MAX17055 7µA 1-Cell Fuel Gauge with ModelGauge m5 EZ

General Description

The MAX17055 is a low 7µA operating current fuel gauge that implements Maxim ModelGauge™ m5 EZ algorithm. ModelGauge m5 EZ makes fuel gauge implementation easy by eliminating battery characterization requirements and simplifying host software interaction. The ModelGauge m5 EZ robust algorithm provides tolerance against battery diversity for most lithium batteries and applications.

ModelGauge m5 EZ algorithm combines the short-term accuracy and linearity of a coulomb counter with the long-term stability of a voltage-based fuel gauge, along with temperature compensation to provide industry-leading fuel gauge accuracy. The MAX17055 automatically compensates for cell aging, temperature, and discharge rate, and provides accurate state of charge (SOC in %) and remaining capacity in milliampere-hours (mAh). As the battery approaches the critical region near empty, the ModelGauge m5 algorithm invokes a special compensation that eliminates any error. It also provides three methods for reporting the age of the battery: reduction in capacity, increase in battery resistance, and cycle odometer.

The MAX17055 provides precision measurements of current, voltage, and temperature. Temperature of the battery pack is measured using an internal temperature measurement or external thermistor. A 2-wire I^2C interface provides access to data and control registers.

The MAX17055 is available in a tiny, lead-free 0.4mm pitch 1.4mm x 1.5mm, 9-pin WLP package, and a 2mm x 2.5mm, 10-pin TDFN package.

Benefits and Features

- ModelGauge m5 EZ
  - No Characterization Required for EZ Performance
  - Robust Against Battery Variation
  - Eliminates Error Near Empty Voltage
  - Eliminates Coulomb Counter Drift
  - Current, Temperature, and Age Compensated
  - Does Not Require Empty, Full, or Idle States
- Low 7µA Operating Current
- Wide Sense Resistor Range
  - 1mΩ to 1000mΩ
  - PCB Metal Sensing + Temperature Compensation
- Supports Li+ and Variants Including $LiFePO_4$
- ±1°C Internal Temperature or Thermistor
- Dynamic Power Estimates Power Capability During Discharge
- Time-to-Empty and Time-to-Full Estimation
  - Constant Power or Constant Current
- Predicts Remaining Capacity Under Theoretical Load
- Precision Measurement System
  - No Calibration Required
- Alert Indicator for Voltage, SOC, Temperature, Current and 1% SOC Change

Applications

- Wearables, Smartwatches
- Smartphones
- Tablets, 2-in-1 Laptops
- Bluetooth Headsets
- Health and Fitness Monitors
- Digital Still, Video, and Action Cameras
- Medical Devices
- Handheld Computers and Terminals
- Wireless Speakers
- Home and Building Automation, Sensors
- Portable Game Players
- Toys

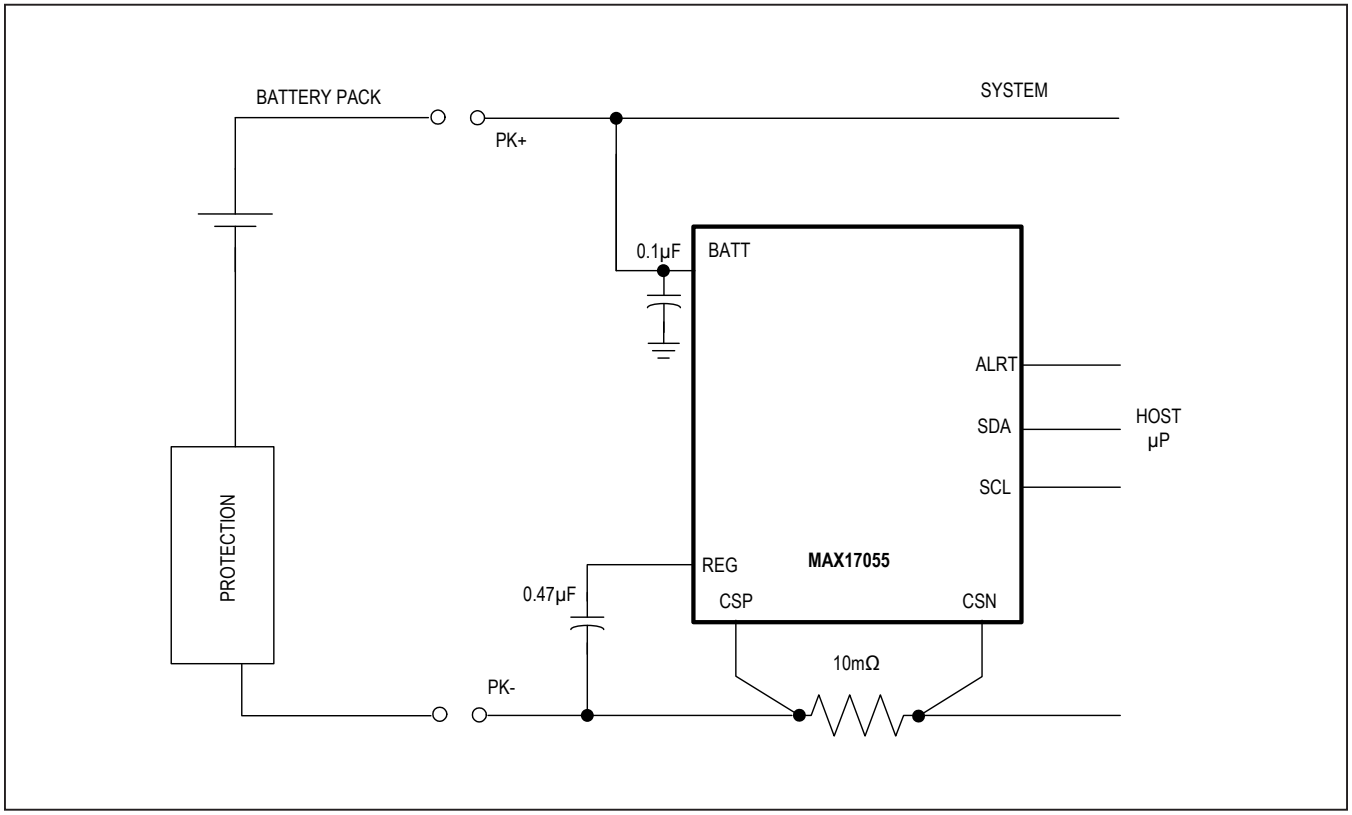
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Ordering Information *appears at end of data sheet.*

19-8726; Rev 0; 1/17

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Simple Fuel Gauge Circuit Diagram



Absolute Maximum Ratings

BATT to CSP .....-0.3V to +6V
ALRT to CSP .....-0.3V to +17V
REG to CSP .....-0.3V to +2.2V
THRM to CSP..... -0.3V to V_{BATT} + 0.3V
AIN to CSP ..... -0.3V to V_{BATT} + 0.3V
CSN to CSP .....-2V to +2V
SDA, SCL to CSP.....-0.3V to +6V

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 absolute maximum rating conditions for extended periods may affect device reliability.

Package Information

WLP

Package Code	W91N1+1
Outline Number	**21-100129**
Land Pattern Number	Refer to **Application Note 1891**
Thermal Resistance, Four-Layer Board:	
Junction to Ambient (θ_{JA})	84ºC/W

TDFN

Package Code	T102A2+1C
Outline Number	**21-100013**
Land Pattern Number	**90-100007**
Thermal Resistance, Four-Layer Board:	
Junction to Ambient (θ_{JA})	102ºC/W
Junction to Case (θ_{JC})	2.9ºC/W

For the latest package outline information and land patterns (footprints), go to **www.maximintegrated.com/packages**. Note that a "+", "#", or "-" in the package code indicates RoHS status only. Package drawings may show a different suffix character, but the drawing pertains to the package regardless of RoHS status.

Package thermal resistances were obtained using the method described in JEDEC specification JESD51-7, using a four-layer board. For detailed information on package thermal considerations, refer to **www.maximintegrated.com/thermal-tutorial**.

