DS2780
Stand-Alone Fuel Gauge IC

www.maxim-ic.com

GENERAL DESCRIPTION

The DS2780 measures voltage, temperature and current, and estimates available capacity for rechargeable Lithium Ion and Lithium Ion Polymer batteries. Cell characteristics and application parameters used in the calculations are stored in on-chip EEPROM. The available capacity registers report a conservative estimate of the amount of charge that can be removed given the current temperature, discharge rate, stored charge and application parameters. Capacity estimation reported in mAh remaining and percentage of full.

APPLICATIONS

Digital Still Cameras

Sub-Notebook Computers

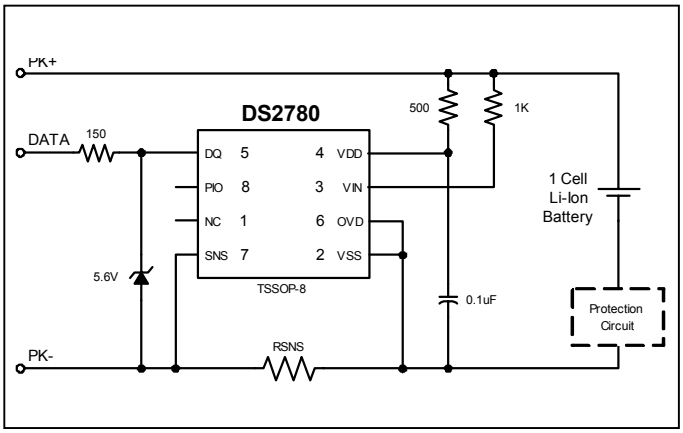
Handheld PC Data Terminals

3G Multimedia Wireless Handsets

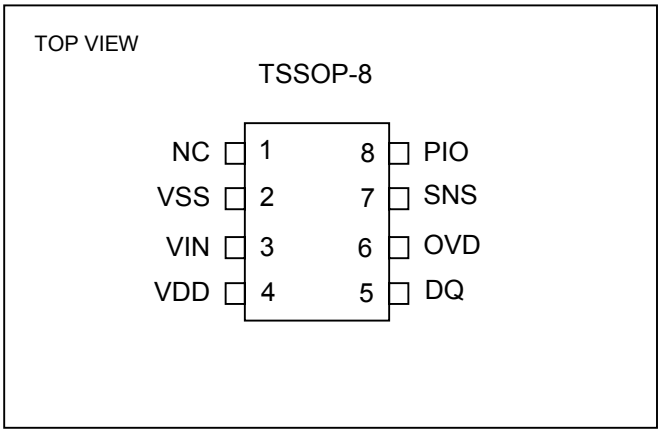
FEATURES

- Precision Voltage, Temperature, and Current Measurement System
- Accurate, Temperature Stable Internal Time Base
- Absolute and Relative Capacity Estimated from Coulomb Count, Discharge Rate, Temperature and Battery Cell Characteristics
- Accurate Warning of Low Battery Conditions
- Automatic Backup of Coulomb Count and Age Estimation to Nonvolatile (NV) EEPROM
- Gain and Tempco Calibration Allows the Use of Low-Cost Sense Resistors
- 24-Byte Battery/Application Parameter EEPROM
- 16-Byte User EEPROM
- Unique ID and Multidrop 1-Wire® Interface
- Tiny 8-pin TSSOP Package Embeds Easily in Battery Packs Using Thin Prismatic Cells

TYPICAL OPERATING CIRCUIT



PIN CONFIGURATION



ORDERING INFORMATION

PART	MARKING	PACKAGE INFORMATION
DS2780E	2780	TSSOP
DS2780E/T&R	2780	DS2780E Tape-and-Reel
DS2780E+	2780	Lead-Free TSSOP
DS2780E+T&R	2780	DS2780E+ Tape and Reel

1-Wire is a registered trademark of Dallas Semiconductor.

Note: *Some revisions of this device may incorporate deviations from published specifications known as errata. Multiple revisions of any device may be simultaneously available through various sales channels. For information about device errata, click here: www.maxim-ic.com/errata.*

ABSOLUTE MAXIMUM RATINGS

Voltage Range on Any Pin Relative to VSS	-0.3V to +6.0V
Voltage on VIN Relative to VSS	-0.3V to VDD+0.3
Operating Temperature Range	-40°C to +85°C
Storage Temperature Range	-55°C to +125°C
Soldering Temperature (10s)	+260°C

Stresses beyond those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to the absolute maximum rating conditions for extended periods may affect device.

