Battery Management System ICs for Battery Monitoring

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Neil Krohn | Analog & Sensors

A P R . 2 0 1 4
Agenda

• Session Introduction
• Intelligent Precision Battery Sensors Overview
  – Definition
  – Application Requirements
  – Family Comparison
  – Target Applications
• Hardware Features
  – Overview
  – Acquisition Channels
  – Timers, I/O and Communications
  – Operating Modes & Wakeup
  – Trim & Calibration
• Hardware & Software Tools
Session Overview
What Is The Most Probable Reason For This Stop In The Middle Of The Desert?

Most probably a battery failure!

Battery field failure rates range from 1000 to >10000 ppm for batteries older than three years.
Freescale is Solving This Problem with the MM912J637/8 Intelligent Battery Sensor

- Provides early warning of battery discharge
- Avoids battery failures in the field
Value Drivers for Battery Management Systems

**Sophisticated Vehicle Electronics Functions**
- Increase in Current Demand
- Increasing # of Consumers in the Car

**Stringent Emission & Fuel Consumption Requirements**
- Decrease Engine Idle Speed
- Increase Alternator Efficiency

**Battery Charge**
- Load Regulation
- Idle Speed Control
- Alternator Voltage Control

**Energy Management**

**Battery Management System (BMS)**
- Enables power supply management / power network stabilization
- Enables intelligent alternator control
- Enables regenerative braking
- Provides early warning of battery discharge & avoids battery field failures
- Enables start / stop automatic / crankability prediction
- Determines current availability for critical systems and conditions

Source: Own Slide based on Internet research
Typical Energy Management System

- **Battery Management System (BMS)**
  - Provides battery state
    - State of charge (SoC)
    - State of health (SoH)
    - State of function (SoF)

- **Body Control Module (BCM)**
  - Controls generator
  - Controls power distribution

- **DC/DC**
  - Ensures seamless operation of consumers in the car in case of cranking event
Intelligent Battery Sensor: BMS for 12V Lead Acid Batteries

• Both intelligent battery sensor and precision shunt resistor are physically integrated within the terminal recess of the battery

• Main Functions:
  - Precision measurements
    - Battery current measurement via an external shunt resistor at the negative pole of the battery
    - Battery voltage measurement via a series resistor at the positive pole, measured concurrently with the battery current
    - The integrated temperature sensor combined with battery mounting allows accurate battery temperature measurement
  - Calculation of battery state (SoC, SoH, SoF) with embedded MCU
  - Communicates with BCM with integrated LIN interface
Application Requirements
IBS: Key Application Requirements

• Footprint
  – Essential because of the battery housing
  – Requires a single chip integration of all features

• Low power
  – Needs continuous battery monitoring
  – Typically requires 100 µA standby overall current consumption

• Automotive robustness
  – PHY layer needs to be automotive certified and accepted by OEMs
  – Due to space constraints, EMC/ESD requirements must be achieved with minimum amount of passive components
Algorithm for IBS: What Do We Want To Monitor?

• A battery is an electrochemical cell that converts stored chemical energy into electrical energy

• What are the main performances we want to observe?
  – Available capacity at a given time (is my battery charged?)
  – Lifetime degradation (do I need to change my battery?)

• A typical battery management algorithm will evaluate:
  – SoC: indicates ratio between available capacity and max. capacity
  – SoH: describes decreasing of maximum battery capacity
State of Charge Evaluation: Current Integration Based

- Formula indicating SoC:

\[
SoC(t) = \left( \frac{Q(t_0) + \sum_{n=0}^{\infty} \alpha i(n) |f_s|}{C_r} \right) \times 100
\]

- This method is also known as Coulomb counting

- Requirements:
  - Strongly depends on accurate current measurement
  - Implies a known and stable time reference
  - Current must be monitored permanently, in both directions
  - Battery temperature must be known
State of Charge Evaluation: Open Circuit Voltage Based

• Another possibility is to use the relation between SoC and OCV
  - Open Circuit Voltage is defined as the voltage at the battery output, with no load current

• However, a good battery will have a very flat OCV= f(SoC) response

• Requirements
  – Very accurate voltage measurement
  – Measurement only after a given amount of time after latest charge/discharge
  – Temperature measurement
State of Health

- SoH describes the decrease in maximum battery capacity due to aging

- As SoC, it can be evaluated in several ways:
  - Looking at the maximum SoC reached after consecutive full charge cycles
  - Counting the number of charge/discharge cycles
  - Measuring an electrical parameter well correlated with SoH

- Generally, final algorithm will consider all these evaluations (and more, depending on the complexity) to determine the SoH
SoH Estimation: Internal Impedance Measurement

- A battery can be modeled with a voltage source and a series impedance
- In particular, internal impedance of a battery does increase with aging
- Cranking condition is the best situation to measure this impedance

- Requirements
  - Synchronous measurement of $V$ and $I$
  - Measure high current peaks
  - Fast sampling rates