Electrical Characteristics

(V_{BATT} = 2.3V to 4.9V, T_A = -40ºC to 85ºC, typical values are T_A = +25ºC, Limits are 100% tested at T_A = +25°C. Limits over the operating temperature range and relevant supply voltage range are guaranteed by design and characterization. Specifications marked GBD are guaranteed by design and not production tested.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
POWER SUPPLY						
Supply Voltage	V_{BATT}	(Note 1)	2.3		4.9	V
Startup Voltage	V_{BATTSU}	(Note 1)			3.0	V
Shutdown Supply Current	I_{DD0}	$T_A \le +50°C$		0.5	0.9	µA
Hibernate Supply Current	I_{DD1}	$T_A \le +50°C$, average current		7	12	µA
Active Supply Current	I_{DD2}	$T_A \le +50°C$, not including thermistor measurement current		18	30	µA
Regulation Voltage	V_{REG}			1.8		V
ANALOG-TO-DIGITAL CONVERSION						
BATT Measurement Error	V_{GERR}	T_A = +25°C	-7.5		+7.5	mV
		T_A = -40°C to +85°C	-20		+20	
BATT Measurement Resolution	V_{LSB}			78.125		µV
BATT Measurement Range	V_{FS}		2.3		4.9	V
Current Measurement Offset Error	I_{OERR}	V_{CSN} = 0V, long-term average		±1.5		µV
Current Measurement Gain Error	I_{GERR}		-1		+1	% of reading
Current Measurement Resolution	I_{LSB}			1.5625		µV
Current Measurement Range	I_{FS}			±51.2		mV
Internal Temperature Measurement Error	TI_{GERR}			±1		ºC
Internal Temprature Measurement Resolution	TI_{LSB}			0.00391		ºC
INPUT/OUTPUT						
Output Drive High, THRM	V_{OH}	I_{OH} = -1mA, V_{BATT} = 2.3V	V_{BATT} - 0.1			V
Output Drive Low, ALRT, SDA	V_{OL}	I_{OL} = 4mA, V_{BATT} = 2.3V			0.4	V
Input Logic-High, ALRT, SCL, SDA	V_{IH}		1.5			V
Input Logic-Low, ALRT, SCL, SDA	V_{IL}				0.5	V

Electrical Characteristics (continued)

(V_{BATT} = 2.3V to 4.9V, T_A = -40ºC to 85ºC, typical values are T_A = +25ºC, Limits are 100% tested at T_A = +25°C. Limits over the operating temperature range and relevant supply voltage range are guaranteed by design and characterization. Specifications marked GBD are guaranteed by design and not production tested.)

PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
Battery Detach Detection Threshold	V_{DET}	Observed between AIN and CSP, as a fraction of the voltage between THRM and CSP, AIN rising	92.5	95	97.5	%
Battery Detach Detection Threshold Hysteresis	$V_{DET-HYS}$	AIN falling		1		%
Battery Detach Comparator Delay	t_{TOFF}	AIN step from 70% to 100% of THRM voltage to ALRT falling, EnAIN = 1, FTHRM = 1			100	µs
RESISTANCE AND LEAKAGE						
Leakage Current, CSN, ALRT, AIN, THRM	I_{LEAK}	V_{ALRT} < 15V	-1		+1	µA
Input Pulldown Current	I_{PD}	V_{SDA}, V_{SCL} = 0.4V	0.05	0.2	0.4	µA
2-WIRE INTERFACE						
SCL Clock Frequency	f_{SCL}	(Note 2)	0		400	kHz
Bus Free Time Between a STOP and START Condition	t_{BUF}		1.3			µs
Hold Time (Repeated) START Condition	$t_{HD:STA}$	(Note 3)	0.6			µs
Low Period of SCL Clock	t_{LOW}		1.3			µs
High Period of SCL Clock	t_{HIGH}		0.6			µs
Setup Time for a Repeated START Condition	$t_{SU:STA}$		0.6			µs
Data Hold Time	$t_{HD:DAT}$	(Notes 4, 5)	0		0.9	µs
Data Setup Time	$t_{SU:DAT}$	(Note 4)	100			ns
Rise Time of Both SDA and SCL Signals	t_R		5		300	ns
Fall Time of Both SDA and SCL Signals	t_F		5		300	ns
Setup Time for STOP Condition	$t_{SU:STO}$	(Note 6)	0.6			µs
Spike Pulse Width Suppressed by Input Filter	t_{SP}	(Note 7)			50	ns
Capacitive Load for Each Bus Line	C_B				400	pF
SCL, SDA Input Capacitance	C_{BIN}			6		pF

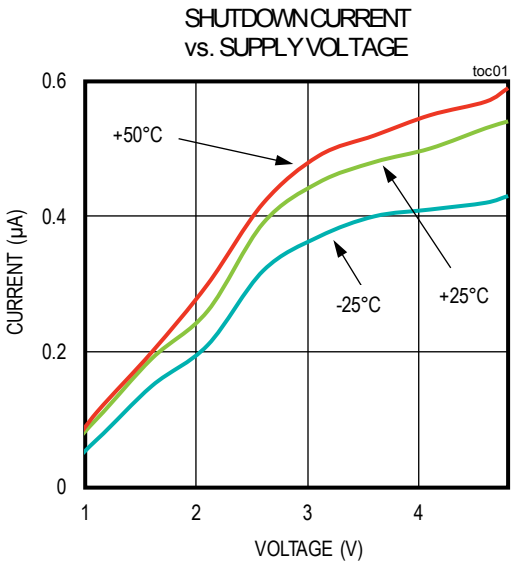
Electrical Characteristics (continued)

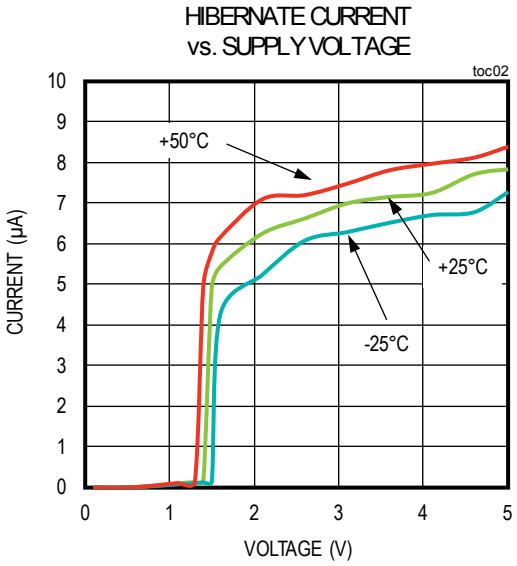
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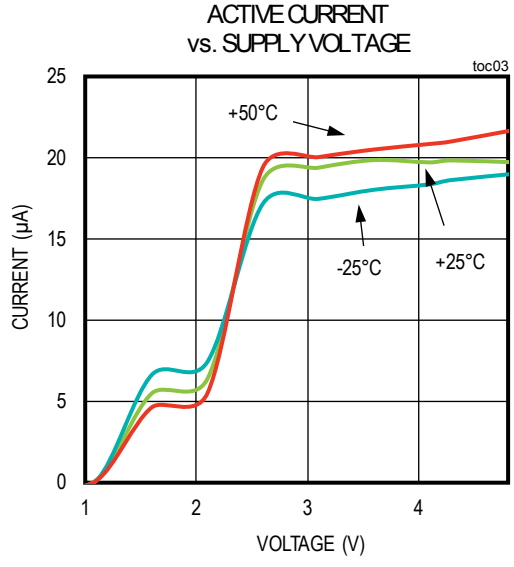
PARAMETER	SYMBOL	CONDITIONS	MIN	TYP	MAX	UNITS
TIMING						
Time-Base Accuracy	t_{ERR}	T_A = +25°C	-1		+1	%
AIN Precharge Time	t_{PRE}	Time between turning on the THRM pullup and analog-to-digital conversions, the time constant on AIN must be smaller than 1/10 of this value	8.48			ms

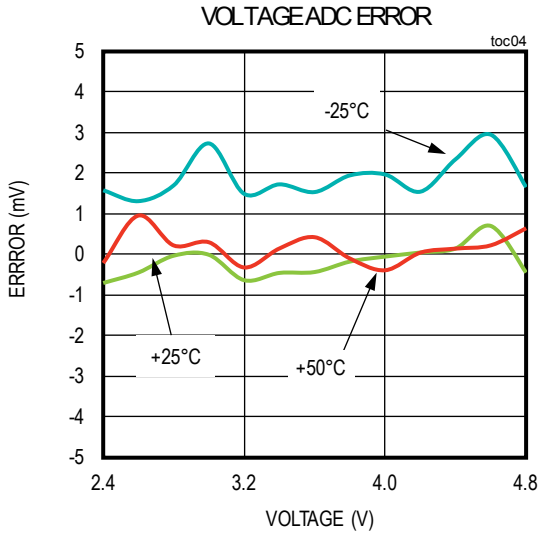
Note 1: All voltages are referenced to CSP.:
Note 2: Timing must be fast enough to prevent the IC from entering shutdown mode due to bus low for a period greater than the shutdown timer setting.
Note 3: f_{SCL} must meet the minimum clock low time plus the rise/fall times.
Note 4: The maximum $t_{HD:DAT}$ has only to be met if the device does not stretch the low period (t_{LOW}) of the SCL signal.
Note 5: This device internally provides a hold time of at least 100ns for the SDA signal (referred to the minimum V_{IH} of the SCL signal) to bridge the undefined region of the falling edge of SCL.
Note 6: Filters on SDA and SCL suppress noise spikes at the input buffers and delay the sampling instant.
Note 7: CB is the total capacitance of one bus line in pF.