RECOMMENDED DC OPERATING CHARACTERISTICS

(VDD = 2.5V to 5.5V, T_A = -20°C to +70°C, unless otherwise noted. Typical values are at T_A = +25°C)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Supply Voltage	VDD	(Note 1)	+2.5		+5.5	V
DQ, PIO, OVD Voltage Range		(Note 1)	-0.3		+5.5	V

DC ELECTRICAL CHARACTERISTICS

(VDD = 2.5V to 5.5V, T_A = -20°C to +70°C, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
ACTIVE Current	I_{ACTIVE}	2.5V ≤ VDD ≤ 4.2V		65	95	µA
					105	
SLEEP Mode Current	I_{SLEEP}	2.5V ≤ VDD ≤ 4.2V		1	3	µA
Input Logic High: DQ, PIO	V_{IH}	(Note 1)	1.5			V
Input Logic Low: DQ, PIO	V_{IL}	(Note 1)			0.6	V
Output Logic Low: DQ, PIO	V_{OL}	I_{OL} = 4mA (Note 1)			0.4	V
Pulldown Current: DQ, PIO	I_{PD}	V_{DQ}, V_{PIO} = 0.4V		0.2		µA
Input Logic High: OVD	V_{IH}	(Note 1)	0.7 x VDD			V
Input Logic Low: OVD	V_{IL}	(Note 1)			0.3 x VDD	V
VIN Input Resistance	R_{IN}		15			MΩ
DQ Capacitance	C_{DQ}			50		pF
DQ SLEEP Timeout	t_{SLEEP}	DQ < V_{IL} (Note 5)			2.2	s
Undervoltage SLEEP Threshold	V_{SLEEP}	(Note 1)	2.40	2.45	2.50	V

ELECTRICAL CHARACTERISTICS: TEMPERATURE, VOLTAGE, CURRENT

(V_{CC} = 2.5V to 5.5V, T_A = -20°C to +70°C, unless otherwise noted. Typical values are at T_A = +25°C.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Temperature Resolution	T_{LSB}			0.125		°C
Temperature Error	T_{ERR}				±3	°C
Voltage Resolution	V_{LSB}			4.88		mV
Voltage Full-Scale	V_{FS}		0		4.992	V
Voltage Error	V_{ERR}				±50	mV
Current Resolution	I_{LSB}			1.56		µV
Current Full-Scale	I_{FS}				±51.2	mV

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Current Gain Error	I_{GERR}	(Note 2)			±1	% Full-Scale
Current Offset Error	I_{OERR}	0°C ≤ T_A ≤ +70°C, 2.5V ≤ VDD ≤ 4.2V (Note 4)	- 7.82		+ 12.5	µV
Accumulated Current Offset	q_{OERR}	0°C ≤ T_A ≤ +70°C, 2.5V ≤ VDD ≤ 4.2V VSNS = VSS, (Notes 3, 4)	- 188		+ 0	µVhr/ day
Timebase Error	t_{ERR}	VDD = 3.8V, T_A = +25°C			±1	%
		0°C ≤ T_A ≤ +70°C, 2.5V ≤ VDD ≤ 4.2V			±2	
					±3	

ELECTRICAL CHARACTERISTICS: 1-WIRE INTERFACE, STANDARD

(V_{CC} = 2.5V to 5.5V, T_A = -20°C to +70°C.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Time Slot	t_{SLOT}		60		120	µs
Recovery Time	t_{REC}		1			µs
Write-0 Low Time	t_{LOW0}		60		120	µs
Write-1 Low Time	t_{LOW1}		1		15	µs
Read Data Valid	t_{RDV}				15	µs
Reset Time High	t_{RSTH}		480			µs
Reset Time Low	t_{RSTL}		480		960	µs
Presence Detect High	t_{PDH}		15		60	µs
Presence Detect Low	t_{PDL}		60		240	µs

ELECTRICAL CHARACTERISTICS: 1-WIRE INTERFACE, OVERDRIVE

(V_{CC} = 2.5V to 5.5V, T_A = -20°C to +70°C.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Time Slot	t_{SLOT}		6		16	µs
Recovery Time	t_{REC}		1			µs
Write-0 Low Time	t_{LOW0}		6		16	µs
Write-1 Low Time	t_{LOW1}		1		2	µs
Read Data Valid	t_{RDV}				2	µs
Reset-Time High	t_{RSTH}		48			µs
Reset-Time Low	t_{RSTL}		48		80	µs
Presence-Detect High	t_{PDH}		2		6	µs
Presence-Detect Low	t_{PDL}		8		24	µs

EEPROM RELIABILITY SPECIFICATION

(V_{CC} = 2.5V to 5.5V, T_A = -20°C to +70°C, unless otherwise noted. Typical values are at T_A = +25°C.)