Remember Thevenin’s theorem!
Algorithms: Summary of Requirements

• Strong dependence on current measurement accuracy
• Current must be monitored permanently, in both directions
• Measure high current peaks

• Very accurate voltage measurement
• Measurement only after a given amount of time after latest charge/discharge

• Battery temperature must be known

• Implies a known and stable time reference

• Synchronous measurement of V and I
• Fast sampling rates (to allow cranking pulse measurements)
Device Overview and Target Applications
**Freescale’s Intelligent Precision Battery Sensors Overview**

**MM912J637 – 12V Pb (LIN)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCU</td>
<td>S12 (16-bit)</td>
</tr>
<tr>
<td>Flash</td>
<td>96k/128k</td>
</tr>
<tr>
<td>Data Flash</td>
<td>4k</td>
</tr>
<tr>
<td>RAM</td>
<td>6k</td>
</tr>
</tbody>
</table>

**Mixed-Signal Chip**
- LIN Physical Layer (ESD 15kV)
- Watchdog
- Standby Current <100 µA (1sec Isense)
- Vreg capability 50 mA
- Operating Voltage 3.5..28V
- RAM Contents Guaranteed: 2.5...3.5V
- 3x ADC (2nd Order Sigma Delta) 16-bit
- Current Measurement
  - Relative Accuracy <0.5%
- Voltage Measurement
  - Relative Accuracy <0.2%
- Temperature Measurement
  - Relative Accuracy <2K
- Operating Temperature: -40°C<Ta<125°C

**MM9Z1J638 – Multi Applications (LIN, msCAN)**

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>MCU</td>
<td>S12Z (32-bit ALU)</td>
</tr>
<tr>
<td>Flash</td>
<td>96k/128k</td>
</tr>
<tr>
<td>EEPROM</td>
<td>4k</td>
</tr>
<tr>
<td>RAM</td>
<td>8k</td>
</tr>
<tr>
<td>msCAN</td>
<td></td>
</tr>
</tbody>
</table>

**Mixed-Signal Chip**
- LIN Physical Layer
- Watchdog
- Standby Current <100 µA (1sec Isense)
- Vreg capability 150 mA
- Operating Voltage 3.5..28V (Vs3:52V)
- RAM Contents Guaranteed: 2.5...3.5V
- 3x ADC (2nd Order Sigma Delta) 16-bit
- Current Measurement
  - Relative Accuracy <0.5%
- Voltage Measurement
  - Relative Accuracy <0.15%
- Temperature Measurement
  - Relative Accuracy <2K
- Operating Temperature: -40°C<Ta<125°C
Freescale Intelligent Battery Sensors: Feature Comparison

**MM912J637AM2**
- **Application**
  - 12V PB battery (LIN)
- **Supply:** 12V Vreg
- **Communication**
  - LIN, SCI, SPI
- **Just enough MCU performance**
- **Features**
  - Cranking mode
  - 2nd Vsense
  - External temp sense
- **Full temp range**
  - -40°C to 125°C

**MM9Z1J638BM2**
- **Applications**
  - 12V Pb battery (Lin, CAN), 14V Li-ion battery, multi-battery apps, HV battery junction box
- **Supply:** 12V Vreg
- **Communication**
  - msCAN, LIN, SCI, SPI
- **Higher MCU performance**
- **Features**
  - Cranking mode
  - 4 attenuated Vsense and 4 direct voltage pins
  - 4 external temperature sensors
- **Full temperature range**
  - -40°C to 125°C
## MCU Die - Comparison ‘637 vs. ‘638

### System Block Diagram

**Legend:**
- Change vs. previous version, Validated on previous silicon /pizza mask
- No Change vs. previous version, AEC Q100 qualified

### Benefit/Impact

<table>
<thead>
<tr>
<th>Benefit/Impact</th>
<th>MCU (637)</th>
<th>MCU (638)</th>
<th>Data Flash/EEPROM</th>
</tr>
</thead>
<tbody>
<tr>
<td>More performance. New compiler, minor SW adoptions needed mainly on linker level. Peripheral SW modules can be reused</td>
<td>S12I</td>
<td>S12Z</td>
<td>4k Dataflash with ECC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4k EEPROM with ECC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>True EEPROM. Different EEPROM Driver &amp; Data Storage System, Different Flash SW driver (only relevant if programming feature available in boot loader)</td>
</tr>
<tr>
<td>More performance</td>
<td>Up to 32 MHz</td>
<td>Up to 50 MHz bus freq. (100 MHz CPU)</td>
<td></td>
</tr>
<tr>
<td>simple S/W, faster access</td>
<td>Paging</td>
<td>Linear addressing</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extended to 8k, added ECC feature</td>
<td>6k</td>
<td>8k with ECC</td>
<td></td>
</tr>
<tr>
<td>Added msCAN module</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>msCAN</td>
<td>no</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>
### Analog Die - Comparison ‘637 vs. ‘638