Typical Operating Characteristics

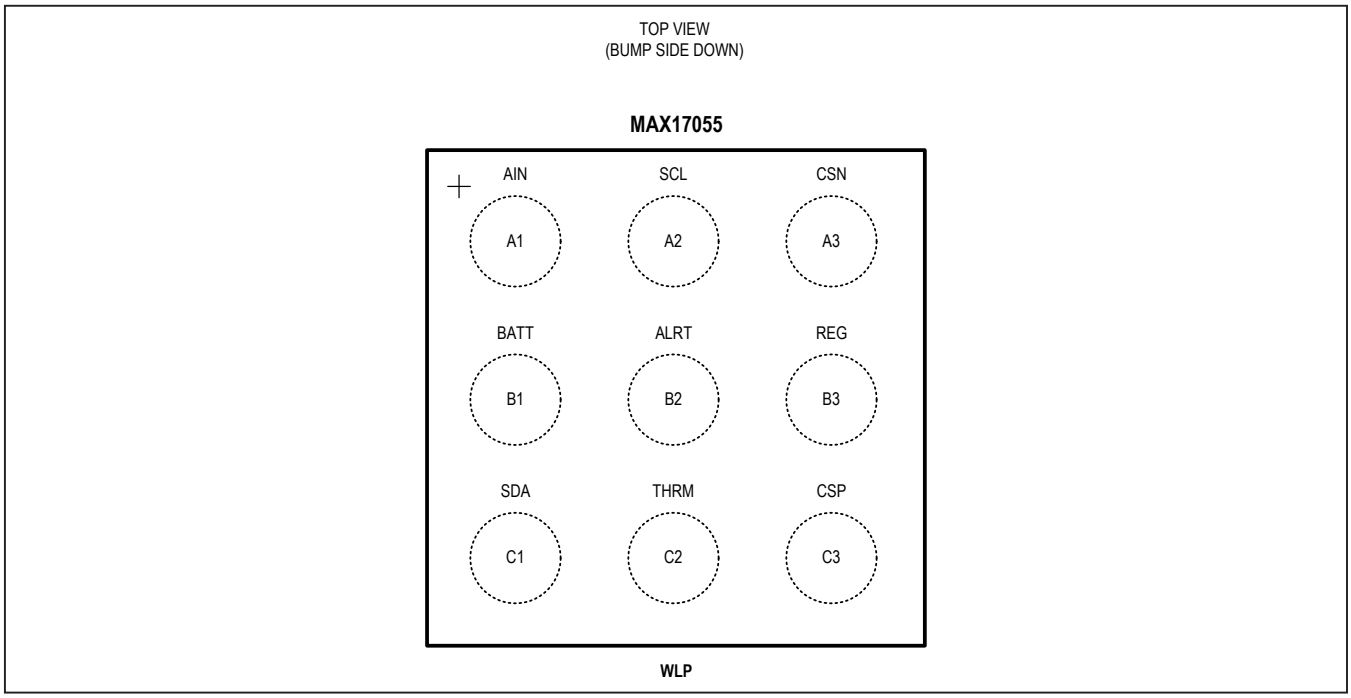


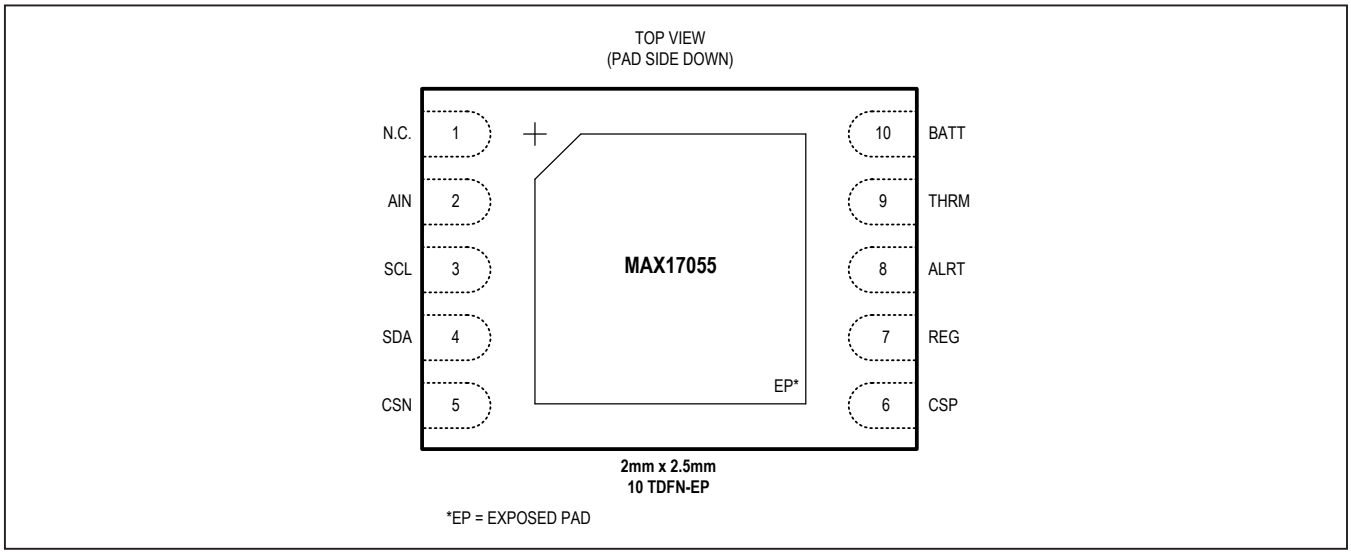






Pin Configurations

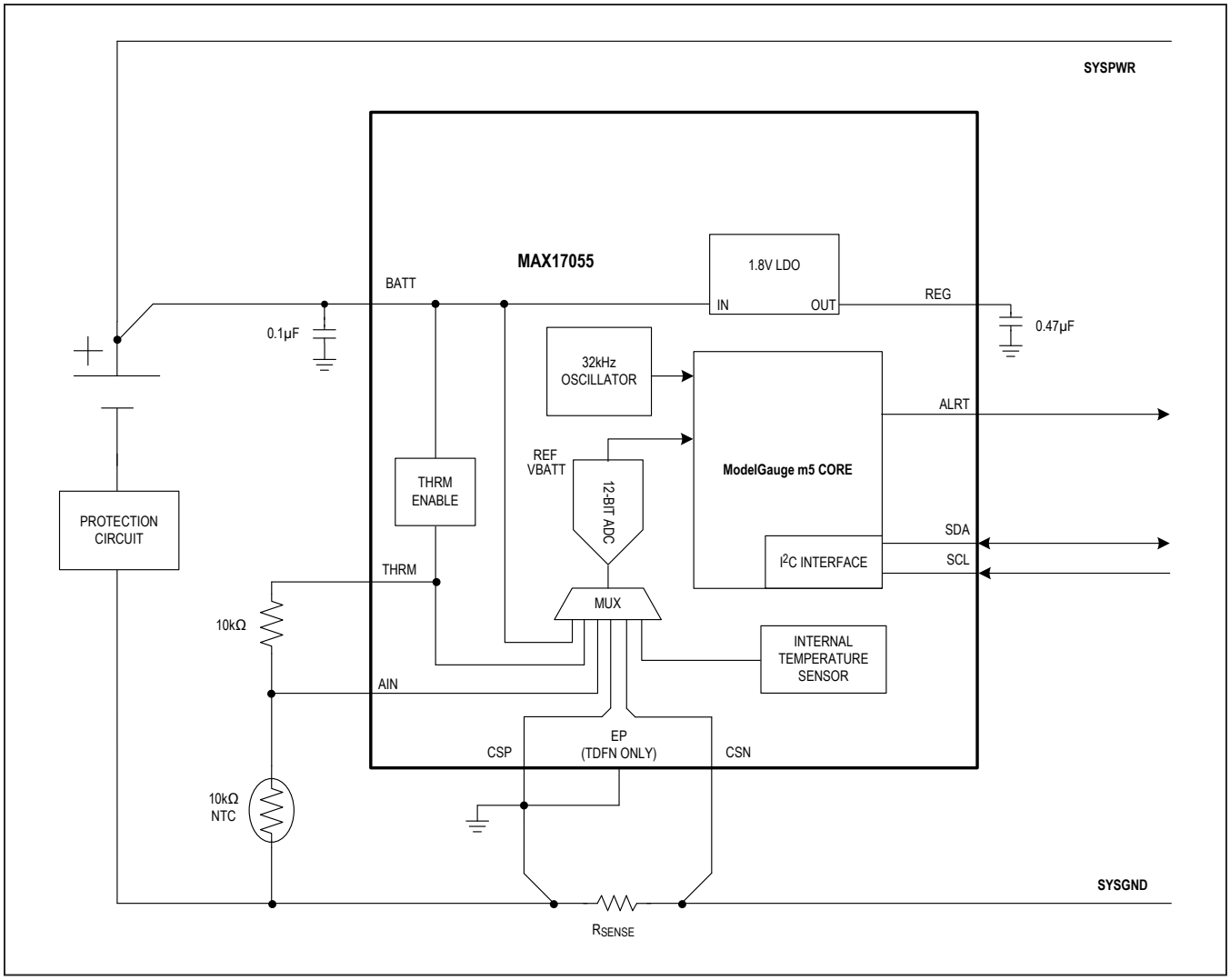




Pin Description

PIN		NAME	FUNCTION
WLP	TDFN		
—	1	N.C.	No Connection. No electrical connection to IC.
A1	2	AIN	Auxiliary Voltage Input. Auxiliary voltage input from external thermistor-measurement network. AIN also provides battery insertion/removal detection. Connect to CSP, if not used.
A2	3	SCL	Serial Clock Input. 2-wire clock line. Input only. SCL has an internal pulldown (IPD) for sensing disconnection.
C1	4	SDA	Serial Data Input/Output. 2-wire data line. Open-drain output driver. SDA has an internal pulldown (IPD) for sensing disconnection.
A3	5	CSN	Sense Resistor Negative Sense Point. Kelvin connect to the load side of the sense resistor.
C3	6	CSP	IC Ground. Sense resistor positive sense point. Kelvin connect to the battery side of the sense resistor.
B3	7	REG	Internal 1.8V Regulator Output. Bypass with external 0.47µF capacitor to CSP.
B2	8	ALRT	Alert Output. The ALRT pin is an open-drain, active-low output that indicates fuel-gauge alerts. In many applications, connect to an interrupt pin of a microcontroller.
C2	9	THRM	Thermistor Bias Connection. Supply for thermistor resistor-divider. Connect to the high side of the thermistor/resistive-voltage-divider. THRM connects internally to BATT during temperature measurement.
B1	10	BATT	Power-Supply and Battery Voltage Sense Input. Connect to positive terminal of battery cell. Bypass with a 0.1µF capacitor to CSP.
—	—	EP	Exposed Pad (TDFN Only). Connect to CSP.

