoltage 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. In-circuit calibration of the voltage is done at the time of manufacture to obtain accuracy in addition to high resolution. Cell voltage measurements can be accurate to within ±20 mV.

3.1.4 TEMPERATURE MEASUREMENTS

The A/D can measure temperature from the internal temperature sensor or an external thermistor connected to the NTC pin. The A/D uses a default of 11-bit plus sign resolution 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 NTC pin and the other to ground.

A linearization algorithm is used to convert the voltage measurement seen at the 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.

Calibration of the temperature measurements involves a correction factor and an offset exactly like the current measurement. The internal temperature measurement makes use of correction factor, **CFTempI** and offset, **COTempI**, while the NTC pin for the optional external thermistor makes use of correction factor, **CFTempE**.

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TABLE 3-1: A/D OPERATION PARAMETERS

Parameter Name	# of Bytes	Units	Typical Value	Operational Description
NullCurr	1	mA	3	Zero zone control is built into the PS810 so that electrical noise 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.
CFCurr	2	unsigned word	4200	Correction Factor for Current. Adjusts the scaling of the sense resistor current measurements.
COCurr	1	signed byte	0	Correction Offset for Current. This is the value the A/D reads when zero current is flowing through the sense resistor.
COD	1	signed byte	0	Correction Offset Deviation. Offset value for the auto-zero calibration of the current readings.
AOMInterval	1	op cycles	60	Interval of time between auto-offset calibrations.
AVGIScale	1	coded	b00100000	Time period over which current is averaged to calculate average current: $I_{AVG} = I_{AVG} + (I - I_{AVG})/(\textbf{AVGIScale} * 2)$. **Note:** Only Most Significant set bit is used, others are ignored.
CFVoltage	2	integer	2250	Correction Factor for Pack Voltage. Adjusts the scaling of the VC1 pin measurement.
CFCoin	2	integer	2250	Correction Factor for Coin Cell Measurement. Adjusts the scaling of the V_{COIN} pin measurement.
CFTempE	2	integer	326	Correction Factor for Temperature. Adjusts the scaling of temperature measured across an external thermistor at the NTC input pin.
CFTempI	2	integer	2038	Correction Factor for Temperature. Adjusts the scaling of temperature measured from the internal temperature sensor.
COTempI	2	signed word	21298	Correction Offset for Temperature. Used for temperature measurement using internal temperature sensor.

3.2 Operational Modes

The PS810 operates on a continuous cycle, measuring current, voltage and temperature, then performing fuel gauge calculations. There are four power modes: Run mode, in which the measuring and calculating loop constantly repeats; Bus Inactive Low-Power mode, in which only self-discharge is calculated; Low-Voltage Sleep mode, in which there are no measurements and only wake-up circuitry is powered; and Shelf-Sleep mode, in which only communication line sensors are powered.

3.2.1 RUN MODE

Run mode is the highest power consuming mode. During Run mode, all measurements and calculations occur. Current, voltage and temperature measurements are each made sequentially. Run mode is active until voltage drops below the Sleep voltage, the bus goes inactive or the Shelf-Sleep command is executed.

3.2.2 BUS INACTIVE LOW-POWER MODE

The PS810 enters Low-Power mode when all of the following conditions are true:

- Current is zero (optional)
- The communication pins are low for at least 8 periods of 512 ms each
- There is no communication attempt for at least 8 periods of 512 ms each

To enter this mode, typically, there must be no load or charger present and no communication host. The pack is out of the system. In this mode, the PS810 will draw less current from the battery, approximately 25 μA and will only track self-discharge. Alternatively, if self-discharge tracking is not required, Ultra Low-Power mode can be used and the PS810 will draw less than 1 microamp.

3.2.3 LOW-VOLTAGE SLEEP MODE

Entry to Low-Voltage Sleep mode can only occur when the measured pack voltage at VC1 input is below a preset limit set by the parameter **SleepVoltage** (in mV) and the current is zero (less than **NullCurr**). Sleep mode may be exited to Run mode when the voltage at VC1 is greater than the wake-up voltage, which is 3.2 volts, 10%.

While in 10% Sleep mode, no measurements occur and no calculations are made. The fuel gauge display is not operational, no 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.

There are two power levels that can be chosen for Low-Voltage Sleep mode. Low-Power mode draws approximately 20 μA and will wake-up automatically when the voltage rises above the wake-up voltage, which is a constant 3.2 volts above the wake-up volts, +/-5%. Ultra Low-Power mode draws less than 1 μA and requires an external source to drive the communication line high to wake-up, since the voltage wake-up comparator is powered down.

3.2.4 SHELF-SLEEP MODE

Shelf-Sleep mode can be entered by a battery data command on the communication bus for conserving energy while shipping battery packs. It can be exited only by an external source driving the communication data line high. This mode uses the Ultra Low-Power Sleep mode, resulting in current draw less than 1 microamp. This mode is entered by writing a password to SMBus command code, 0x43. A word write protocol is used to write the password, 0x5A7A.

TABLE 3-2: OPERATIONAL MODES

Mode	Entry	Exit	Notes
Run	Voltage > Wake-up voltage or data line driven high	Voltage less than **SleepVoltage**, bus Idle or Shelf-Sleep command issued	Highest power consumption and accuracy.
Bus Inactive Low-Power	Current < **NullCurr**, communication lines low and no communication attempts	Activity on communication lines	Only self-discharge calculated.
Low-Voltage Sleep	VC(1) < **SleepVoltage,** Current is not zero	Voltage > Wake-up voltage (Low-Power mode), Data line driven high (Ultra Low-Power mode)	No measurements made.
Shelf-Sleep	Can be entered by SMBus command	Data line driven high	No measurements made.

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TABLE 3-3: OPERATIONAL MODE PARAMETERS

Parameter Name	# Bytes	Units	Typical Value	Operational Description
SleepVoltage	2	mV	2700	The pack voltage at which the PS810 will enter Low-Voltage Sleep mode.
PwrConsumSleep	1	1/256 mA	7	The average current that the battery module typically draws from the battery while in Low-Power mode.
PowerModes	1	bitmap	b00000101	bit 5: 1 = Bus Inactive mode, always uses Ultra Low-Power mode until first bus communication after POR 0 = Disable Bus Inactive Low-Power mode bit 4: 1 = Enable Bus Inactive Low-Power mode 0 = Disable Bus Inactive Low-Power mode bit 3: 1 = Use Ultra Low-Power mode as Bus Inactive Low-Power mode (no self-discharge calculations) 0 = Use Low-Power mode with self-discharge calculations as Bus Inactive Low-Power mode bit 2: 1 = Require **NullCurr** for Bus Inactive Low-Power mode and Low-Voltage Sleep mode 0 = No **NullCurr** requirement for Sleep modes bit 1: 1 = Use Ultra Low-Power mode as Low-Voltage Sleep mode 0 = Use Low-Power mode as Low-Voltage Sleep mode bit 0: 1 = Set remcap to zero when entering Low-Voltage Sleep mode 0 = Do not change remcap when entering Low-Voltage Sleep mode

NOTES:

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4.0 CAPACITY MONITORING

The PS810 uses the voltage, current and temperature data from the A/D converter, along with battery algorithms and cell models, to determine the state of the battery and to process the battery data 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 PS810 creates an accurate fuel gauge under all battery conditions.

4.1 Capacity Calculations

The PS810 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 the current into and out of the battery cells, along with accurate three-dimensional cell models, the PS810 is able to provide accurate predictions of SOC and run time.

The capacity calculations consider two separate states: charge or Capacity Increasing (CI) and discharge or Capacity Decreasing (CD). The CI state only occurs when a charge current larger than the parameter **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. Self-discharge is modelled internally in the PS810 and is a factor of temperature and State-Of-Charge.

Since the PS810 electronics also drain current from the battery system, another parameter 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 31 represents the modules nominal power consumption, including PS810 typical consumption of 85 µA.

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

EQUATION 4-1:

$\Delta Charge = \Sigma i \Delta t$ (the current integrated over time)
- **PwrConsumption** * Δt
- Self-discharge percentage * FCC

The battery current will be precisely measured and integrated in order to calculate total charge removed from or added to the battery. Based on look-up table values, the capacity is adjusted relative to discharge rate and temperature.

4.2 Discharge Termination

Remaining capacity is determined based on the End-Of-Discharge (EOD) voltage point. The voltage level at which this point occurs will change depending on the temperature and discharge rate, since these factors affect the voltage curve and total capacity of the battery. The EOD voltage look-up table predicts the voltage point at which this EOD will be reached based on discharge rate and temperature.

The PS810 will monitor temperature and discharge rate continuously and update the EOD voltage from the look-up table in real time. When the voltage measured on the cell is below the EOD voltage for the duration of **EODRecheck** x periods (500 ms), a valid EOD has occurred. When a valid EOD has been reached, the FULLY_DISCHARGED bit in BatteryStatus will be set.