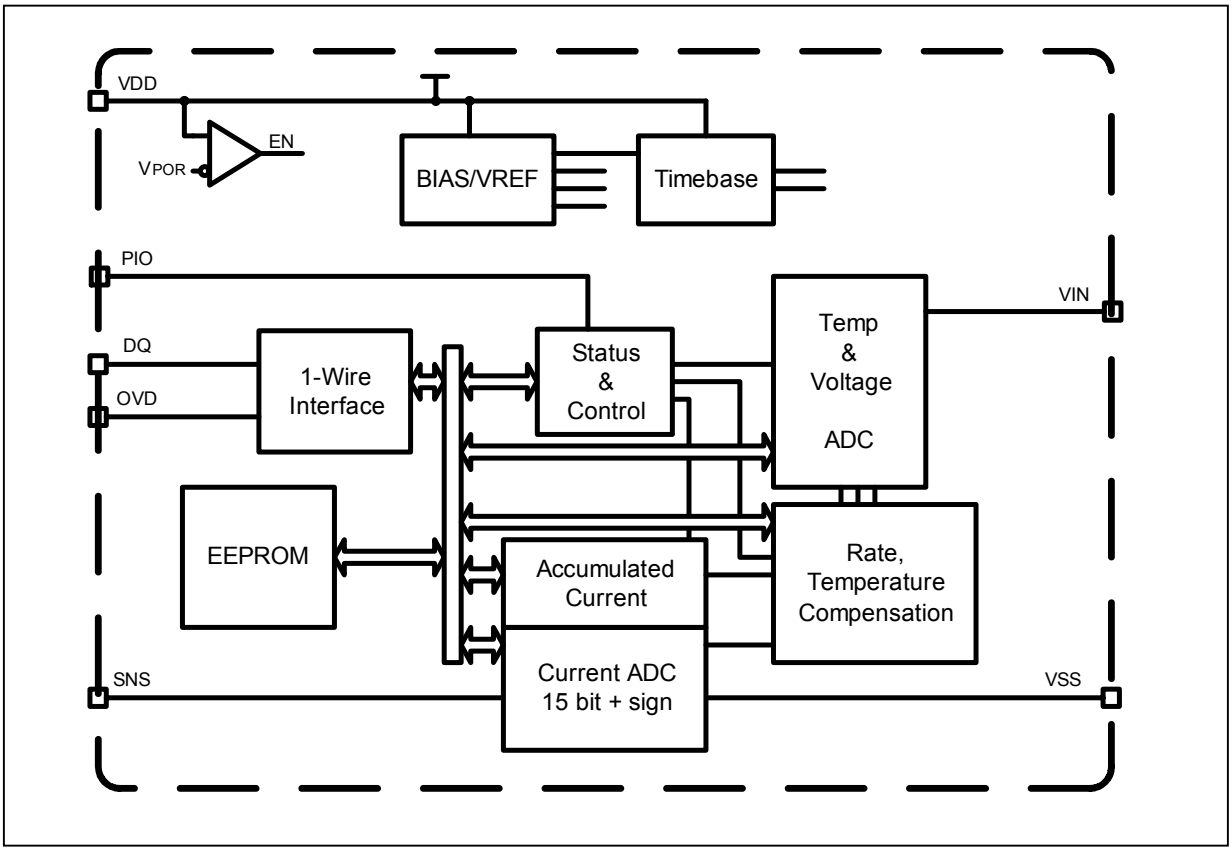
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
EEPROM Copy Time	t_{EEC}				10	ms
EEPROM Copy Endurance	N_{EEC}	T_A = +50°C	50,000			cycles

Note 1: All voltages are referenced to VSS.
Note 2: Factory calibrated accuracy. Higher accuracy can be achieved by in-system calibration by the user.
Note 3: Accumulation bias register set to 00h.
Note 4: Parameters guaranteed by design.
Note 5: The application must wait for the maximum DQ SLEEP Timeout to confirm that the IC has entered sleep mode.