Functional Diagram



Detailed Description

The MAX17055 is a low power 7µA operating current fuel gauge IC that implements Maxim ModelGauge m5 EZ algorithm. ModelGauge m5 EZ makes fuel gauge implementation easy by eliminating battery characterization requirements and simplifying host software interaction.

The MAX17055 measures voltage, current, and temperature to produce fuel gauge results. The MAX17055 uses either an external thermistor or internal die temperature to measure temperature of the battery pack.

The ModelGauge m5 EZ robust algorithm provides tolerance against battery diversity. This additional robustness enables simpler implementation for most applications and batteries by avoiding time-consuming battery characterization.

The ModelGauge m5 algorithm combines the short-term accuracy and linearity of a coulomb counter with the long-term stability of a voltage-based fuel gauge, along with temperature compensation to provide industry-leading fuel gauge accuracy. The MAX17055 automatically compensates for aging, temperature, and discharge rate and provides accurate state of charge (SOC) in milliampere-hours (mAh) or percentage (%) over a wide range of operating conditions. The MAX17055 ensures that fuel gauge error always converges to 0% as the cell approaches empty. The MAX17055 provides accurate estimation of time-to-empty and time-to-full and provides three methods for reporting the age of the battery: reduction in capacity, increase in battery resistance, and cycle odometer.

Communication to the host occurs over standard I²C interface.

Typical Application Circuits

Figure 1 shows two application circuits. One where the MAX17055 is located in a system that has a removable battery pack and the other where the MAX17055 is located in a system with a captive battery. In both cases, the IC is mounted outside of the protector circuit to allow communication to the pack even when the protection FETs are disabled. Take care to avoid exceeding the maximum operating voltage on any pin under fault conditions. In the removable battery system, temperature readings are made using an external thermistor divider network. In the captive pack system, temperature measurements are made internal to the IC saving the cost and size of two components. System current is measured using an external sense resistor connected between the CSP and CSN pins. System voltage measurements are made between the BATT and CSP pins. Keep the BATT and REG bypass capacitor loop areas as small as possible by connecting them directly to CSP. Note that when using the TDFN package option connect the exposed pad (EP) directly to CSP.

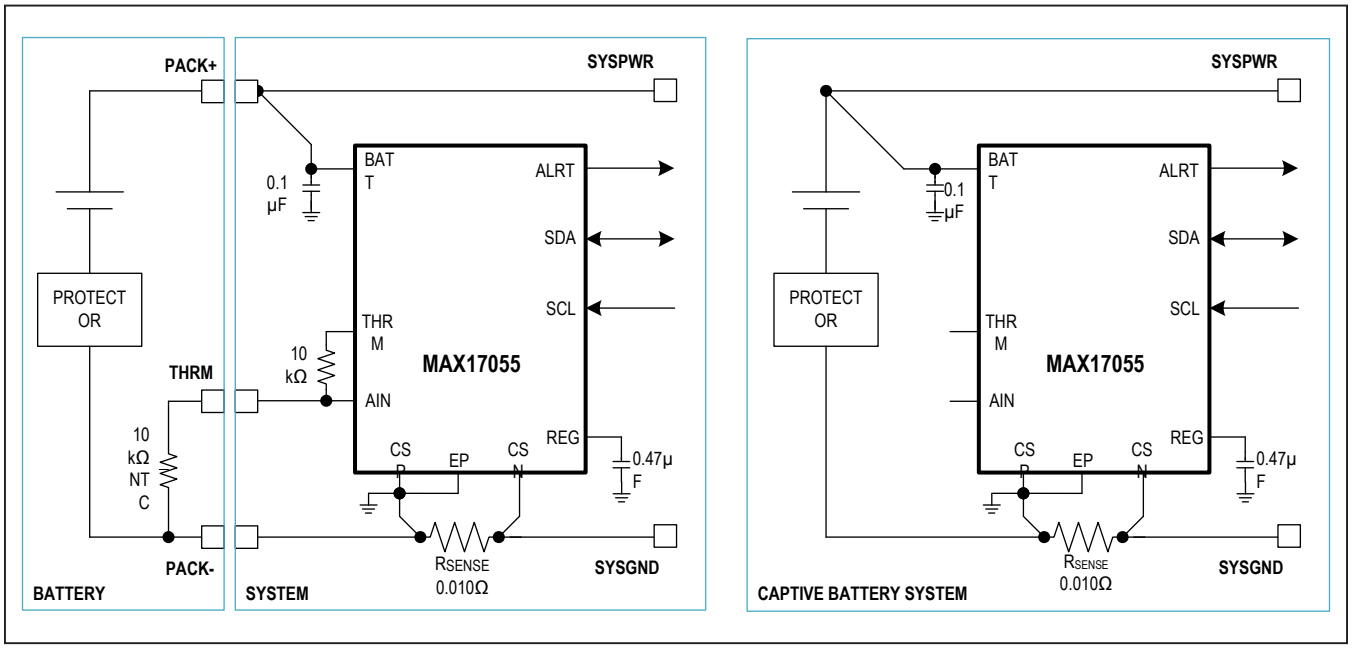


Figure 1. Typical Application Schematics

ModelGauge m5 EZ Performance

ModelGauge m5 EZ performance provides plug-and-play operation when the MAX17055 is connected to most lithium batteries. While the MAX17055 can be custom tuned to the application's specific battery through a characterization process for ideal performance, the MAX17055 has the ability to provide reasonable performance for most applications with no custom characterization required. Figure 2 and Table 1 show the performance of the ModelGauge m5 algorithm in applications using only the default cell model information.

While ModelGauge m5 EZ provides good performance for most cell types, some chemistries such as lithium-iron-phosphate (LiFePO4) and Panasonic NCR/NCA series cells require a custom model for best performance.

ModelGauge m5 EZ Configuration Registers

The following registers are inputs to the ModelGauge m5 algorithm and store characterization information for the application cells as well as important application specific parameters. They are described only briefly here. Contact Maxim for information regarding cell characterization.

Only the following information is required for configuring ModelGauge m5 EZ:

- Label Capacity—DesignCap
- Empty Voltage—VEmpty
- Charge Termination Current—ICHGTerm

Refer to the MAX17055 Software Implementation Guide for more details on how to initialize this information.

DesignCap Register(18h)

Register Type: Capacity

The DesignCap register holds the nominal capacity of the cell.

VEmpty Register (3Ah)

Initial Value: 0xA561 (3.3V/3.88V)

The VEmpty register sets thresholds related to empty detection during operation. Table 2 shows the register format.