4.3 Capacity Relearn

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. The difference between the old FCC and the new learned FCC will be limited to 256 mAh, except when cycles are less than **RLCycles**.

4.4 EOD Voltage Look-up Table

4.4.1 NEAR EMPTY RESERVE CAPACITY POINT

Available capacity in the battery varies with temperature and discharge rate. Since the remaining capacity will vary with temperature and discharge rate, a shutdown point, or End-Of-Discharge voltage, will also vary with temperature and discharge rate in order to leave enough reserve energy in the battery to allow a system to perform a shutdown procedure under all conditions.

The End-Of-Discharge voltage look-up table allows for entry of 64 different voltages as a function of 8 different temperature regions and 8 different discharge rate regions. Linear interpolation is used to determine the End-Of-Discharge voltage within the regions.

It is recommended to use the table in one of three ways:

1. Constant Shutdown Voltage

   If the system does not require any reserve energy, then the same voltage can be used in all table entries. This should be the lowest voltage the battery can safely discharge to, or the lowest voltage that will support system operation, whichever is higher.

2. Constant Remaining Capacity

   To give a warning of a certain amount of capacity left, the voltage that represents this capacity for a certain temperature and discharge rate is used in each entry. Plotting voltage versus capacity for different temperatures and discharge rates will identify these points

3. Constant Reserve Energy for System Shutdown

   If the system needs a certain amount of energy for a system shutdown procedure that will require a certain discharge rate and a certain amount of time, then the discharge rate could change suddenly as soon as the End-Of-Discharge voltage point is hit. The voltage entries should then represent a remaining capacity that exists at the future discharge rate of the shutdown procedure.

Plotting voltage versus capacity at various temperatures and discharge rates, along with the voltage versus capacity at the shutdown procedure discharge rate, will identify the voltage point at which shutdown should occur assuming a switch from the first discharge rate to the shutdown discharge rate.

The residual capacity entries represent the difference between the ideal capacity of the battery and the capacity available at the specific temperature and discharge rate. To compensate remaining capacity, the residual capacity will be subtracted from remaining capacity. The compensation adjustment will 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 the remaining capacity. Every time the temperature increases by one degree, the remaining capacity will be held constant until the discharged capacity equals the interpolated value that should have been added to the remaining capacity (to avoid capacity increases during discharge). This compensation will not begin until after the fully charged status is reset, allowing the remaining capacity to be 100% when the battery is full.

TABLE 4-1: V_EOD LOOK-UP TABLE EXAMPLE

	<-10°	**<0°**	**<10°**	**<20°**	**<30°**	**<40°**	**<50°**	**>50°**
< 0.2C	3200 mV	3100 mV	3050 mV	—				
< 0.5C	3125 mV	—	—					
< 0.8C	3075 mV	—						
< 1.1C	—							
< 1.4C								
< 1.7C								
< 2.0C								
> 2.0C								
Residual Capacity	20%	10%	5%	3%	0%	0%	0%	0%

Table 4-1 is an example of the various voltage values that will signal the shutdown points as a function of temperature and discharge rate.

Table 4-2 shows the actual names of the values in the memory. Table 4-3 shows the value definitions.

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TABLE 4-2: VALUE NAMES IN THE MEMORY

	TEOD(1)	TEOD(2)	TEOD(3)	TEOD(4)	TEOD(5)	TEOD(6)	TEOD(7)	TEOD(7)
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(7)	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)

4.4.2 COMPENSATING FOR CELL AGING

As lithium ion cells age, the voltage versus capacity curves become depressed. That is, the battery cell can no longer deliver as high of a voltage as it once could for a given capacity. The overall capacity loss is adjusted for by the relearning of full charge capacity. The End-Of-Discharge voltage points, which are voltage points at which a certain capacity remains, are adjusted using a scaling factor.

The End-Of-Discharge voltage points will become lower with each cycle. A cycle is defined as a total amount of discharge capacity equal to full charge capacity. Cycle count is used to determine the age of the cells and the parameter, **AgeFactor**, determines the number of millivolts that the voltage becomes depressed per cycle. **AgeFactor** is subtracted from the End-Of-Discharge voltage for every cycle the battery has been through. **AgeFactor** units are in eighths of millivolts. Thus, with the effect of aging, the actual End-Of-Discharge voltage becomes:

EQUATION 4-2:

$$VEOD_{aged} = \mathbf{VEOD} - (\underline{\text{CycleCount}} * \mathbf{AgeFactor} * 0.125)\ \text{mV}$$

TABLE 4-3: CAPACITY MONITORING PARAMETERS

Parameter Name	# of Bytes	Units	Typical Value	Operational Description
DesignCapacity	2	mAh	2200	Battery data value for DesignCapacity. This is the first capacity loaded into the FullChargeCapacity upon power-up.
RemCap	2	mAh	440	The initial capacity of the battery. When the PS810 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 **RemCap** to compute relative State-Of-Charge percentage.
NullCurr	1	mA	3	A zero zone control is built into the PS810 so that any electrical noise 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.
PwrConsumption	1	1/256 mA	31	Current consumption of the battery module. This is the average current that the battery module typically draws from the battery (255 = 1 mA).
ClrFullyChrg	1	%	90	Reset FULLY_CHARGED bit at this level, 100 = 100%. When discharging begins, the FULLY_CHARGED bit must remain set until the cell voltages are below **EOCVolt**, so that a small current will not trigger a false End-Of-Charge trigger. Thus, **ClrFullyChrg** is set at about 90%. FULLY_CHARGED bit will be on until the battery has discharged to less than 90%.
ConfigCAP	1	bitmap	11100100	bit 7: Compensate remaining capacity – the displayed remaining capacity actually equals FCC minus capacity used minus residual capacity. bit 6: Remaining capacity decrease only – when compensating, if temperature changed causing a decrease in residual capacity, do not let remaining capacity rise to reflect this. Instead, hold it steady until discharge catches up. bit 5: Only compensate on discharge. bit 4: Compensate on null current. bit 3: Unused. bit 2: Set capacity to positive immediately upon charging. If discharged below zero, this allows capacity to count up immediately upon charging. bit 1: Learn unconditionally – relearn FCC under any conditions. Typically used for testing only. bit 0: Disable self-discharge.

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TABLE 4-3: CAPACITY MONITORING PARAMETERS (CONTINUED)

Parameter Name	# of Bytes	Units	Typical Value	Operational Description
FLAGS1	1	bitmap	b00100000	Bit coded as follows: Bit Function 7 Unused 6 Unused 5 Int/Ext temperature 4 Disable Sleep in main Idle mode. 3 Unused 2 Disable safety GPIO 1 Unused 0 Unused
RemCapDelta	1	1/4 mAh	2	Maximum change in remaining capacity per measurement period.
EODRecheck	1	integer	8	Recheck period for EOD. Voltage must be below **VEOD** for this many measurement periods.
ClrFullyDischrg	1	%	10	Reset FULLY_DISCHARGED bit, 100 = 100%. Once fully discharged bit is set, it will stay set until capacity rises above this value, typically 10%.
EODCap	2	mAh	100	Capacity remaining in battery at EOD. Remaining capacity is loaded with **EODCap** at EOD.
FullCapacity	2	mAh	2200	Learned value of battery capacity. Used for battery data 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.
RLCycles	1	integer	2	The number of initial cycles without a relearn limit. Normally, full charge capacity will change by a maximum of 256 mAh when relearned. Since **FullCapacity** can vary greatly with the first learning cycle, the initial capacity may not be correct; thus, this should be set to at least 2.
TEOD	7	(°Celsius * 10 + 200)/4	5, 20, 35, 50, 80, 113, 150	EOD temperature boundaries – 8 increasing values of temperature coded as: **TEOD**x = (°Celsius * 10 + 200)/4.
CEOD	7	1/64 C	19, 32, 48, 64, 77, 90, 109	EOD C-rate boundaries – 8 increasing values of C-rates coded as: **CEOD**x = C-rate * 64.
FCCP	8	255 = 100%	50, 25, 12, 8, 0, 0, 0, 0	Unusable residual capacity before save to disk, corresponding to temperature, 255 = 100%.
VEODOffset	2	mV	2700	Baseline for **VEOD** formula.
VEOD	64	voltage – **VEODOffset**/4	75	End-Of-Discharge voltage, voltage = **VEODOffset** + 4 * **VEOD**. Cell voltage at which save to disk is signaled.
AgeFactor	1	0.125 mV	1	Scale factor for EOD voltages due to aging (in units of .125 mV), $VEOD_{aged}$ = **VEOD** – (CycleCount * .125 * **AgeFactor**).
VEODCoin	2	mV	2500	Voltage at which coin cell is determined to be empty.