PIN DESCRIPTION

PIN	NAME	FUNCTION
1	NC	**Not Connected**. Pin not connected internally, float or connect to VSS.
2	VSS	**Device Ground.** Connect directly to the negative terminal of the battery cell. Connect the sense resistor between VSS and SNS.
3	VIN	**Voltage Sense Input.** The voltage of the battery cell is monitored through this input pin.
4	VDD	**Power-Supply Input.** Connect to the positive terminal of the battery cell through a decoupling network.
5	DQ	**Data Input/Output**. 1-Wire data line. Open-drain output driver. Connect this pin to the DATA terminal of the battery pack. This pin has a weak internal pulldown (I_{PD}) for sensing pack disconnection from host or charger.
6	OVD	**1-Wire Bus Speed Control.** Input logic level selects the speed of the 1-Wire bus. Logic 1 selects overdrive (OVD) and Logic 0 selects standard timing (STD). On a multidrop bus, all devices must operate at the same speed.
7	SNS	**Sense Resistor Connection.** Connect to the negative terminal of the battery pack. Connect the sense resistor between VSS and SNS.
8	PIO	**Programmable I/O Pin.** Can be configured as input or output to monitor or control user-defined external circuitry. Output driver is open drain. This pin has an weak internal pulldown (I_{PD}).

Figure 1. Block Diagram



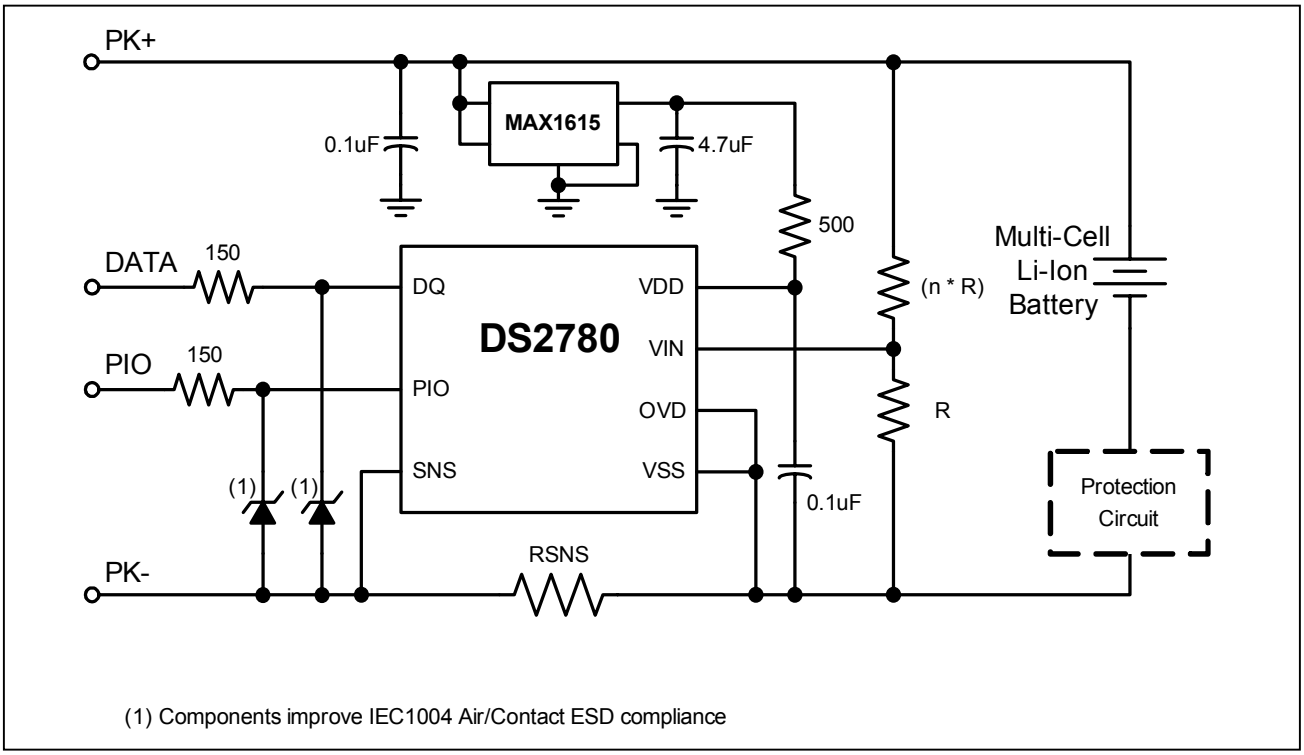
DETAILED DESCRIPTION

The DS2780 operates directly from 2.5V to 5.5V and supports single cell Lithium-ion battery packs. As shown in Figure 2, the DS2780 accommodates multicell applications by adding a voltage regulator for VDD and voltage divider for VIN. Nonvolatile storage is provided for cell compensation and application parameters. Host side development of fuel-gauging algorithms is eliminated. On-chip algorithms and convenient status reporting of operating conditions reduce the serial polling required of the host processor.