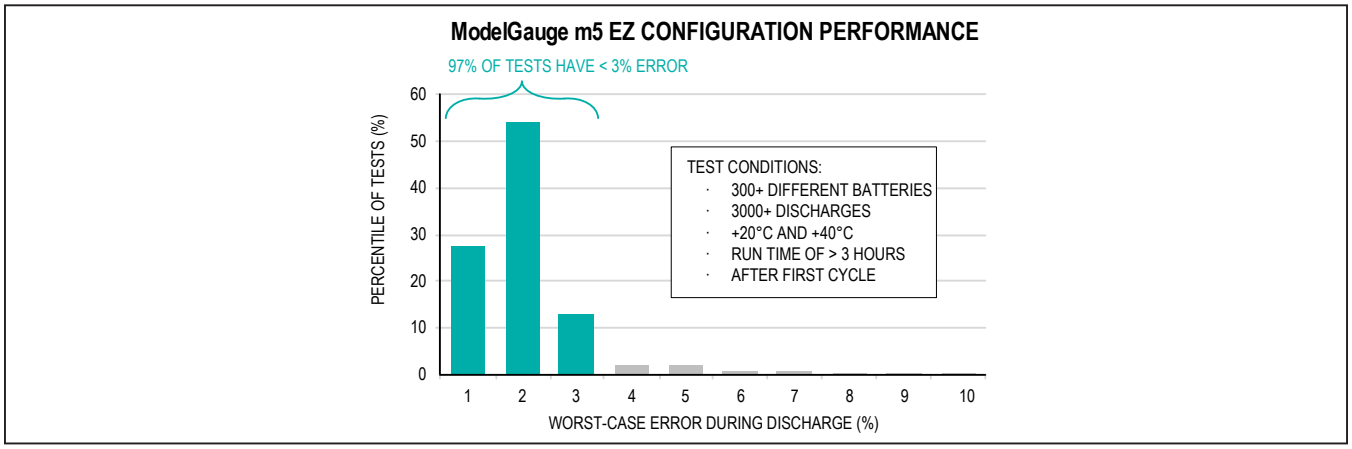


Figure 2. EZ Configuration Performance Histogram

Table 1. ModelGauge m5 EZ Performance

DESCRIPTION	AFTER FIRST CYCLE* (%)	AFTER SECOND CYCLE* (%)
Tests with error less than 3%	97	97.6
Tests with error less than 5%	99	99.5
Tests with error less than 10%	100	100

**Test conditions: +20°C and +40°C, run time of > 3 hours.*

Table 2. VEmpty (3Ah) Format

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
VE									VR						

VE: Empty voltage target, during load. The fuel gauge provides capacity and percentage relative to the empty voltage target, eventually declaring 0% at VE. A 10mV resolution gives a 0V to 5.11V range. This value defaults to 3.3V after reset.

VR: Recovery voltage. Sets the voltage level for clearing empty detection. Once the cell voltage rises above this point, empty voltage detection is reenabled. A 40mV resolution gives a 0V to 5.08V range. This value defaults to 3.88V, which is recommended for most applications.

ModelCfg Register (DBh)

The ModelCFG register controls basic options of the EZ algorithm. Table 3 shows the register format.

Refresh: Set Refresh to 1 to command the model reload. After execution the MAX17055 clears Refresh to 0.

ModelID: Choose from one of the following lithium models supported by EZ without characterization. For the majority of batteries, use ModelID = 0.

ModelID = 0: Use for most lithium cobalt-oxide variants (a large majority of lithium in the market-place).

ModelID = 2: Use for lithium NCR or NCA cells such as Panasonic.

ModelID = 6: Use for lithium iron-phosphate (LiFePO4). However, since LiFePO4 is a challenging chemistry, custom characterization is usually recommended.

VChg: Set VChg to 1 for charge voltage higher than 4.25V (4.3V–4.4V). Set VChg to 0 for 4.2V charge voltage.

IChgTerm Register (1Eh)

Register Type: Current

Initial Value: 0x0640 (250mA on 10mΩ)

The IChgTerm register allows the device to detect when charge termination has occurred. Program IChgTerm to the exact charge termination current used in the application.

Refer to the *End-of-Charge Detection* section of the MAX17055 User Guide for more details.

Config Register (1Dh) and Config2 Register (BBh)

Register Type: Special

Initial Value: 0x2210 for Config, 0x3658 for Config2

The Config register holds all shutdown enable, alert enable, and temperature enable control bits. Writing a bit location enables the corresponding function within one task period. Table 4 and Table 5 show the register formats.

0: Bit must be written 0. Do not write 1.

1: Bit must be written 1. Do not write 0.

POWR: Sets the time constant for the AvgPower register. The default POR value of 0100b gives a time constant of 11.25s. The equation setting the period is:

AvgPower time constant = 45s x $2^{(POWR-6)}$

Table 3. ModelCFG (DBh) Format

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Refresh	0	0	0	0	VChg	0	0	ModelID				0	0	0	0

Table 4. Config (1Dh) Format

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
TSel	SS	TS	VS	IS	AINSH	Ten	Tex	SHDN	COMMSH	0	ETHRM	FTHRM	Aen	Bei	Ber

Table 5. Config2 (BBh) Format

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
0	0	AtRateEn	DPEn	POWR				dSOCen	TAlrtEn	LDMDL	1	10		CPMode	0

IS (Current ALRT Sticky): When IS = 1, current alerts can only be cleared through software. When IS = 0, current alerts are cleared automatically when the threshold is no longer exceeded.

AtRateEn (AtRate Enable): When this bit is set to 0, AtRate calculations are disabled and registers AtQResidual/AtTTE/AtAvSOC/AtAvCap can be used as general purpose memory.

DPEn (Dynamic Power Enable): When this bit is set to 0, Dynamic Power calculations are disabled and registers MaxPeakPower/SusPeakPower/MPPCurrent/SPPCurrent can be used as general purpose memory.

CPMode (Constant Power Mode): Set to 1 to enable constant-power mode. If it is set to 0, AtRate/AvgCurrent is used for (At)TTE/(At)QResidual/(At)AvSOC/(At)AvCap. If it is set to 1, AtRate/AvgCurrent x ($\frac{AvgVCell}{\frac{AvgVCell + VEmpty}{2}}$) is used for those calculations.

TSel: 0 to use internal die temperature. 1 to use temperature information from thermistor. ETHRM bit should be set to 1 when TSel is 1.

Ber: Enable alert on battery removal when the IC is mounted host side. When Ber = 1, a battery-removal condition, as detected by the AIN pin voltage, triggers an alert.

Bei: Enable alert on battery insertion when the IC is mounted host side. When Bei = 1, a battery-insertion condition, as detected by the AIN pin voltage, triggers an alert.

Aen (Enable Alert on Fuel-Gauge Outputs): When Aen = 1, violation of any of the alert threshold register values by temperature, voltage, or SOC triggers an alert. This bit affects the ALRT pin operation only. The Smx, Smn, Tmx, Tmn, Vmx, Vmn, Imx, and Imn bits of the Status register (00h) are not disabled.

FTHRM (Force Thermistor Bias Switch): This allows the host to control the bias of the thermistor switch or enable fast detection of battery removal. Set FTHRM = 1 to always enable the thermistor bias switch. With a standard 10kΩ thermistor, this adds an additional ~200µA to the current drain of the circuit.

ETHRM (Enable Thermistor): Set to logic 1 to enable the automatic THRM output bias and AIN measurement.

COMMSH: (Communication Shutdown): Set to logic 1 to force the device to enter shutdown mode if both SDA and SCL are held low for more than timeout of the ShdnTimer register. This also configures the device to wake up on a rising edge of any communication. Note that if COMMSH and AINSH are both set to 0, the device wakes up an edge of any of the SDA or SCL pins. See the *Modes of Operation* section.

SHDN (Shutdown): Write this bit to logic 1 to force a shutdown of the device after timeout of the ShdnTimer register (default 45s delay). SHDN is reset to 0 at power-up and upon exiting shutdown mode. To command shutdown within 45s, first write HibCFG = 0x0000 to enter active mode.

Tex (Temperature External): When set to 1, the fuel gauge requires external temperature measurements to be written from the host. When set to 0, the IC's own measurements as used as selected by Config.TSEL.

Ten (Enable Temperature Channel): Set to 1 and set ETHRM or FTHRM to 1 to enable temperature measurements selected by Config.TSel.

AINSH (AIN Pin Shutdown): Set to 1 to enable device shutdown when the IC is mounted host side and the battery is removed. The IC enters shutdown if the AIN pin remains high (AIN > V_{THRM} - V_{DET}) for longer than the timeout of the ShdnTimer register. This also configures the device to wake up when AIN is pulled low on cell insertion. Note that if COMMSH and AINSH are both set to 0, the device wakes up an edge of any of the SDA or SCL pins.

VS (Voltage ALRT Sticky): When VS = 1, voltage alerts can only be cleared through software. When VS = 0, voltage alerts are cleared automatically when the threshold is no longer exceeded.

TS (Temperature ALRT Sticky): When TS = 1, temperature alerts can only be cleared through software. When TS = 0, temperature alerts are cleared automatically when the threshold is no longer exceeded.

SS (SOC ALRT Sticky): When SS = 1, SOC alerts can only be cleared through software. When SS = 0, SOC alerts are cleared automatically when the threshold is no longer exceeded.

TAlrten (Temperature Alert Enable): Set this bit to 1 to enable temperature based alerts. Write this bit to 0 to disable temperature alerts. This bit is set to 1 at power-up.

dSOCen (SOC Change Alert Enable): Set this bit to 1 to enable alert output with the Status.dSOCi bit function. Write this bit to 0 to disable alert output with the Status.dSOCi bit. This bit is set to 0 at power-up.

LDMdl: Host sets this bit to 1 in order to initiate firmware to finish processing a newly loaded model. Firmware clears this bit to zero to indicate that model loading is finished.

ModelGauge m5 EZ Algorithm

Classical coulomb-counter-based fuel gauges have excellent linearity and short-term performance. However, they suffer from drift due to the accumulation of the offset error in the current-sense measurement. Although the offset error is often very small, it cannot be eliminated. It causes the reported capacity error to increase over time and requires periodic corrections. Corrections are traditionally performed at full, or empty. Some other systems also use the relaxed battery voltage to perform corrections. These systems determine the true state of charge (SOC) based on the battery voltage after a long time of no current flow. Both have the same limitation: if the correction condition is not observed over time in the actual application, the error in the system is boundless. The performance of classic coulomb counters is dominated by the accuracy of such corrections. Voltage measurement based SOC estimation has accuracy limitations due to imperfect cell modeling, but does not accumulate offset error over time.