NOTES:

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5.0 CHARGE CONTROL

5.1 Full Charge Detection Methods

For a typical lithium ion constant-current/constant-voltage charge system, the PS810 will monitor the taper current that enters the battery. Once the battery has reached the final voltage level of the charger, when VC1 is greater than **EOCVolt**, taper monitoring will begin. Once the taper current falls between **TaperCRate** and **TaperLow**, indicating that the battery is full, the End-Of-Charge (EOC) will be triggered. For pulse charging, the average current will be monitored. When average current falls below **EOCCurAvg**, the EOC will be triggered. So that a sudden drop or removal of charge current doesn't trigger a false EOC when using taper current, the current and the average current must be within **StableCurr** of each other.

Thus, the conditions to trigger EOC are:

1. Cell Voltage > **EOCVolt** and
2. **TaperCRate** > Current > **TaperLow** and
3. Average Current – Current < **StableCurr**

For pulse charging, replace condition 2 with Average Current < **EOCCurAvg** and remove condition 3.

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

- The FULLY_CHARGED status bit in BatteryStatus is set to '1' to indicate a full condition. (This will remain set until RelativeStateOfCharge drops below the **ClrFullyChrg** value in memory.)
- Remaining capacity is set to FCC and thus, RelativeStateOfCharge is set to 100%.

5.2 Temperature Algorithms

The PS810 provides a temperature alarm set point.

HighTempAl: When the measured temperature is greater than **HighTempAl**, the OVER_TEMP_ALARM bit is set.

TABLE 5-1: CHARGE CONTROL PARAMETERS

Parameter Name	# Bytes	Units	Typical Value	Operational Description
HighTempAl	1	(°Celsius * 10 + 200)/4	200	OVER_TEMP_ALARM threshold bit in AlarmWarning register, coded value = (°Celsius * 10 + 200)/4. When the temperature exceeds **HighTempAl**, the OVER_TEMP_ALARM becomes active.
EOCCurAvg	2	mA	200	EOC trigger for pulse charging. If the average current during pulse charging has dropped below the **EOCCurAvg** threshold for a pass count equal to the parameter value, **EOCRecheck**, the End-Of-Charge state will be reached.
EOCRecheck	1	integer	6	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	2	mV	4150	EOC trigger cell voltage. When a cell reaches this voltage, the End-Of-Charge determination will start monitoring the current to determine when the battery is full. When the current is in the proper range and the cell voltage is greater than **EOCVolt**, then FULLY_CHARGED bit in BatteryStatus will be set.
StableCurr	1	mA	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.
TaperCRate	1	1/64 C	3	Upper limit EOC taper current based on temperature, 64 = 1C.
TaperLow	1	1/64 C	1	Lower limit EOC taper current, 64 = 1C.
ConfigEOCD	1	bitmap	10011111	Bit coded as follows: Bit Function 7 Limit remcap to FCC 6 Unused 5 Trigger EOC on average current 4 Trigger EOC on taper current 3 Disallow multiple EODs 2 Limit capacity to **EODCap** until EOD 1 Set capacity to residual capacity at **VEOD** 0 Learn FCC at **VEOD**

NOTES:

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6.0 GPIO CONFIGURATION

6.1 Configuring Inputs and Outputs

GPIOs can be set up to act as inputs or outputs that are based on conditions involving battery data parameters, or GPIO levels, compared to constants. This powerful programming model allows for customizing GPIO to set on any possible fuel gauge conditions and reset on any other possible fuel gauge conditions in any groupings.

Four parameters define the global behavior of each pin as follows:

- **GPIOSTATE:** defines the state, high or low, the GPIO is in during initialization of the fuel gauge.
- **GPIODIRECTION:** Defines whether the GPIO is an input or an output.
- **GPIOCONFIG:** enables analog functions NTC and VCOIN vs. GPIO (high byte), enables pull-up or pull-down on inputs (low byte).
- **GPIOPOLARITY:** defines active and inactive polarities. All GPIOs will drive high to VBAT, except for IO0 and IO3, which will drive high to VBAT – 1 volt. All GPIOs have pull-ups and pull-downs when configured as inputs, except IO0 and IO3, which only have pull-downs. IO0 is only available in SPS mode and IO3 is only available when not using VCOIN. Similarly, IO2 is only available when not using NTC.

TABLE 6-1: GPIO PARAMETERS

Name	Definition	Bit Description
GPIOSTATE	Reset State of GPIO	Bit number corresponds to GPIO number bit setting: bit (x) = 1: GPIO defaults to high bit (x) = 0: GPIO defaults to low
GPIODIRECTION	GPIO Input or Output	Bit number corresponds to GPIO number bit setting: bit (x) = 1: GPIO is an input bit (x) = 0: GPIO is an output
GPIOCONFIG High Byte	Analog or GPIO	bit (5) = 1: Pin 1 is NTC thermistor input bit (5) = 0: Pin 1 is GPIO bit (4) = 1: Pin 2 is VCOIN coin cell input bit (4) = 0: Pin 2 is GPIO bit (0) = 1: Disable pull-up and pull-down resistors on inputs bit (0) = 0: Enable pull-up and pull-down resistors on inputs
GPIOCONFIG Low Byte	Pull-up or Pull-down on Inputs	If GPIO is configured as input, then: bit (7-2): 1 = Pull-down 0 = Pull-up bit (1-0): 1 = 1.8V communication 0 = TTL communication
GPIOPOLARITY	Default and Active Polarity	Bit number corresponds to GPIO number bit setting: bit (x) = 1: GPIO is default high, active-low bit (x) = 0: GPIO is default low, active-high

TABLE 6-2: PARAMETER NUMBER/GPIO NUMBER CORRESPONDENCE

Parameter Bit #	GPIO #
0	0/SCL
1	SDA/SPS
2	6
3	5
4	4
5	3
6	2
7	1

6.2 Configuring Output Functions

Powerful and flexible programming protocols allow GPIO configured as outputs to be defined with complex functions based on battery data. Virtually all information about the battery can be used in a multiple level trigger function or Reset function. This programming is accomplished using Microchip programming development tool, PowerTool™ 800.

GPIO output functions can be based on the following information functions:

- All battery data functions, such as voltage, current, battery status, etc.
- The high or low level of any other GPIO
- The miscellaneous flags byte which contains the following information:
  - bit 0: Charge started
  - bit 1: Discharge started
  - bit 2: Charge increasing
  - bit 3: POR detected
  - bit 4: Unused
  - bit 5: Wake from Sleep
  - bit 6: In Low-Voltage Sleep mode
  - bit 7: In Shelf-Sleep mode
  - bit 8: In Bus Sleep mode

Once an argument is selected from above, an operator is selected to compare it to a constant. The operators are >, <, =, AND and NOR. The latter two are used to compare individual bits in a bit map. For example, AND a bit map against the operand `00000000 00000010` will be true if bit one is a '`1`'. NOR a bit map against the operand `11111111 11111101` will be true if bit one is a '`0`'.

An example of a condition is :

Voltage < 3200

This condition is true if the battery data of voltage is less than 3200 mV.

Condition groups can be created by ANDing and ORing individual conditions together. An example condition group is:

(Voltage < 3200) AND (Current > 100) OR
(Temperature > 60) AND (Current > 200)

Because of precedence the equation would be interpreted:

((Voltage < 3200) AND (Current > 100)) OR
((Temperature > 60) AND (Current > 200))

This entire condition group can be programmed to activate a single GPIO. A Reset condition can then be assigned to reset the GPIO if it had triggered as a result of its trigger condition group.

Example Reset condition group:

(Voltage > 3200) OR (Current = 0)

Furthermore, multiple trigger condition groups, each with their own individual Reset condition groups, can be assigned to a single GPIO. This is all accomplished by programming with PowerTool™ 800.

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7.0 KEELOQ® SECURITY

The PS810 will employ KEELOQ security coding which can ensure only proprietary batteries can be used with the host device. Since the batteries are tailored to the system requirements, an incompatible battery may cause poor performance or even non-performance. A verification challenge will be issued to the battery from the host. The battery will encrypt the challenge data and return it to the host. The host will encrypt the challenge data also and verify that the battery's encrypted response matches. For technical KEELOQ specifications, see Microchip application note *AN827, "Using KEELOQ® to Validate Subsystem Compatibility"* (DS00827).

The host issues a "challenge" (i.e., a 32-bit random number) by writing it to the KEELOQ bus function on the PS810. The PS810 firmware contains the KEELOQ encryption algorithm and a 64-bit key. The PS810 runs the 32-bit challenge data along with its 64-bit key through the KEELOQ decrypt algorithm to create a 32-bit response. The host then reads the response from the PS810 using the KEELOQ bus function. The host verifies the response by also running the challenge through the decrypt algorithm using the same key. If the results are the same, authentication is successful.

When a challenge is written to the battery, it takes time to generate the encrypted response. Battery status bit 1 is set to one ('1') when a challenge is written and reset to zero ('0') when the response is ready and may be read from the PS810.

The security of authentication relies not on the secrecy of the algorithm, but on secrecy and management of the key. The key, the function that stores the key and the KEELOQ decrypt algorithm that uses it are located in memory that is protected from reads and writes. This prevents the key from being read except by code in the boot block and prevents the boot block from being altered without being first erased. The key is stored in an encoded form and during normal execution, never appears in its entirety in RAM.