Additionally, 16 bytes of EEPROM memory are made available for the exclusive use of the host system and/or pack manufacturer. The additional EEPROM memory can be used to facilitate battery lot and date tracking and non-volatile storage of system or battery usage statistics.

A Dallas 1-Wire interface provides serial communication at the standard 16kbps or overdrive 140kbps speeds allows access to data registers, control registers and user memory. A unique, factory programmed 64-bit registration number (8-bit family code + 48-bit serial number + 8-bit CRC) assures that no two parts are alike and enables absolute traceability. The Dallas 1-Wire interface on the DS2780 supports multidrop capability so that multiple slave devices may be addressed with a single pin.

Figure 2. Multicell Application Example



POWER MODES

The DS2780 has two power modes: ACTIVE and SLEEP. On initial power up, the DS2780 defaults to ACTIVE mode. While in ACTIVE mode, the DS2780 is fully functional with measurements and capacity estimation continuously updated. In SLEEP mode, the DS2780 conserves power by disabling measurement and capacity estimation functions, but preserves register contents. SLEEP mode is entered under two different conditions and an enable bit for each condition makes entry into SLEEP optional. SLEEP mode can be enabled using the Power Mode (PMOD) bit or the Under Voltage Enable (UVEN) bit.

The PMOD type SLEEP is entered if the PMOD bit is set AND DQ is low for t_{SLEEP} (2s nominal). The condition of DQ low for t_{SLEEP} can be used to detect a pack disconnection or system shutdown, in which no charge or discharge current will flow. A PMOD SLEEP condition transitions back to ACTIVE mode when DQ is pulled high.

The second option for entering SLEEP is an under voltage condition. When the UVEN bit is set, the DS2780 transitions to SLEEP if the voltage on VIN is less than V_{SLEEP} (2.45V nominal) AND DQ is stable at a low or high logic level for t_{SLEEP}. An under-voltage condition occurs when a pack is fully discharged, where loading on the battery should be minimized. UVEN type SLEEP relieves the battery of the I_{ACTIVE} load until communication on DQ resumes.

NOTE: *PMOD and UVEN SLEEP features must be disabled when a battery is charged on an external charger that does not connect to the DQ pin. PMOD SLEEP can be used if the charger pulls DQ high. UVEN SLEEP can be used if the charger toggles DQ. The DS2780 remains in SLEEP and therefore does not measure or accumulate current when a battery is charged on a charger that failures properly drive DQ.*

INITIATING COMMUNICATION IN SLEEP

When beginning communication with a DS2780 in PMOD SLEEP, DQ must be pulled up first and then a 1-Wire Reset pulse must be issued by the master. In UVEN SLEEP, the procedure depends on the state of DQ when UVEN SLEEP was entered. If DQ was low, DQ must be pulled up and then a 1-Wire Reset pulse must be issued by the master as with PMOD SLEEP. If DQ was high when UVEN SLEEP was entered, then the DS2780 is prepared to receive a 1-Wire reset from the master. In the first two cases with DQ low during SLEEP, the DS2780 *does not respond* to the first rising edge of DQ with a presence pulse.

VOLTAGE MEASUREMENT

Battery voltage is measured at the VIN input with respect to VSS over a range of 0V to 4.992V, with a resolution of 4.88mV. The result is updated every 440ms and placed in the VOLTAGE register in two's compliment form. Voltages above the maximum register value are reported at the maximum value; voltages below the minimum register value are reported at the minimum value. The format of the voltage register is shown in Figure 3.

Figure 3. Voltage Register Format

VOLT Read Only

MSB—Address 0Ch

S	2^9	2^8	2^7	2^6	2^5	2^4	2^3

MSb LSb

LSB—Address 0Dh

2^2	2^1	2^0	X	X	X	X	X

MSb LSb

"S": sign bit(s), "X": reserved

Units: 4.88mV

VIN is usually connected to the positive terminal of a single cell Lithium-Ion battery via a 1kΩ resistor. The input impedance is sufficiently large (15MΩ) to be connected to a high impedance voltage divider in order to support multiple cell applications. The pack voltage should be divided by the number of series cells to present a single cell average voltage to the VIN input. In Figure 2, the value of R can be up to 1MΩ without incurring significant error due to input loading.

TEMPERATURE MEASUREMENT

The DS2780 uses an integrated temperature sensor to measure battery temperature with a resolution of 0.125°C. Temperature measurements are updated every 440ms and placed in the temperature register in two's complement form. The format of the temperature register is shown in Figure 4.