The MAX17055 includes an advanced voltage fuel gauge (VFG) that estimates open-circuit voltage (OCV), even during current flow, and simulates the nonlinear internal dynamics of a Li+ battery to determine the SOC with improved accuracy. The model considers the time effects of a battery caused by the chemical reactions and impedance in the battery to determine SOC. This SOC estimation does not accumulate offset error over time.

The ModelGauge m5 algorithm combines a high-accuracy coulomb counter with a VFG. See Figure 3. The complementary combined result eliminates the weaknesses of both the coulomb counter and the VFG while providing the strengths of both. A mixing algorithm weighs and combines the VFG capacity with the coulomb counter and weighs each result so that both are used optimally to determine the battery state. In this way, the VFG capacity result is used to continuously make small adjustments to the battery state, canceling the coulomb counter drift.

The ModelGauge m5 algorithm uses this battery state information and accounts for temperature, battery current, age, and application parameters to determine the remaining capacity available to the system. As the battery approaches the critical region near empty, the ModelGauge m5 algorithm invokes a special error correction mechanism that eliminates any error.

The ModelGauge m5 algorithm continually adapts to the cell and application through independent learning routines. As the cell ages, its change in capacity is monitored and updated and the voltage-fuel-gauge dynamics adapt based on cell-voltage behavior in the application.

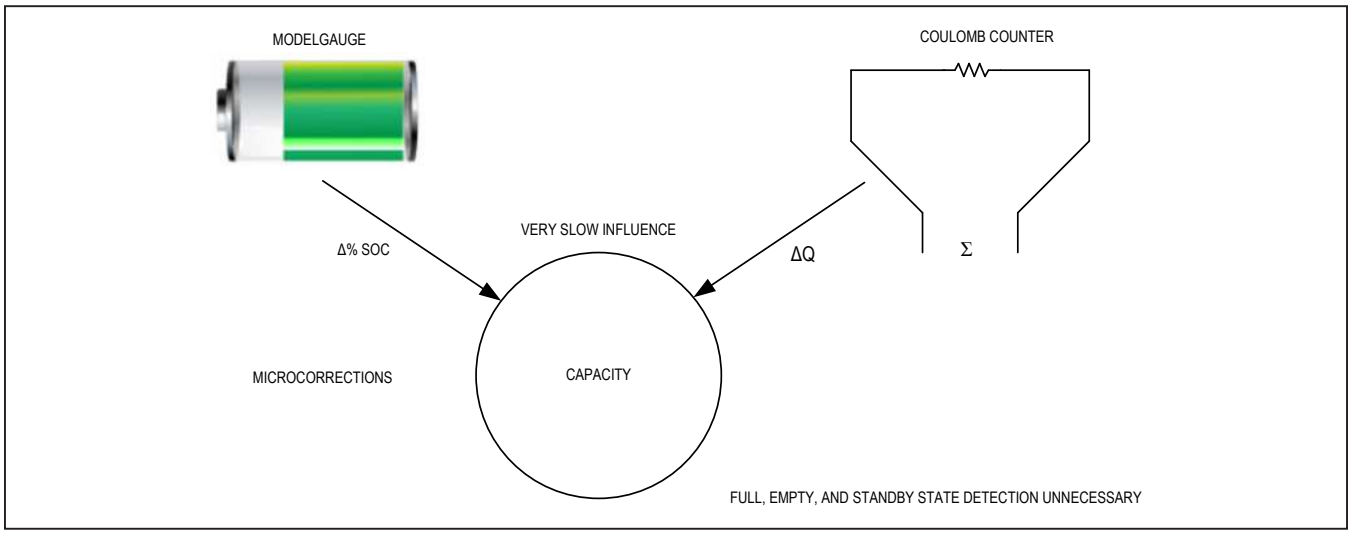


Figure 3. Merger of Coulomb Counter and Voltage-Based Fuel Gauge

Application Notes

Refer to the following application notes for additional reference material:

- Application Note 6358: MAX17055 User Guide
  - Documents full register set
  - More details about ModelGauge m5 algorithm
  - Discusses additional applications
- Application Note 6365: MAX17055 Software Implementation Guide
  - Guidelines for Software Drivers including example code

Standard Register Formats

Unless otherwise stated during a given register's description, all IC registers follow the same format depending on the type of register. See Table 6 for the resolution and range of any register described hereafter. Note that current and capacity values are displayed as a voltage and must be divided by the sense resistor to determine Amps or Amp-hours.

ModelGauge m5 Algorithm Output Registers

The following registers are outputs from the ModelGauge m5 algorithm. The values in these registers become valid 351ms after the MAX17055 is configured.

RepCap Register (05h)

Register Type: Capacity

RepCap or reported remaining capacity in mAh. This register is protected from making sudden jumps during load changes.

RepSOC Register (06h)

Register Type: Percentage

RepSOC is the reported state-of-charge percentage output for use by the application GUI.

FullCapRep Register (10h)

Register Type: Capacity

This register reports the full capacity that goes with RepCap, generally used for reporting to the user. A new full-capacity value is calculated at the end of every charge cycle in the application.

TTE Register (11h)

Register Type: Time

The TTE register holds the estimated time to empty for the application under present temperature and load conditions.

Table 6. ModelGauge Register Standard Resolutions

REGISTER TYPE	LSB SIZE	MINIMUM VALUE	MAXIMUM VALUE	NOTES
Capacity	5.0µVH/ R_{SENSE}	0.0µVH	327.675mVH/ R_{SENSE}	Equivalent to 0.5mA with a 0.010Ω sense resistor.
Percentage	1/256%	0.0%	255.9961%	1% LSb when reading only the upper byte.
Voltage	1.25mV/16	0.0V	5.11992V	
Current	1.5625µV/ R_{SENSE}	-51.2mV/ R_{SENSE}	51.1984mV/ R_{SENSE}	Signed 2's complement format. Equivalent to 156.25µA with a 0.010Ω sense resistor.
Temperature	1/256°C	-128.0°C	127.996°C	Signed 2's complement format. 1°C LSb when reading only the upper byte.
Resistance	1/4096Ω	0.0Ω	15.99976Ω	
Time	5.625s	0.0s	102.3984h	
Special				Format details are included with the register description.

TTF Register (20h)

Register Type: Time

The TTF register holds the estimated time to full for the application under present conditions. The TTF value is determined by learning the constant current and constant voltage portions of the charge cycle based on experience of prior charge cycles. Time to full is then estimated by comparing present charge current to the charge termination current. Operation of the TTF register assumes all charge profiles are consistent in the application.

Cycles Register (17h)

Register Type: Special

The Cycles register maintains a total count of the number of charge/discharge cycles of the cell that have occurred. The result is stored as a percentage of a full cycle. For example, a full charge/discharge cycle results in the Cycles register incrementing by 100%.

The Cycles register accumulates fractional or whole cycles. For example, if a battery is cycled 10% x 10 times, then it tracka 100% of one cycle.

The Cycles register has a full range of 0 to 655.35 cycles with a 1% LSb.

Status Register (00h)

Register Type: Special

Initial Value: 0x0002

The Status register maintains all flags related to alert thresholds and battery insertion or removal. Table 7 shows the Status register format.

POR (Power-On Reset): This bit is set to a 1 when the device detects that a software or hardware POR event has occurred. This bit must be cleared by system software to detect the next POR event. POR is set to 1 at power-up.

Imn and Imx (Minimum/Maximum Current Alert Threshold Exceeded): These bits set to a 1 whenever a Current register reading is below (Imn) or above (Imx) the IAlrtTh thresholds. These bits may or may not need to be cleared by system software to detect the next event. See Config.IS bit description. Imn and Imx are cleared to 0 at power-up.

Vmn and Vmx (Minimum/Maximum Voltage Alert Threshold Exceeded): These bits set to a 1 whenever a VCell register reading is below (Vmn) or above (Vmx) the VAlrtTh thresholds. These bits may or may not need to be cleared by system software to detect the next event. See Config.VS bit description. Vmn and Vmx are cleared to 0 at power-up.

Tmn and Tmx (Minimum/Maximum Temperature Alert Threshold Exceeded): These bits set to a 1 whenever a Temperature register reading is below (Tmn) or above (Tmx) the TAlrtTh thresholds. These bits may or may not need to be cleared by system software to detect the next event. See Config.TS bit description. Tmn and Tmx are cleared to 0 at power-up.

Smn and Smx (Minimum/Maximum SOC Alert Threshold Exceeded): These bits set to a 1 whenever SOC is below (Smn) or above (Smx) the SAlrtTh thresholds. These bits may or may not need to be cleared by system software to detect the next event. See Config.SS description. Smn and Smx are cleared to 0 at power-up.