A battery pack's key is stored at time of manufacture. Each pack can have a unique key, further improving security, which is a function of a master key and the pack's serial number. A host would use the master key, the pack serial number and a key generation algorithm to determine an individual pack's key.

NOTES:

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8.0 COMMUNICATION

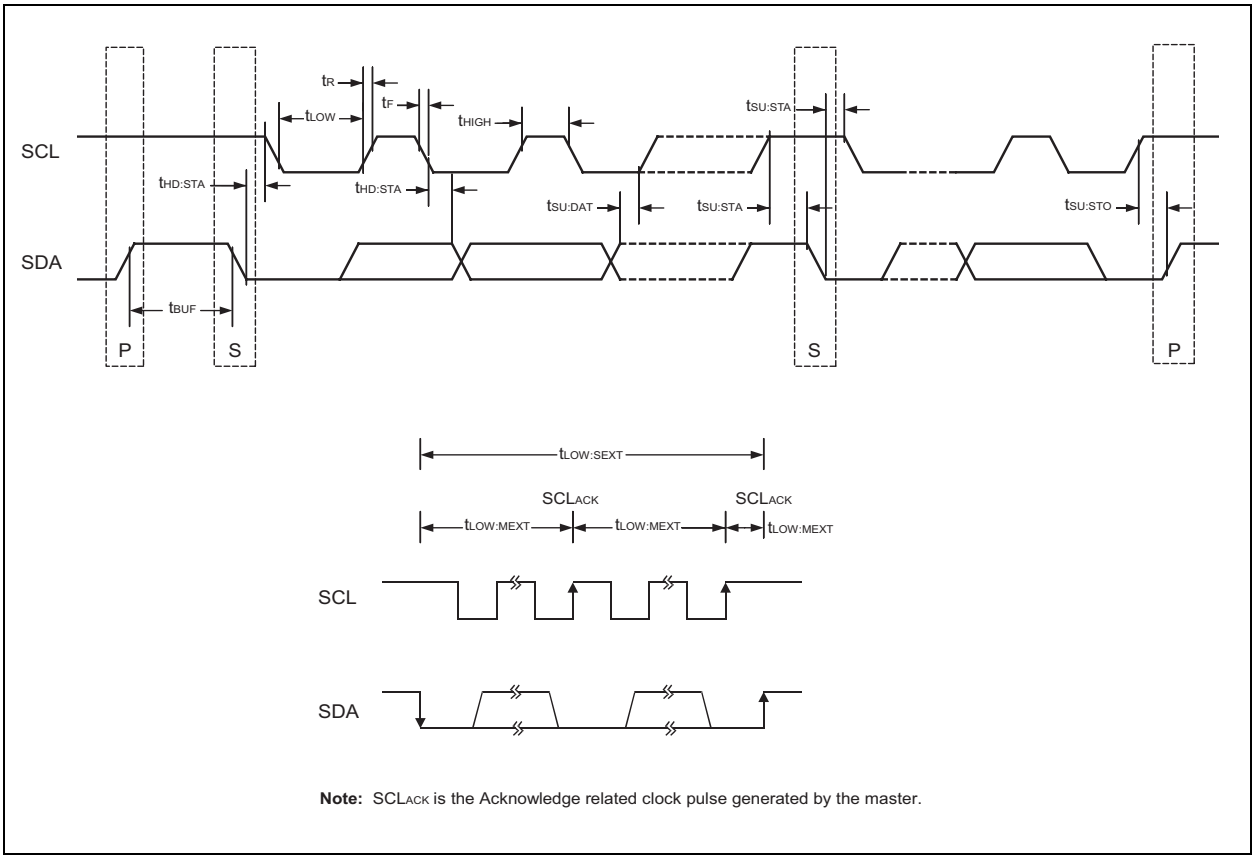
8.1 SMBus/I²C Battery Data Interface

The PS810 uses a two-pin communication protocol compatible with the System Management Bus (SMBus) and the Inter IC Communication (I²C™) protocols to communicate to the host. One pin is the clock and one is the data. The SMBus/I²C port responds to all battery data commands listed in Table 8-1. To receive information about the battery, the host sends the appropriate commands to the SMBus/I²C port. The battery data command set is summarized in Table 8-1.

The PS810 SMBus/I²C 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 and PEC (CRC-8) error checking. The SMBus port serves as a slave for both read and write functions. SMBus slave protocols supported include Read Word, Write Word, Read Block and Write Block, all with or without PEC (CRC-8) error correction.

The SMBus protocol used for PS810 is for the host to master the SMBus. PS810 operates only in Slave mode. The master will send the PS810 device's SMBus write address (0x16 for write) followed by the command code. The host will then send the PS810 device's read address (0x17 for read) and await data. As a response to the read request, the PS810 will send all the data bytes required.

FIGURE 8-1: SMBus TIMING



Note: SCLACK is the Acknowledge related clock pulse generated by the master.

8.2 SPS Single Pin Serial Battery Data Interface

The PS810 can also communicate using one pin, the SDA pin with the Single Pin Serial protocol (SPS). The single pin serial interface communication is an asynchronous return-to-one protocol. The signal requires an external pull-up resistor. The timing of the driven low pulses defines the communication.

A Break cycle starts a command from the host to the battery. The command is eight bits long. After this, eight data bits are either sent to the battery or received from the battery. The Least Significant bits are sent first.

The Break cycle is defined by a low period for a time equal to or greater than t_B, then returned high for a time greater than or equal to t_{BR}.

The data bits consist of three sections each:

1. Start: a logic low for at least time t_{STR}.
2. Data: data high or low valid by time t_{DS} and held until time $t_{DH/V}$.
3. Stop: logic high by time t_{SSU} and held until time T_{CYC}.

The SPS protocol only allows one byte to be read per command code. Thus, commands that receive two-byte pieces of data must be executed one byte at a time. To get a two-byte data, the command code for the high byte must be sent, the high data byte received and then, the command code for the low data byte must be sent to receive the low data byte.

Furthermore, it is possible that the piece of data has changed in between the time it took to get the high byte and the low byte if the host system is communicating slowly. Therefore, it is recommended to always verify the data hasn't changed. This is done by reading the high byte, then reading the low byte, then rereading the high byte and comparing it to the first read to make sure it is the same. If it is not the same, then the low byte can be reread and matched with the new high byte.

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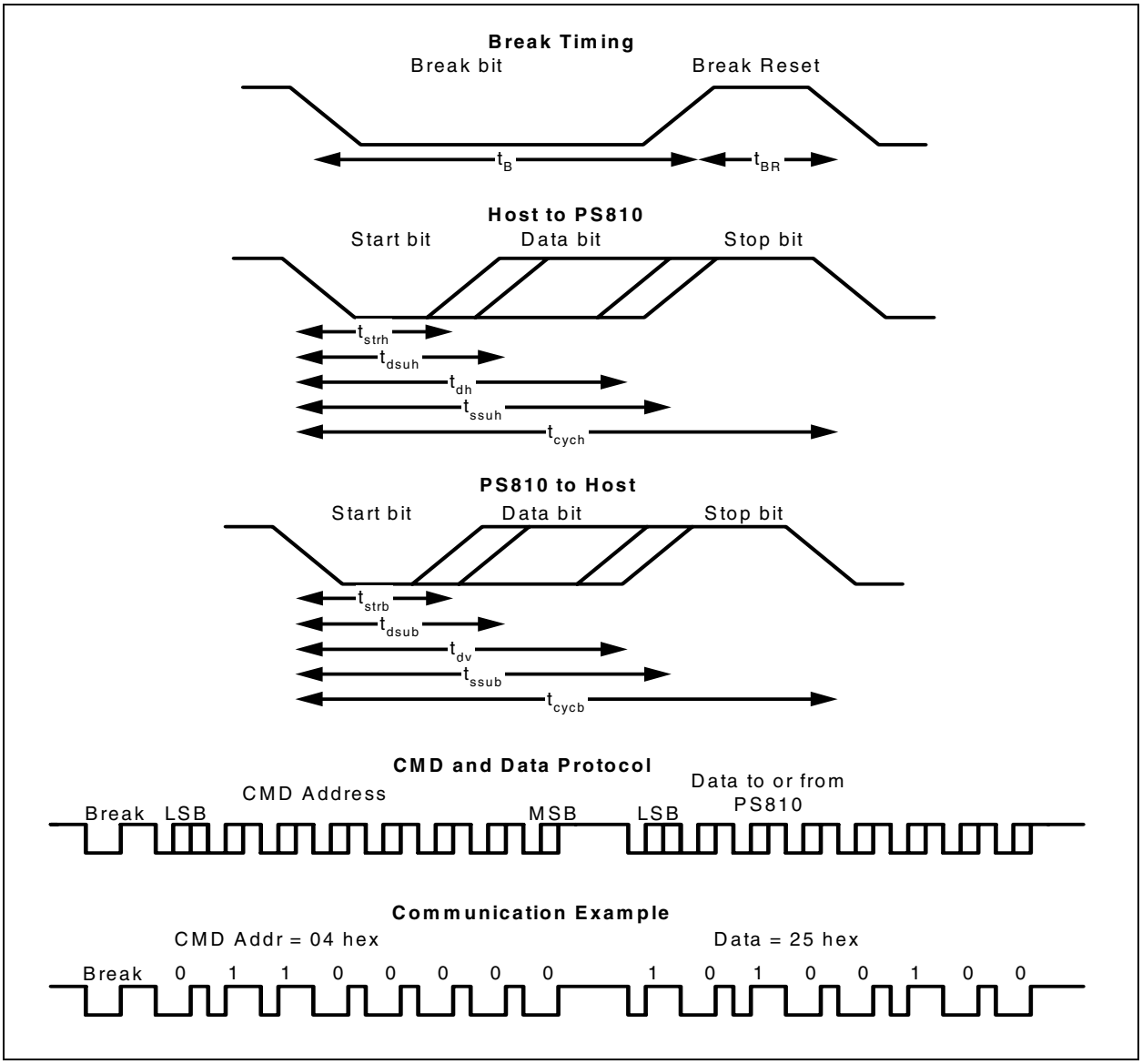
FIGURE 8-2: SINGLE PIN SERIAL TIMING