Figure 4. Temperature Register Format

TEMP Read Only

MSB—Address 0Ah

S	2^9	2^8	2^7	2^6	2^5	2^4	2^3

MSb LSb

LSB—Address 0Bh

2^2	2^1	2^0	X	X	X	X	X

MSb LSb

"S": sign bit(s), "X": reserved

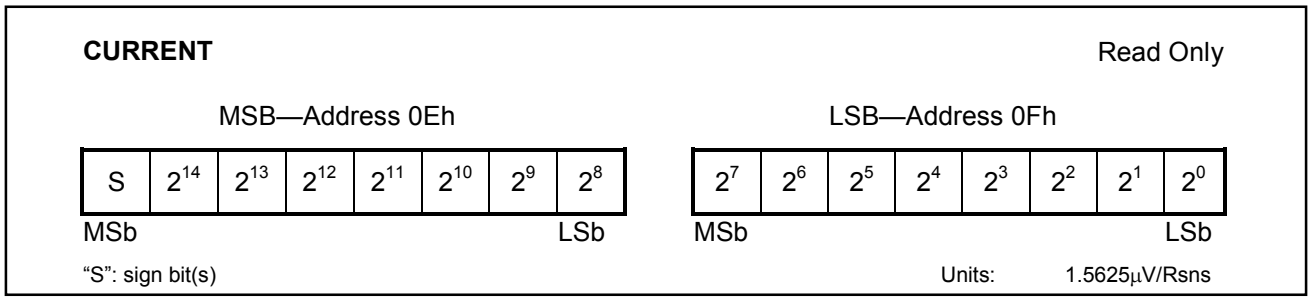
Units: 0.125°C

CURRENT MEASUREMENT

In the ACTIVE mode of operation, the DS2780 continually measures the current flow into and out of the battery by measuring the voltage drop across a low-value current-sense resistor, R_{SNS}. The voltage-sense range between SNS and VSS is ±51.2mV. The input linearly converts peak signal amplitudes up to 102.4mV as long as the continuous signal level (average over the conversion cycle period) does not exceed ±51.2mV. The ADC samples the input differentially at 18.6kHz and updates the Current register at the completion of each conversion cycle.

The Current register is updated every 3.515s with the current conversion result in two's complement form. Charge currents above the maximum register value are reported at the maximum value (7FFFh = +51.2mV). Discharge currents below the minimum register value are reported at the minimum value (8000h = -51.2mV).

Figure 5. Current Register Format

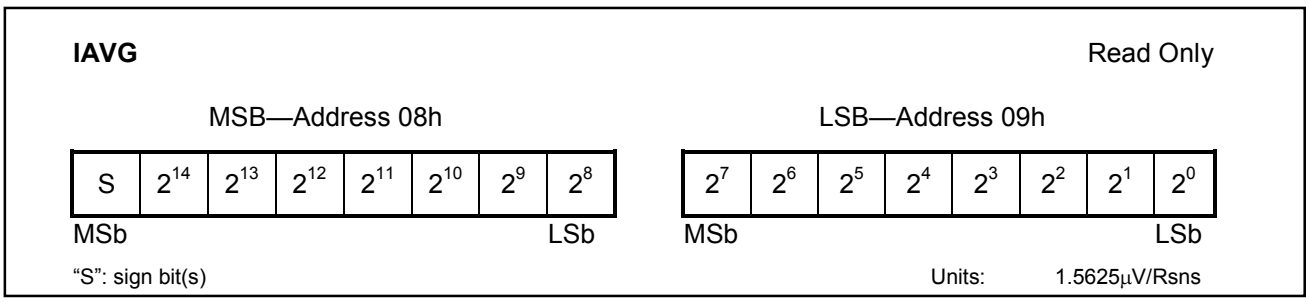


CURRENT RESOLUTION (1 LSB)				
VSS - VSNS	R_{SNS}			
	20mΩ	15mΩ	10mΩ	5mΩ
1.5625µV	78.13µA	104.2µA	156.3µA	312.5µA

AVERAGE CURRENT MEASUREMENT

The Average Current register reports an average current level over the preceding 28 seconds. The register value is updated every 28s in two's complement form, and is the average of the 8 preceding Current register updates. The format of the Average Current register is shown in Figure 6. Charge currents above the maximum register value are reported at the maximum value (7FFFh = +51.2mV). Discharge currents below the minimum register value are reported at the minimum value (8000h = -51.2mV).