Bst (Battery Status): Useful when the IC is used in a host side application. This bit is set to 0 when a battery is present in the system and set to 1 when the battery is absent. Bst is set to 0 at power-up.

dSOCi (State of Charge 1% Change Alert): This is set to 1 whenever the RepSOC register crosses an integer percentage boundary such as 50.0%, 51.0%, etc. Must be cleared by host software. dSOCi is set to 0 at power-up.

Bi (Battery Insertion): Useful when the IC is used in a host-side application. This bit is set to a 1 when the device detects that a battery has been inserted into the system by monitoring the AIN pin. This bit must be cleared by system software to detect the next insertion event. Bi is set to 0 at power-up.

Br (Battery Removal): Useful when the IC is used in a host side application. This bit is set to a 1 when the system detects that a battery has been removed from the system. This bit must be cleared by system software to detect the next removal event. Br is set to 0 at power-up.

X (Don't Care): This bit is undefined and can be logic 0 or 1.

Table 7. Status (00h) Format

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
Br	Smx	Tmx	Vmx	Bi	Smn	Tmn	Vmn	dSOCi	Imx	X	X	Bst	Imn	POR	X

Analog Measurements

The MAX17055 monitors voltage, current, and temperature. This information is provided to the fuel guage algorithm to predict cell capacity and also made available to the user.

Voltage Measurement

The MAX17055 monitors the battery voltage at BATT. See the following sections for the voltage register description details.

VCell Register (09h)

Register Type: Voltage

VCell reports the voltage measured between BATT and CSP.

AvgVCell Register (19h)

Register Type: Voltage

The AvgVCell register reports an average of the VCell register readings.

MaxMinVolt Register (1Bh)

Register Type: Special

Initial Value: 0x00FF

The MaxMinVolt register maintains the maximum and minimum of VCell register values since device reset. At power-up, the maximum voltage value is set to 00h (the minimum) and the minimum voltage value is set to FFh (the maximum). Therefore, both values are changed to the voltage register reading after the first update. Host software can reset this register by writing it to its power-up value of 0x00FF. The maximum and minimum voltages are each stored as 8-bit values with a 20mV resolution. Table 8 shows the register format.

MaxVCELL: Maximum VCell register reading

MinVCELL: Minimum VCell register reading

Current Measurement

The MAX17055 monitors the current flow through the battery by measuring the voltage between the CSN and CSP pins over a ±51.2mV range. The MAX17055 is pre-calibrated for current-measurement accuracy.

The MAX17055 also supports PCB trace current-sensing, and automatically compensates for the temperature coefficient of the metal (usually copper). Refer to the MAX17055 User Guide for more information on this application.

Additionally, the MAX17055 maintains a record of the minimum and maximum current measured by the MAX17055 and an average current.

See *Layout Guidelines* for the recommended board layout to minimize current-sense error.

Current Register (0Ah)

Register Type: Current

The IC measures the voltage between the CSP and CSN pins and the result is stored as a two's complement value in the Current register. Voltages outside the minimum and maximum register values are reported as the minimum or maximum value. The register value should be divided by the sense resistance to convert to Amperes. The value of the sense resistor determines the resolution and the full-scale range of the current readings. Table 9 shows range and resolution values for typical sense resistances.

Table 8. MaxMinVolt (1Bh) Format

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
MaxVCELL								MinVCELL							

Table 9. Current Measurement Range and Resolution vs. Sense Resistor Value

BATTERY FULL CAPACITY (mAh)	SENSE RESISTOR (mΩ)	CURRENT REGISTER RESOLUTION (µA)	CURRENT REGISTER RANGE (A)	CAPACITY RESOLUTION (mAh)
> 800	5	312.5	±10.24	1
> 400	10	156.25	±5.12	0.5
> 200	20	78.125	±2.56	0.25
> 80	50	31.25	±1.024	0.1

AvgCurrent Register (0Bh)

Register Type: Current

The AvgCurrent register reports an average of Current register readings.

MaxMinCurr Register (1Ch)

Register Type: Special

Initial Value: 0x807F

The MaxMinCurr register maintains the maximum and minimum Current register values since the last IC reset or until cleared by host software. At power-up, the maximum current value is set to 80h (most negative) and the minimum current value is set to 7Fh (most positive). Therefore, both values are changed to the Current register reading after the first update. Host software can reset this register by writing it to its power-up value of 0x807F. The maximum and minimum currents are each stored as two's complement 8-bit values with 0.4mV/R_{SENSE} resolution. Table 10 shows the register format.

MaxCurrent: Maximum Current register reading

MinCurrent: Minimum Current register reading

Temperature Measurement

The MAX17055 can be configured to measure its own internal die temperature or an external NTC thermistor.

Set Config.TSEL = 0 (default) to enable die temperature measurement. Set Config.TSEL = 1 to enable thermistor measurement.

Thermistor conversions are initiated by periodically connecting the THRM and BATT pins internally. This enables the active pullup to the external resistive voltage-divider network. After the pullup is enabled, the IC waits for a settling period of t_{PRE} prior to making measurements on the AIN pin. Measurement results are compared to the voltage of the THRM pin and converted to a ratiometric value from 0% to 100%. The active pullup is disabled when temperature measurements are complete. This feature limits the time the external resistor-divider network is active below 1% duty and lowers the total amount of current used by the system.

The ratiometric results are converted to temperature using the temperature gain (TGain), temperature offset (TOff), and temperature curve (Curve) register values. Internal die temperature measurements are factory calibrated and are not affected by TGain, TOff, Curve register settings. Refer to the MAX17055 User Guide for more details. Additionally, the MAX17055 maintains a record of the minimum and maximum temperature measured and an average temperature.

Temp Register (08h)

Register Type: Temperature

The Temp register provides the temperature measured by the thermistor or die temperature. The Temp register is the input to the fuel gauge algorithm.

AvgTA Register (16h)

Register Type: Temperature

The AvgTA register reports an average of the readings from the Temp register.

MaxMinTemp Register (1Ah)

Register Type: Special

Initial Value: 0x807F

The MaxMinTemp register maintains the maximum and minimum Temp register (08h) values since the last fuel-gauge reset or until cleared by host software. At power-up, the maximum value is set to 0x80 (most negative) and the minimum value is set to 0x7F (most positive). Therefore, both values are changed to the Temp register reading after the first update. Host software can reset this register by writing it to its power-up value of 0x807F. The maximum and minimum temperatures are each stored as two's complement 8-bit values with 1°C resolution. Table 11 shows the format of the register.

MaxTemperature: Maximum Temp register reading

MinTemperature: Minimum Temp register reading

Table 10. MaxMinCurr (1Ch) Format

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
MaxCurrent								MinCurrent							

Table 11. MaxMinTemp (1Ah) Format

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
MaxTemperature								MinTemperature							

DieTemp Register (034h)

Register Type: Temperature

The DieTemp register provides the internal die temperature measurement. If Config.TSel = 0, DieTemp and Temp registers have the value of the die temperature.

Power Register (B1h)

Instant power calculation from immediate current and voltage. The LSB is 0.8mW with a 10mΩ sense resistor.

AvgPower Register (B3h)

Filtered average power from the power register. LSB is 0.8mW with a 10mΩ sense resistor.

Alert Function

The Alert Threshold registers allow interrupts to be generated by detecting a high or low voltage, current, temperature, or state of charge. Interrupts are generated on the ALRT pin open-drain output driver. An external pullup is required to generate a logic-high signal. Alerts can be triggered by any of the following conditions:

- Battery removal: (V_{AIN} > V_{THRM} - V_{DET}) and battery removal detection enabled (Ber = 1).
- Battery insertion: (V_{AIN} < V_{THRM} - $V_{DET-HYS}$) and battery insertion detection enabled (Bei = 1).
- Over/undervoltage: VAlrtTr register threshold violation (upper or lower) and alerts enabled (Aen = 1).
- Over/undertemperature: TAlrtTr register threshold violation (upper or lower) and alerts enabled (Aen = 1).
- Over/undercurrent: IAlrtTr register threshold violation (upper or lower) and alerts enabled (Aen = 1).
- Over/under SOC: SAlrtTr register threshold violation (upper or lower) and alerts enabled (Aen = 1).
- 1% SOC change: RepSOC register bit d8 (1% bit) changed (dSOCen = 1).

To prevent false interrupts, the threshold registers should be initialized before setting the Aen bit. Alerts generated by battery insertion or removal can only be reset by clearing the corresponding bit in the Status (00h) register. Alerts generated by a threshold-level violation can be configured to be cleared only by software, or cleared automatically when the threshold level is no longer violated. See the Config (1Dh) and Config2 (BBh) register descriptions for details of the alert function configuration.

VAlrtTh Register (01h)

Register Type: Special

Initial Value: 0xFF00 (Disabled)

TheVAlrtTh register shown in Table 12 sets upper and lower limits that generate an alert if exceeded by the VCell register value. The upper 8 bits set the maximum value and the lower 8 bits set the minimum value. Interrupt threshold limits are selectable with 20mV resolution over the full operating range of the VCell register.

VMAX: Maximum voltage reading. An alert is generated if the VCell register reading exceeds this value.