8.3 Battery Data Function Description

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

TABLE 8-1: PS810 SMBus DATA FUNCTIONS

Battery Data Function Name	SMBus Command Code	Access	Parameter Reference	Units
Temperature	0x00	Read		0.1° Celsius
Voltage	0x01	Read		mV
Current	0x02	Read		mA
AverageCurrent	0x03	Read		mA
RelativeStateOfCharge	0x04	Read		%
AbsoluteStateOfCharge	0x05	Read		%
RemainingCapacity	0x06	Read		mAh
FullChargeCapacity	0x07	Read		mAh
AverageTimeToEmpty	0x08	Read		MInutes
BatteryStatus	0x09	Read	**BatStatus**	Bit Code
CycleCount	0x0A	Read	**Cycles**	Integer
DesignCapacity	0x0B	Read	**DesignCapacity**	mAh
CoinVoltage	0x0C	Read		mV
ManufactureDate	0x0D	Read	**MFGDate**	Coded
SerialNumber	0x0E	Read	**SerialNumber**	Hex Word
ManufacturerID	0x0F	Read	**MFGID**	Hex Word
DeviceID	0x10	Read	**DevID**	Hex Word
KEELOQ	0x17	Read/Write		Block Data
UserData	0x16	Read		Block Data

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TABLE 8-2: PS810 SINGLE PIN SERIAL DATA FUNCTIONS

Battery Data Function Name	SPS Command Code	Access	Parameter Reference	Units
Temperature *(low byte)*	0x00	Read		0.1° Celsius
Temperature *(high byte)*	0x01	Read		
Voltage *(low byte)*	0x02	Read		mV
Voltage *(high byte)*	0x03	Read		
Current *(low byte)*	0x04	Read		mA
Current *(high byte)*	0x05	Read		
AverageCurrent *(low byte)*	0x06	Read		mA
AverageCurrent *(high byte)*	0x07	Read		
RelativeStateOfCharge	0x08	Read		%
reserved	0x09	—		
AbsoluteStateOfCharge	0x0A	Read		%
reserved	0x0B	—		
RemainingCapacity *(low byte)*	0x0C	Read		mAh
RemainingCapacity *(high byte)*	0x0D	Read		
FullChargeCapacity *(low byte)*	0x0E	Read		mAh
FullChargeCapacity *(high byte)*	0x0F	Read		
AverageTimeToEmpty *(low byte)*	0x10	Read		MInutes
AverageTimeToEmpty *(high byte)*	0x11	Read		
BatteryStatus	0x12	Read	**BatStatus**	Bit Code
reserved	0x13	—		
CycleCount *(low byte)*	0x14	Read	**Cycles**	Integer
CycleCount *(high byte)*	0x15	Read	**Cycles**	
DesignCapacity *(low byte)*	0x16	Read	**DesignCapacity**	mAh
DesignCapacity *(high byte)*	0x17	Read	**DesignCapacity**	
CoinVoltage *(low byte)*	0x18	Read	**DesignVPack**	mV
CoinVoltage *(high byte)*	0x19	Read	**DesignVPack**	
ManufactureDate *(low byte)*	0x1A	Read	**MFGDate**	Coded
ManufactureDate *(high byte)*	0x1B	Read	**MFGDate**	
SerialNumber *(low byte)*	0x1C	Read	**SerialNumber**	Hex Word
SerialNumber *(high byte)*	0x1D	Read	**SerialNumber**	
ManufacturerID *(low byte)*	0x1E	Read	**MFGID**	Hex Word
ManufacturerID *(high byte)*	0x1F	Read	**MFGID**	
DeviceID *(low byte)*	0x20	Read	**DevID**	Hex Word
DeviceID *(high byte)*	0x21	Read	**DevID**	
KEELOQ *(low byte)*	0x28	Read/Write	**MFGData**	Hex Double Word
KEELOQ *(second byte)*	0x29	Read/Write	**MFGData**	
KEELOQ *(third byte)*	0x2A	Read/Write	**MFGData**	
KEELOQ *(high byte)*	0x2B	Read/Write	**MFGData**	

8.3.1 Temperature (0.1° CELSIUS)

Returns the cell pack's internal temperature.

8.3.2 Voltage (mV)

Returns the pack voltage.

8.3.3 Current (mA)

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

8.3.4 AverageCurrent (mA)

Returns a rolling average of the current being supplied (or accepted) through the battery's terminals. The time period over which current is averaged is adjustable.

8.3.5 RelativeStateOfCharge (%)

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

8.3.6 AbsoluteStateOfCharge (%)

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

8.3.7 RemainingCapacity (mAh)

Returns the predicted remaining battery capacity. The RemainingCapacity value is expressed as: Current x Time.

8.3.8 FullChargeCapacity (mAh)

Returns the predicted pack capacity when it is fully charged.

8.3.9 AverageTimeToEmpty (MINUTES)

Returns a rolling average of the predicted remaining battery life. The time period over which it is averaged is the same as AverageCurrent.

8.3.10 BatteryStatus (FLAGS)

Returns the Smart Battery's status word. The BatteryStatus function is used by the power management system to get alarm and status bits.

Battery Status Bits:

bit 7: INITIALIZED

bit 6: DISCHARGING

bit 5: FULLY_CHARGED

bit 4: FULLY_DISCHARGED

bit 3: OVER_TEMP_ALARM

bit 2: Unused

bit 1: KEELOQ response processing

bit 0: COIN_CELL_EMPTY

8.3.11 CycleCount (INTEGER)

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

8.3.12 DesignCapacity (mAh)

Returns the theoretical capacity of a new pack.

8.3.13 CoinCellVoltage (mV)

Returns the voltage of the coin cell.

8.3.14 ManufactureDate (CODE)

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

8.3.15 SerialNumber (HEX WORD)

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

8.3.16 ManufacturerID (HEX WORD)

This function returns a hex word containing the battery manufacturer's ID.

8.3.17 DeviceID (HEX WORD)

This function returns a hex word that contains the battery's ID.

8.3.18 KEELOQ (BLOCK DATA)

This function is used for identification of the battery to the system. The host system writes a 4-byte challenge of random data to the battery. The PS810 runs the challenge data through the KEELOQ algorithm using a safe key entered at time of manufacture. (An option is to have this key based on a manufacturer's key and the serial number.) The host then reads the 4-byte response and compares it with an internally generated response using the same key. The responses must match for validation.

8.3.19 UserData (BLOCK DATA)

Reads 1 to 32 bytes from the UserData block in Flash. The number of bytes read is determined by parameter **UserDataLen**. This is a general purpose storage of any information a user may want to read.

Note:	This command is only available in SMBus mode, not SPS mode.

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9.0 PARAMETER SETUP

This section documents all of the programmable parameters that are resident in the memory.