Figure 6. Average Current Register Format



CURRENT OFFSET CORRECTION

Every 1024th conversion, the ADC measures its input offset to facilitate offset correction. Offset correction occurs approximately once per hour. The resulting correction factor is applied to the subsequent 1023 measurements. During the offset correction conversion, the ADC does not measure the sense resistor signal. A maximum error of 1/1024 in the accumulated current register (ACR) is possible; however, to reduce the error, the current measurement made just prior to the offset conversion is displayed in the current register and is substituted for the dropped current measurement in the current accumulation process. This results in an accumulated current error due to offset correction of less than 1/1024.

CURRENT MEASUREMENT CALIBRATION

The DS2780's current measurement gain can be adjusted through the RSGAIN register, which is factory-calibrated to meet the data sheet specified accuracy. RSGAIN is user accessible and can be reprogrammed after module or pack manufacture to improve the current measurement accuracy. Adjusting RSGAIN can correct for variation in an external sense resistor's nominal value, and allows the use of low-cost, non-precision current sense resistors. RSGAIN is an 11 bit value stored in 2 bytes of the Parameter EEPROM Memory Block. The RSGAIN value adjusts the gain from 0 to 1.999 in steps of 0.001 (precisely 2^{-10}). The user must program RSGAIN cautiously to ensure accurate current measurement. When shipped from the factory, the gain calibration value is stored in two separate locations in the Parameter EEPROM Block, RSGAIN which is reprogrammable and FRSGAIN which is read only. RSGAIN determines the gain used in the current measurement. The read-only FRSGAIN is provided to preserve the factory value only and is not used in the current measurement.

SENSE RESISTOR TEMPERATURE COMPENSATION

The DS2780 is capable of temperature compensating the current sense resistor to correct for variation in a sense resistor's value over temperature. The DS2780 is factory programmed with the sense resistor temperature coefficient, RSTC, set to zero, which turns off the temperature compensation function. RSTC is user accessible and can be reprogrammed after module or pack manufacture to improve the current accuracy when using a high temperature coefficient current-sense resistor. RSTC is an 8-bit value stored in the Parameter EEPROM Memory Block. The RSTC value sets the temperature coefficient from 0 to +7782ppm/ºC in steps of 30.5ppm/ºC. The user must program RSTC cautiously to ensure accurate current measurement.

Temperature compensation adjustments are made when the Temperature register crosses 0.5°C boundaries. The temperature compensation is most effective with the resistor placed as close as possible to the VSS terminal to optimize thermal coupling of the resistor to the on-chip temperature sensor. If the current shunt is constructed with a copper PCB trace, run the trace under the DS2780 package if possible.

CURRENT ACCUMULATION

Current measurements are internally summed, or accumulated, at the completion of each conversion period with the results displayed in the Accumulated Current Register (ACR). The accuracy of the ACR is dependent on both the current measurement and the conversion timebase. The ACR has a range of 0 to 409.6mVh with an LSb of 6.25μVh. Additional read-only registers (ACRL) hold fractional results of each accumulation to avoid truncation errors. Accumulation of charge current above the maximum register value is reported at the maximum register value (7FFFh); conversely, accumulation of discharge current below the minimum register value is reported at the minimum value (8000h).

Charge currents (positive Current register values) less than 100μV are not accumulated in order to mask the effect of accumulating small positive offset errors over long periods. This limits the minimum charge current, for coulomb-counting purposes, to 5mA for RSNS = 0.020Ω and 20mA for RSNS = 0.005Ω.

Read and write access is allowed to the ACR. The ACR must be written MSByte first then LSByte. Whenever the ACR is written, the fractional accumulation result bits are cleared. The write must be completed within 3.515s (one ACR register update period). A write to the ACR forces the ADC to perform an offset correction conversion and update the internal offset correction factor. Current measurement and accumulation begins with the second conversion following a write to the ACR. Writing ACR clears the fractional values in ACRL. The Format of the ACR register is shown in Figure 7, and the format of ACRL is shown in Figure 8.

In order to preserve the ACR value in case of power loss, the ACR value is backed up to EEPROM. The ACR value is recovered from EEPROM on power-up. See the Memory Map in Table 2 for specific address location and backup frequency.