VMIN: Minimum voltage reading. An alert is generated if the VCell register reading falls below this value.

TAlrtTh Register (02h)

Register Type: Special

Initial Value: 0x7F80 (Disabled)

The TAlrtTh register (Table 13) sets upper and lower limits that generate an alert if exceeded by the Temp register value. The upper 8 bits set the maximum value and the lower 8 bits set the minimum value. Interrupt threshold limits are stored in 2's-complement format with 1°C resolution over the full operating range of the Temp register.

TMAX: Maximum temperature reading. An alert is generated if the Temp register reading exceeds this value.

TMIN: Minimum temperature reading. An alert is generated if the Temp register reading falls below this value.

Table 12. VAlrtTh (01h) Format

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
VMAX								VMIN							

Table 13. TAlrtTh (02h) Format

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
TMAX								TMIN							

SAlrtTh Register (03h)

Register Type: Special

Initial Value: 0xFF00 (Disabled)

The SAlrtTh register shown (Table 14) sets upper and lower limits that generate an alert if exceeded by RepSOC. The upper 8 bits set the maximum value and the lower 8 bits set the minimum value. Interrupt threshold limits are configurable with 1% resolution over the full operating range of the RepSOC register.

SMAX: Maximum state of charge threshold. An alert is generated if the RepSOC register exceeds this value.

SMIN: Minimum state of charge threshold. An alert is generated if the RepSOC register falls below this value.

IAlrtTh Register (B4h)

Register Type: Special

Initial Value: 0x7F80 (Disabled)

The IAlrtTh register (Table 15) sets upper and lower limits that generate an alert if exceeded by the Current register value. The upper 8 bits set the maximum value and the lower 8 bits set the minimum value. Interrupt threshold limits are selectable with 0.4mV/R_{SENSE} resolution over the full operating range of the Current register.

IMAX: Maximum current reading. An alert is generated if the current register reading exceeds this value.

IMIN: Maximum current reading. An alert is generated if the current register reading falls below this value.

MAX17055 Memory Space

Commonly used registers are described within this data sheet. Other register descriptions can be found in the MAX17055 User Guide. Table 16 shows the user memory space. Register locations shown in gray are reserved locations and should not be written to.

Layout Guidelines

Proper circuit layout as shown in Figure 4 is essential for voltage, temperature, and current measurement accuracy. The recommended layout guidelines are as follows:

- CSN and CSP traces should make Kelvin connections to the sense resistor. Current is measured differentially through the CSN and CSP pins. Any shared high current paths on these traces affect current measurement accuracy.
- For TDFN package designs, connect EP directly to the CSP pin.
- REG capacitor trace loop area should be minimized. REG should be connected to the CSP pin as close as possible to the IC. Run only a single CSP trace to the sense resistor. This helps filter any noise from the internal regulated supply.
- All other ground connections should be kept separate from the CSP or CSN traces.
  - The kelvin lines should not be shared with other circuits.
  - Vias on the kelvin traces are not recommended.

There are no limitations on any other IC connection. Other IC pins as well as any external components mounted to these pins have no special layout requirements.

Table 14. SAlrtTh (03h) Format

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
SMAX								SMIN							

Table 15. IAlrtTh (B4h) Format

D15	D14	D13	D12	D11	D10	D9	D8	D7	D6	D5	D4	D3	D2	D1	D0
IMAX								IMIN							

Table 16. MAX17055 Register Memory Map

PAGE/ WORD	00H	10H	20H	30H	40H	B0H	D0H
0h	Status	FullCapRep	TTF	Reserved	UserMem1	Status2	RSense / UserMem3
1h	VAlrtTh	TTE	DevName	Reserved	Reserved	Power	ScOcvLim
2h	TAlrtTh	QRTable00	QRTable10	QRTable20	QRTable30	ID / UserMem2	Reserved
3h	SAlrtTh	FullSocThr	FullCapNom	Reserved	RGain	AvgPower	SOCHold
4h	AtRate	RCell	Reserved	DieTemp	Reserved	IAlrtTh	MaxPeakPower
5h	RepCap	Reserved	Reserved	FullCap	dQAcc	TTFCfg	SusPeakPower
6h	RepSOC	AvgTA	Reserved	Reserved	dPAcc	CVMixCap	PackResistance
7h	Age	Cycles	AIN	Reserved	Reserved	CVHalfTime	SysResistance
8h	Temp	DesignCap	LearnCfg	RComp0	Reserved	CGTempCo	MinSysVoltage
9h	VCell	AvgVCell	FilterCfg	TempCo	ConvgCfg	Curve	MPPCurrent
Ah	Current	MaxMinTemp	RelaxCfg	VEmpty	VFRemCap	HibCfg	SPPCurrent
Bh	AvgCurrent	MaxMinVolt	MiscCfg	Reserved	Reserved	Config2	ModelCfg
Ch	QResidual	MaxMinCurr	TGain	Reserved	Reserved	VRipple	AtQResidual
Dh	MixSOC	Config	TOff	FStat	QH	RippleCfg	AtTTE
Eh	AvSOC	IChgTerm	CGain	Timer	Reserved	TimerH	AtAvSOC
Fh	MixCap	AvCap	COff	ShdnTimer	Reserved	Reserved	AtAvCap

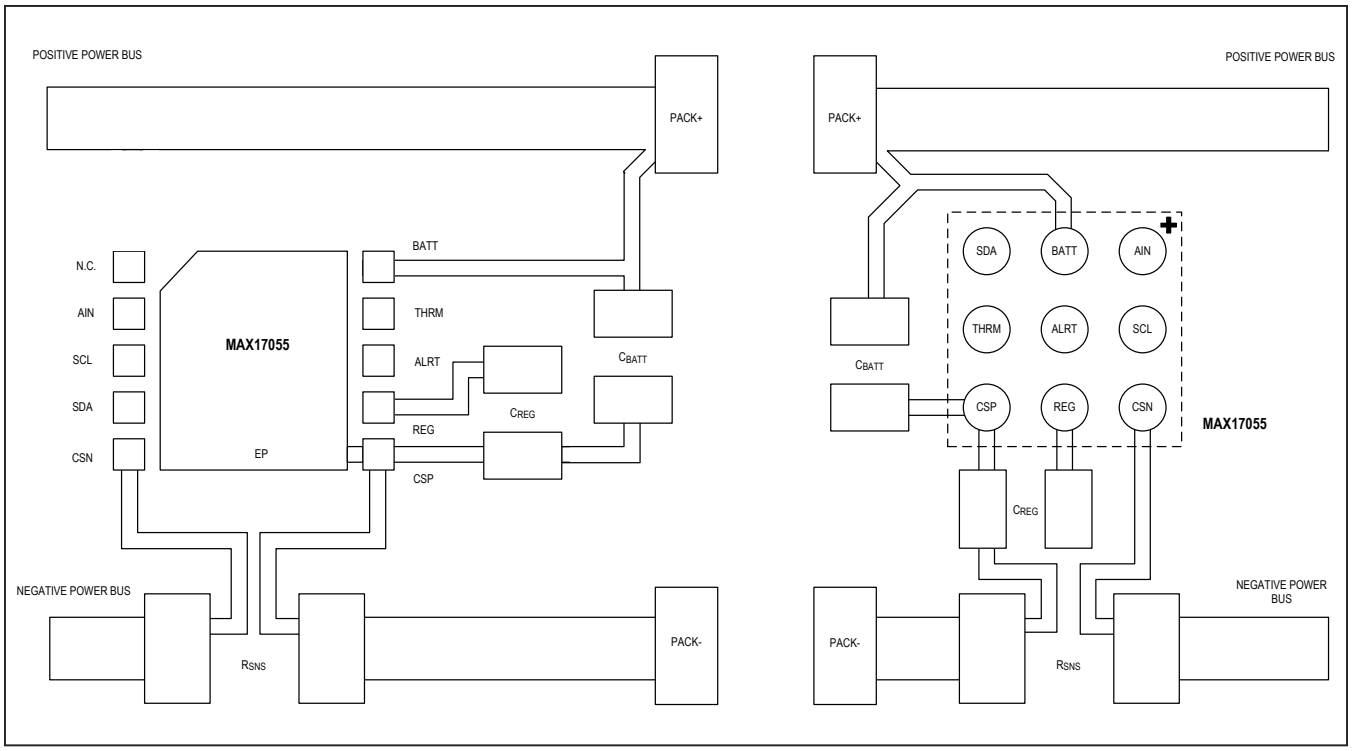


Figure 4. Layout Examples

Ordering Information

PART NUMBER	TEMP RANGE	PIN-PACKAGE
MAX17055EWL+	-40°C to +85°C	9 WLP
MAX17055EWL+T	-40°C to +85°C	9 WLP
MAX17055ETB+	-40°C to +85°C	10 TDFN-EP*
MAX17055ETB+T	-40°C to +85°C	10 TDFN-EP*

+Denotes a lead(Pb)-free/RoHS-compliant package.
T = Tape and reel.
**EP = Exposed pad.*

Revision History

REVISION NUMBER	REVISION DATE	DESCRIPTION	PAGES CHANGED
0	1/17	Initial release	—

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