TABLE 9-1: ALPHABETICAL LISTING OF PARAMETERS

Parameter Name	# Bytes	Units	Typical Value	Operational Description
AgeFactor	1	0.125 mV	0	Scale factor for EOD voltages due to aging. In units of .125 mV, $VEOD_{aged}$ = **VEOD** – (CycleCount * **AgeFactor**).
AOMInterval	1	op cycles	60	Interval between auto-offset calibrations.
AVGIScale	1	coded	b00100000	Time period over which current is averaged to calculate average current, IAVG = IAVG + (I – IAVG)/**AVGIScale**. **Note:** Only Most Significant set bit is used, others are ignored. 1xxxxxxx: IAVG = IAVG + (I – IAVG)/256 01xxxxxx: IAVG = IAVG + (I – IAVG)/128 001xxxxx: IAVG = IAVG + (I – IAVG)/64 0001xxxx: IAVG = IAVG + (I – IAVG)/32 00001xxx: IAVG = IAVG + (I – IAVG)/16 000001xx: IAVG = IAVG + (I – IAVG)/8 0000001x: IAVG = IAVG + (I – IAVG)/4 00000001: IAVG = IAVG + (I – IAVG)/2
BGCal	1	integer	14	Band gap voltage calibration factor.
CalStatus	1	bitmap	b11111111	Bit coded as follows: Bit Function 7 RCOSC 6 TEMP 5 CURRENT 4 VC1 3 VCOIN 0 = Not calibrated 1 = Calibrated
CFCoin	2	integer	2250	Correction Factor for Coin Cell Voltage.
CFCurr	2	integer	4200	Correction Factor for Current. Adjusts the scaling of the sense resistor current measurements.
CFTempE	2	integer	326	Correction Factor for Temperature. Adjusts the scaling of temperature measured across an external thermistor at the NTC input pin.
CFTempI	2	integer	2038	Correction Factor for Temperature. Adjusts the scaling of temperature measured from the internal temperature sensor.
CFVoltage	2	integer	2250	Correction Factor for Pack Voltage. Adjusts the scaling of the pack voltage measurements. Used to calibrate the measurement of pack voltage between VC1 input pin and ground.
ClrFullyChrg	1	%	90	Reset FULLY_CHARGED bit at this level, 100 = 100%. When discharging begins, the FULLY_CHARGED bit should remain set until the cell voltages are below **EOCVolt**, so that a small current will not trigger a false End-Of-Charge trigger.
ClrFullyDischrg	1	%	10	Reset FULLY_DISCHARGED bit, 100 = 100%. Once fully discharged bit is set, it will stay set until capacity rises above this value, typically 10%.
COCurr	1	signed byte	0	Correction Offset for Current. This is the value the A/D reads when zero current is flowing through the sense resistor.

TABLE 9-1: ALPHABETICAL LISTING OF PARAMETERS (CONTINUED)

Parameter Name	# Bytes	Units	Typical Value	Operational Description
COD	1	signed byte	0	Correction Offset Deviation. Offset value for the module effect on the current readings.
Config1	1	bitmap	b00010000	bit 7: Internal use only. bit 6: 1 = FG overrides bootloader high priority interrupt service bit 5: 1 = Bootloader write commands disabled until locked bit 4: 1 = Disable bootloader write commands bit 3: 1 = Start in SMBus mode 0 = SPS mode bit 2: 1 = 32 ms SMBus time-out 0 = 16 ms SMBus time-out bit 1: 1 = Flash reading is locked 0 = Flash reading is unlocked bit 0: Unused.
ConfigCAP	1	bitmap	11100100	bit 7: Compensate remaining capacity – the displayed remaining capacity actually equals FCC minus capacity used minus residual capacity. bit 6: Remaining capacity decrease only – when compensating, if temperature change causes a decrease in residual capacity, do not let remaining capacity rise to reflect this. Instead, hold it steady until discharge catches up. bit 5: Only compensate remaining capacity on discharge. bit 4: Enable compensation during null current. bit 3: Unused bit 2: Set capacity to positive immediately upon charging. If discharged below zero, this allows capacity to count up immediately upon charging. bit 1: Learn unconditionally – relearn FCC under any conditions. Typically used for testing only. bit 0: Disable self-discharge.

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TABLE 9-1: ALPHABETICAL LISTING OF PARAMETERS (CONTINUED)

Parameter Name	# Bytes	Units	Typical Value	Operational Description
ConfigEOCD	1	bitmap	10011111	Bit coded as follows: Bit Function 7 Limit remaining capacity to FCC 6 Unused 5 Trigger EOC on average current 4 Trigger EOC on taper current 3 Disallow multiple EODs 2 Limit capacity to **EODCap** until EOD 1 Set capacity to residual capacity at **VEOD** 0 Learn FCC at **VEOD**
COTempE	2	signed word	21198	Correction offset for external temperature.
COTempI	2	signed word	21198	Correction offset for internal temperature.
Cycles	2	integer	0	Battery data 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 removed from the battery, equivalent to the full capacity.
DesignCapacity	2	mAh	2200	Battery data value for DesignCapacity. This is the first capacity loaded into the FullChargeCapacity upon initial power-up.
DevID	2	hex word	AAAA	Battery data value for DeviceID (2-byte hex word).
EOCCurAvg	2	mA	200	EOC trigger for pulse charging. If the average current during charging has dropped below the threshold for a pass count equal to **EOCRecheck**, the End-Of-Charge state will be reached.
EOCRecheck	1	op cycles	6	Number of checks before EOC trigger. The End-Of-Charge conditions must remain for at least this number of periods before being considered true.
EOCVolt	2	mV	4150	EOC trigger cell voltage. When the cell reaches this voltage, the PS810 will start monitoring the current to determine when the battery is full. When the current is in the proper range and the cell voltage is greater than **EOCVolt**, then the FULLY_CHARGED bit in BatteryStatus will be set.
EODCap	2	mAh	100	Reserve remaining capacity at EOD.
EODRecheck	1	op cycles	8	Recheck period for EOD. Voltage must be below **VEOD** for this many measurement periods.
FDBVersion	1	integer	—	Flash data block version.
FLAGS1	1	bitmap	00100000	Bit coded as follows: Bit Function 7 Unused 6 Unused 5 Int/Ext temperature 4 Disable Sleep in main Idle mode 3 Unused 2 Disable safety GPIO 1 Unused 0 Unused
FullCapacity	2	mAh	2200	Learned value of battery capacity. Used for battery data 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.

TABLE 9-1: ALPHABETICAL LISTING OF PARAMETERS (CONTINUED)

Parameter Name	# Bytes	Units	Typical Value	Operational Description
HighTempAl	1	coded byte	200	OVER_TEMP_ALARM bit threshold, Coded Value = (°Celsius * 10 + 200)/4.
MFGDate	2	coded hex word	0x3246	Battery data value for ManufactureDate. The date of manufacture of the battery pack can be programmed here and retrieved with the battery data ManufactureDate command, Coding: Date = (Year-1980) x 512 + Month x 32 + Day.
MFGID	2	hex word	–	Value for ManufacturerID (2-byte hex word).
NChangeState	1	op cycles	2	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 **NChangeState** periods before the status is changed and capacity is increased or decreased as a result of the new current direction.
NullCurr	1	mA	3	A zero zone control is built into the PS810 so that any electrical noise 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.
OscCal	1	integer	206	RC oscillator trimming.
PowerModes	1	bitmap	b00000101	bit 4: 1 = Enable Bus Inactive Low-Power mode 0 = Disable Bus Inactive Low-Power mode bit 3: 1 = Use Ultra Low-Power mode as Bus Inactive Low-Power mode (no self-discharge calculations) 0 = Use Low-Power mode with self-discharge calculations as Bus Inactive Low-Power mode bit 2: 1 = Require **NullCurr** for Bus Inactive Low-Power mode and Low-Voltage Sleep mode 0 = No **NullCurr** requirement for Sleep modes bit 1: 1 = Use Ultra Low-Power mode as Low-Voltage Sleep mode 0 = Use Low-Power mode as Low-Voltage Sleep mode bit 0: 1 = Set remcap to zero when entering Low-Voltage Sleep mode 0 = Do not change remcap when entering Low-Voltage Sleep mode
PW1	2	integer	–	First password for the battery pack lock.
PW2	2	integer	–	Second password for the battery pack lock.
PwrConsumption	1	1/256 mA	31	Current consumption of the battery module. This is the average current that the battery module typically draws from the battery (255 = 1 mA).
PwrConsumSleep	1	1/256 mA	7	Current consumption of battery module when in Sleep mode.
RefCal	1	integer	0	Reference voltage calibration factor.

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TABLE 9-1: ALPHABETICAL LISTING OF PARAMETERS (CONTINUED)

Parameter Name	# Bytes	Units	Typical Value	Operational Description
RemCap	2	mAh	440	The initial capacity of the battery. When the PS810 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 **RemCap** to compute relative State-Of-Charge percentage.
RemCapDelta	1	1/4 mAh	2	Maximum change in remaining capacity per measurement period.
RLCycles	1	integer	2	The number of initial cycles without a relearn limit. The initial number of cycles where the relearn limit is not active. Normally, full charge capacity will change by a maximum of 256 mAh when relearned. Since **FullCapacity** can vary greatly with the first learning cycle, the initial capacity may not be correct; thus, this should be set to at least 2.
SerialNumber	2	integer	–	Battery data value for SerialNumber. The serial number of the battery pack can be programmed here and retrieved with the battery data SerialNumber command.
SleepVoltage	2	mV	2700	The pack voltage at which the PS810 will enter Low-Voltage Sleep mode.
StableCurr	1	mA	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	1	1/64 C	3	Upper limit EOC taper current, 64 = 1C.
TaperLow	1	1/64 C	1	Lower limit EOC taper current, 64 = 1C.
UserDataLen	1	bytes	2	Number of bytes read by UserData SMBus command.
VEODCoin	2	mV	2500	Empty voltage of coin cell.
VEODOffset	2	mV	2700	Base voltage for **VEOD** look-up table.