Figure 7. Accumulated Current Register Format, ACR

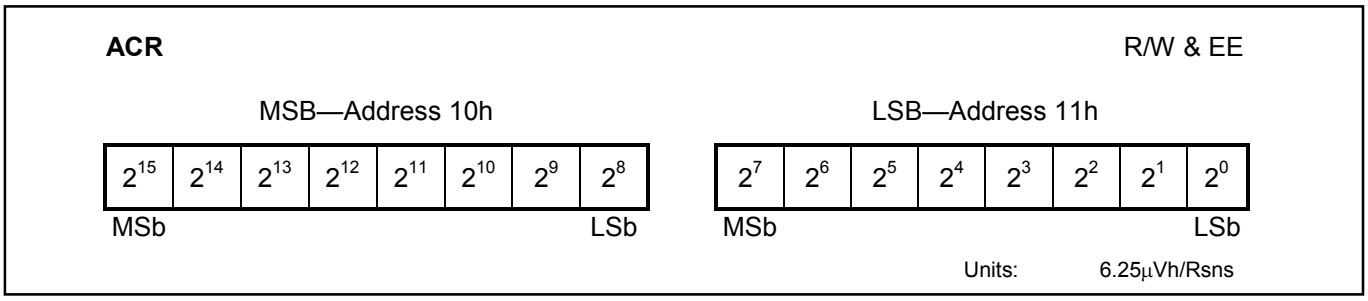
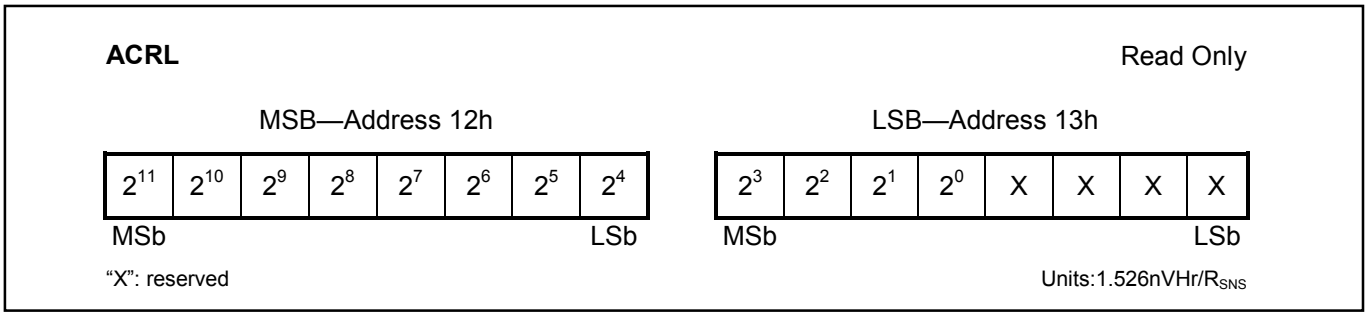


Figure 8. Fractional/Low Accumulated Current Register Format, ACRL



ACR LSb				
VSS - VSNS	R_{SNS}			
	20mΩ	15mΩ	10mΩ	5mΩ
6.25μVh	312.5μAh	416.7μAh	625μAh	1.250mAh

ACR RANGE				
VSS - VSNS	R_{SNS}			
	20mΩ	15mΩ	10mΩ	5mΩ
±409.6mVh	±20.48Ah	±27.30Ah	±40.96Ah	±81.92Ah

ACCUMULATION BIAS

The Accumulation Bias register (AB) allows an arbitrary bias to be introduced into the current-accumulation process. The AB can be used to account for currents that do not flow through the sense resistor, estimate currents too small to measure, estimate battery self-discharge or correct for static offset of the individual DS2780 device. The AB register allows a user programmed constant positive or negative polarity bias to be included in the current accumulation process. The user-programmed two's compliment value, with bit weighting the same as the current register, is added to the ACR once per current conversion cycle. The AB value is loaded on power-up from EEPROM memory. The format of the AB register is shown in Figure 9.

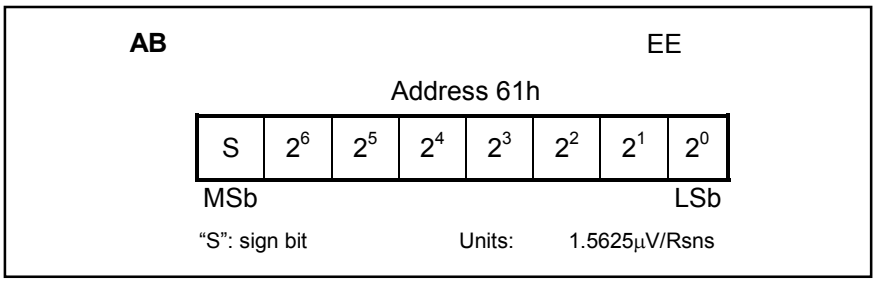



Figure 9. Accumulation Bias Register Formats