NOTES:

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10.0 ELECTRICAL CHARACTERISTICS

TABLE 10-1: ABSOLUTE MAXIMUM RATINGS

Symbol	Description	Min.	Max.	Units
V_{PIN}	Voltage Directly at any pin	-0.5	7.0	V
T_{BIAS}	Temperature under Bias	-20	85	°C
$T_{STORAGE}$	Storage Temperature (package dependent)	-35	120	°C

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

TABLE 10-2: DC CHARACTERISTICS (T_A = -20°C TO +85°C; V_{DD} (INTERNAL) = +2.8V ±7%)

Symbol	Description	Min.	Typ.	Max.	Units	Condition
VC1	Supply Voltage	2.5	—	5.5	V	**(Note 3)**
V_{DD}	Internal Regulated Supply Voltage	—	2.8	—	V	
I_{DD}	Supply Current – Run mode	—	100	125	µA	A/D active **(Note 1)**
I_{DDSLP}	Supply Current – Sleep mode	—	22	25	µA	Sleep mode **(Note 1)**
I_{DDSSLP}	Supply Current – Shelf-Sleep mode	—	600	1000	nA	Shelf-Sleep mode **(Note 1)**
V_{IL}	Input Low Voltage – GPIO	—	—	0.2 * V_{DD}	V	
V_{IH}	Input High Voltage – GPIO	0.8 * V_{DD}	—	—	V	
$I_{IL-IO0PU}$	GPIO Input Low Current – Pull-up mode	7	—	90	µA	Varies with battery voltage
I_{L-IO}	Leakage Current – IO pins Programmed as Outputs or Inputs without Pull-up	—	1	2	µA	
V_{OL-IO}	Output Low Voltage for GPIO	—	—	0.4	V	I_{OL} = 0.5 mA
V_{OH-IO}	Output High Voltage for GPIO Configured as Push-Pull	2.0	—	—	V	I_{OH} = 100 µA
V_{SR}	Sense Resistor Input Voltage Range	-152	—	152	mV	
I_{NTC}	Thermistor Output Current	—	5.2	—	µA	
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	
V_{IL-SMB} (1.8V)	Input Low Voltage for SMBus pins at 1.8V	-0.5	—	0.32	V	
V_{IH-SMB} (1.8V)	Input High Voltage for SMBus pins at 1.8V	1.48	—	2.12	V	
V_{OL-SMB} (1.8V)	Output Low Voltage for SMBus pins at 1.8V	—	—	0.32	V	
V_{OH-SMB} (1.8V)	Output High Voltage for SMBus pins at 1.8V	1.48	—	2.12	V	
$I_{PULLUP-SMB}$	Current through Pull-up Resistor or Current Source for SMBus pins	100	—	350	µA	
$I_{LEAK-SMB}$	Input Leakage Current – SMBus pins	—	—	±8	µA	

Note 1: Does not include current consumption due to external loading on pins.

2: 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.

3: A/D accuracy is maintained between 2.7 volts and 4.5 volts.

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TABLE 10-3: AC CHARACTERISTICS (T_A = -20°C TO +85°C; V_{DD} (INTERNAL) = +2.8V ±7%)

Symbol	Description	Min.	Typ.	Max.	Units	Condition
f_{RC}	Internal RC Oscillator Frequency	509.952	512	514.048	kHz	
$f_{A/D}$	Internal A/D Operating Clock	—	f_{RC}/16	—	kHz	
t_{POR}	Power-on Reset Delay	—	2	10	ms	Delay from time when VC1 voltage exceeds 2.7V
t_{SHELF}	Delay to Entry of Shelf-Sleep mode	1	—	—	ms	
t_{WAKE}	Delay to Exit of Shelf-Sleep mode	1	—	—	ms	SDA and SCL go high

TABLE 10-4: AC CHARACTERISTICS – SMBus/I²C™ (T_A = -20°C TO +85°C; V_{DD} (INTERNAL) = +2.8V ±7%)

Symbol	Description	Min.	Typ.	Max.	Units	Condition
f_{SMB}	SMBus Clock Operating Frequency	10	—	100	kHz	Slave mode
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	0	—	—	ns	
t_{SETUP}	Data Setup Time	250	—	—	ns	
t_{LOW}	Clock Low Period	4.7	—	—	µs	
t_{HIGH}	Clock High Period	4.0	—	50	µs	**(Note 2)**
$t_{LOW:SEXT}$	Message Buffering Time	—	—	10	ms	**(Notes 1, 3)**
$t_{HIGH:MEXT}$	Message Buffering Time	—	—	10	ms	**(Notes 1, 4)**
t_F	Clock/Data Fall Time	—	—	300	ns	**(Note 5)**
t_R	Clock/Data Rise Time	—	—	1000	ns	**(Note 5)**

Note 1: The PS810 will time-out 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 PS810 will reset the communication no later than $T_{TIMEOUT}$, max. of 35 ms.

2: t_{HIGH} max. provides a simple, ensured method for devices to detect bus Idle conditions.

3: $t_{LOW:SEXT}$ is the cumulative time a slave device is allowed to extend the clock cycles in one message from the initial start to the stop.

4: $t_{HIGH:MEXT}$ 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.

5: Rise and fall time is defined as follows: $t_R = (V_{ILMAX} – 0.15)$ to $(V_{IHMIN} + 0.15)$
$t_F = 0.9\ V_{DD}$ to $(V_{ILMAX} – 0.15)$

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TABLE 10-5: AC CHARACTERISTICS: SPS INTERFACE (T_A = -20°C TO +85°C; V_{DD} (INTERNAL) = +2.8V ±7%)

Symbol	Description	Min.	Typ.	Max.	Units	Condition
t_{CYCH}	Cycle Time, Host to Battery	190	—	—	µs	
t_{CYCB}	Cycle Time, Battery to Host	190	205	250	µs	
t_{STRH}	Start Time, Host to Battery	5	—	—	ns	
t_{STRB}	Start Time, Battery to Host	32	—	—	µs	
t_{DSUH}	Data Setup Time, Host to Battery	—	—	50	µs	
t_{DSUB}	Data Setup Time, Battery to Host	—	—	50	µs	
t_{DH}	Data Hold Time, Host to Battery	90	—	—	µs	
t_{DV}	Data Valid Time, Battery to Host	—	—	80	µs	
t_{SSUH}	Stop Setup, Host to Battery	—	—	145	µs	
t_{SSUB}	Stop Setup Time, Battery to Host	—	—	145	µs	
t_{RSPS}	Response Time of Battery to Host	190	—	320	µs	
t_B	Break Time	190	—	—	µs	
t_{BR}	Break Recovery Time	40	—	—	µs	

TABLE 10-6: A/D CONVERTER CHARACTERISTICS (T_A = -20°C TO +85°C; V_{REG} (INTERNAL) = +2.8V ±7%)

Symbol	Description	Min.	Typ.	Max.	Units	Condition
ADRES	A/D Converter Resolution	9	—	15	bits	
tCONV	A/D Conversion Measurement Time, n-bit + sign	—	$2^n/f_{A/D}$	—	s	
VADIN	A/D Converter Input Voltage Range (internal)	-150	—	150	mV	Differential **(Note 1)**
		0	—	300	mV	Single-Ended
EVGAIN	Supply Voltage Gain Error	—	—	0.100	%	
EVOFFSET	Compensated Offset Error	—	—	0.100	%	
ETEMP	Temperature Gain Error	—	—	0.100	%	
EINL	Integrated Nonlinearity Error	—	—	0.004	%	

Note 1: Voltage is internal at A/D converter inputs. SR, PTAT and NTC are measured directly. VC1 and VCOIN inputs are measured using internal level translation circuitry that scales the input voltage range appropriately for the converter.

TABLE 10-7: SILICON TIME BASE CHARACTERISTICS (T_A = -20°C TO +85°C; V_{REG} (INTERNAL) = +2.8V ±7%)

Symbol	Description	Min.	Typ.	Max.	Units	Condition
ETIME	Silicon Time Base Error	—	—	0.4	%	Bias Resistor ROSC Tolerance = 1% TL = ±25 ppm

TABLE 10-8: TEMPERATURE MEASUREMENT ACCURACY (T_A = -20°C TO +85°C; V_{REG} (INTERNAL) = +2.8V ±7%)

Symbol	Description	Min.	Typ.	Max.	Units	Condition
TRES	Reported Temperature Resolution	—	1	—	°C	
TACC	Reported Temperature Accuracy	-3	—	3	°C	VREG = 3.6V, requires calibration in the application
TDRIFT	Reported Temperature Drift	—	-2	—	°C/V	

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NOTES:

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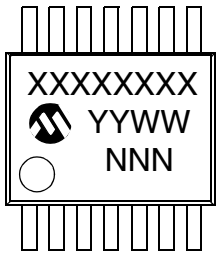
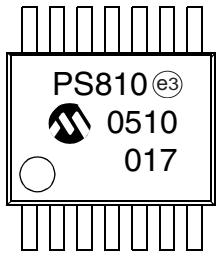
11.0 PACKAGING INFORMATION

11.1 Packaging Marking Information

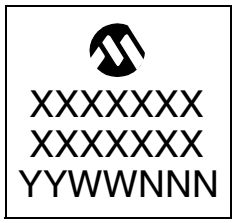
14-Lead TSSOP



Example



16-Lead QFN



Example

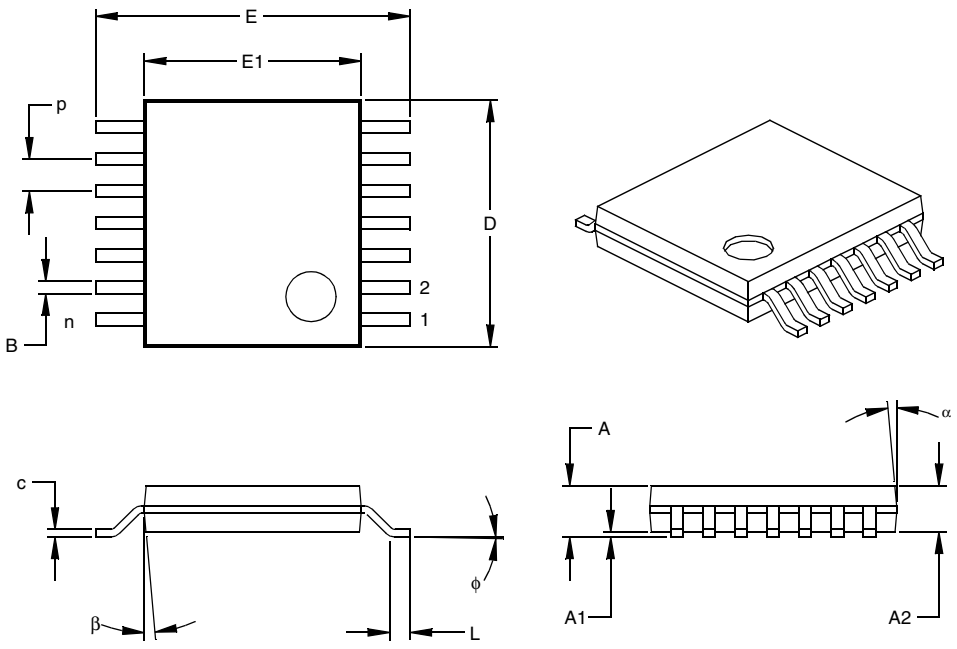
Legend:	XX...X	Customer-specific information
	Y	Year code (last digit of calendar year)
	YY	Year code (last 2 digits of calendar year)
	WW	Week code (week of January 1 is week ‘01’)
	NNN	Alphanumeric traceability code
	(e3)	Pb-free JEDEC designator for Matte Tin (Sn)
	*	This package is Pb-free. The Pb-free JEDEC designator ((e3)) can be found on the outer packaging for this package.

Note: In the event the full Microchip part number cannot be marked on one line, it will be carried over to the next line, thus limiting the number of available characters for customer-specific information.

11.2 Package Details

The following sections give the technical details of the packages.

14-Lead Plastic Thin Shrink Small Outline (ST) – 4.4 mm Body (TSSOP)



Units		INCHES			MILLIMETERS*		
Dimension Limits		MIN	NOM	MAX	MIN	NOM	MAX
Number of Pins	n		14			14	
Pitch	p		.026			0.65	
Overall Height	A			.043			1.10
Molded Package Thickness	A2	.033	.035	.037	0.85	0.90	0.95
Standoff §	A1	.002	.004	.006	0.05	0.10	0.15
Overall Width	E	.246	.251	.256	6.25	6.38	6.50
Molded Package Width	E1	.169	.173	.177	4.30	4.40	4.50
Molded Package Length	D	.193	.197	.201	4.90	5.00	5.10
Foot Length	L	.020	.024	.028	0.50	0.60	0.70
Foot Angle	ϕ	0	4	8	0	4	8
Lead Thickness	c	.004	.006	.008	0.09	0.15	0.20
Lead Width	B	.007	.010	.012	0.19	0.25	0.30
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 .005” (0.127mm) per side.
JEDEC Equivalent: MO-153
Drawing No. C04-087

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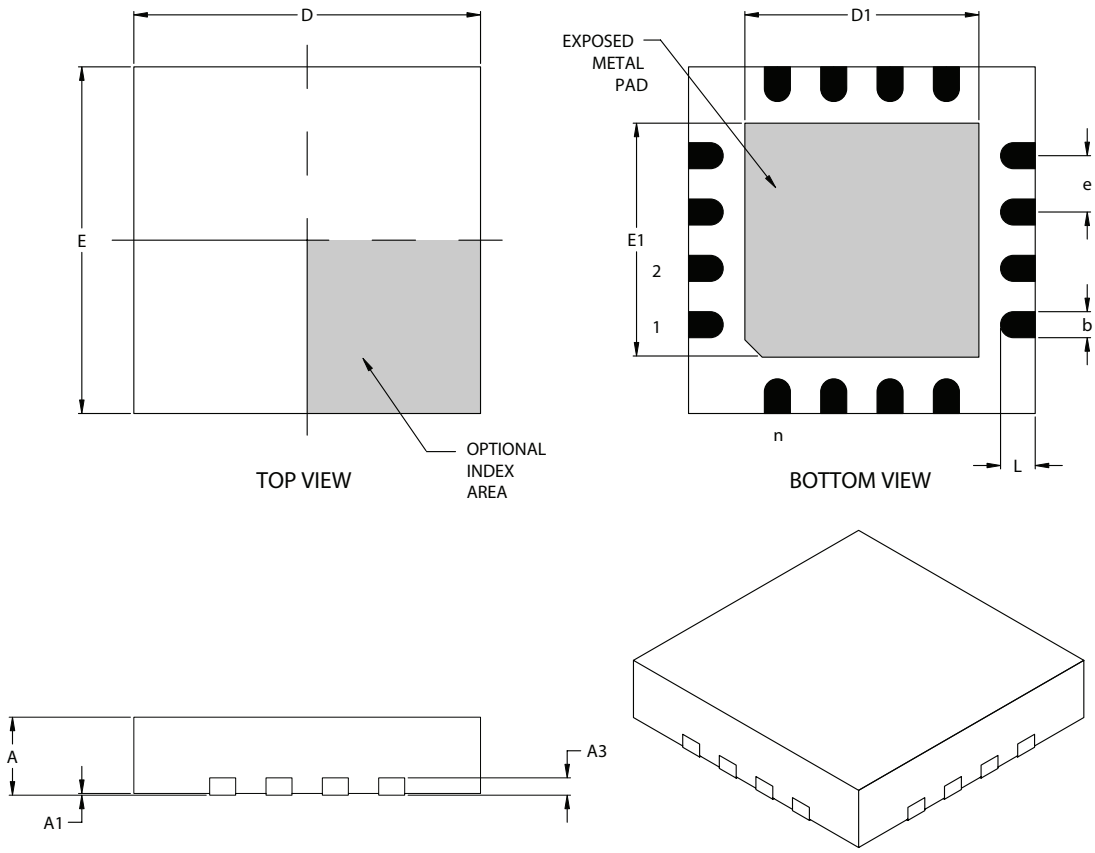
16-Lead Plastic Quad Flat No Lead Package (ML) 4x4x0.9 mm Body (QFN) – Saw Singulated



Units		INCHES			MILLIMETERS*		
Dimension Limits		MIN	NOM	MAX	MIN	NOM	MAX
Number of Pins	n		16			16	
Pitch	e		.026 BSC			0.65 BSC	
Overall Height	A	.031	.035	.039	0.80	0.90	1.00
Standoff	A1	.000	.001	.002	0.00	0.02	0.05
Contact Thickness	A3		.008 REF			0.20 REF	
Overall Width	E	.152	.157	.163	3.85	4.00	4.15
Exposed Pad Width	E2	.100	.106	.110	2.55	2.70	2.80
Overall Length	D	.152	.157	.163	3.85	4.00	4.15
Exposed Pad Length	D2	.100	.106	.110	2.55	2.70	2.80
Contact Width	b	.010	.012	.014	0.25	0.30	0.35
Contact Length	L	.012	.016	.020	0.30	0.40	0.50

*Controlling Parameter

Notes:

JEDEC equivalent: MO-220

Drawing No. C04-127

Revised 04-24-05

NOTES:

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