<table>
<thead>
<tr>
<th>Feature</th>
<th>Analog Die (637)</th>
<th>Analog Die (638)</th>
<th>Benefit/Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vsense</td>
<td>2 inputs, with</td>
<td>Extend to 4 inputs with attenuation, and 4 direct inputs without attenuation (external resistor divider)</td>
<td>Extended sense capabilities</td>
</tr>
<tr>
<td></td>
<td>attenuation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vsup, Vsense max rating</td>
<td>42V</td>
<td>Vsense3 rated 65V, for truck applications</td>
<td>Higher rating for truck applications</td>
</tr>
<tr>
<td>PGA</td>
<td>8 different gains,</td>
<td>Reduced to 4 gains, changed layout to improve noise, auto gain switching</td>
<td>Better accuracy</td>
</tr>
<tr>
<td></td>
<td>auto gain switching</td>
<td></td>
<td></td>
</tr>
<tr>
<td>External Temp sense</td>
<td>1 ext. channel</td>
<td>Up to 5 ext channels. Routed via port B</td>
<td>Extended sense capabilities, ADC cross check</td>
</tr>
<tr>
<td>VDDX</td>
<td>5V – 50 mA</td>
<td>Capability extended to 150mA</td>
<td>CAN PHY consumption</td>
</tr>
<tr>
<td>Vdda</td>
<td>2.5V, capability less than 2mA</td>
<td>VDD a extended up to 4mA</td>
<td>account for additional ext Temp sensors.</td>
</tr>
<tr>
<td>LIN</td>
<td>LIN IP for LIN 2.0-2.1 and J2602-1</td>
<td>Latest LIN IP</td>
<td>Added TxD dominant fault detection</td>
</tr>
<tr>
<td>GPI0 Port B</td>
<td>4 input output ports</td>
<td>Port B extended to 5 pins</td>
<td>Includes CAN wake up, exit Vsense and external T° sense</td>
</tr>
<tr>
<td>CAN Wake up</td>
<td>No msCAN</td>
<td>CAN wake up via PTB</td>
<td></td>
</tr>
</tbody>
</table>

### Diagram

- **Test Interface**
- **Reset Control Module**
- **Trimming / Calibration**
- **Internal Control Module**
- **Die To Die Interface**
- **Cascaded Voltage Regulators**
- **Current Sense Module**
- **PGA with Auto Gain Control**
- **ADC Regulator**
- **Internal Chip Temp Sense (with optional external inputs)**
- **VBAT Sense Module (AAF, and optional inputs)**
- **Low Pass Filter And Control**
- **16 Bit – ADC**
- **16 Bit – ADC**
- **Wake Up Control Module (with Current Threshold and Current Averaging)**
- **4 Channel Timer**
- **BIAS**
- **LIN Physical Layer**
- **LIN IP for LIN 2.0-2.1 and J2602-1**
- **SCI**
- **GPI0 Port B**
- **CAN Wake up**

### Legend
- Change vs previous version, Validated on previous silicon pizza mask
- No Change vs previous version, AEC Q100 qualified
Target Applications

- 12V PB Battery (LIN)
- 12V PB Battery (CAN)
- Multi- Battery
- Multiple Cells
- HV Battery Junction Box
Hardware Features
MM9Z1_638 Intelligent Battery Sensor
Features Summary

• Current sensing (up to +/-2000A with 100 μΩ shunt resistor)
• Voltage sensing (up to 9 inputs)
• Temperature sensing (up to 5 external inputs, 1 internal sensor)
• Embedded MCU (16-bit S12Z MCU w/ 128 kByte flash, 8 kByte RAM, 4 kByte EE PROM, all with ECC)
• Embedded power management
• LIN/CAN/SPI/UART communication
MM9Z1_638 Intelligent Battery Sensor Block Diagram
S12Z CPU Architecture

- 24-bit = 16MByte linear address space (no paging)
- 32-bit wide instruction and data bus in Harvard architecture
- 32-bit ALU
  - Single-cycle 16x16 multiply (2.5 cycles 32x32)
  - MAC unit 32-bit += 32-bit*32-bit (3.5 cycles)
  - Hardware divider 32-bit = 32-bit/32-bit (18.5 cycles)
  - Single cycle multi-bit shifts (Barrel shifter)
  - Fractional Math support
- CPU operates up to 100MHz and 50MHz Bus
  - Optimized bus architecture with 100MHz load and store to RAM
  - NVM works with 1 Wait-state => effective 20ns accesses
- Instructions and addressing modes optimized for C-Programming & Compiler
Acquisition Channels
Same V and I channel structures allow synchronization between voltage and current measurements.
Current Measurement

Feature Summary:
- Dedicated 16 Bit Sigma Delta (ΣΔ) ADC
- Programmable Gain Amplifier (PGA) with 4 programmable gain factors
- Gain Control Block (GCB) for automatic gain adjustment
- Simultaneous sampling with voltage channel
- Gain and offset compensation
- Chopper mode with moving average SINC3 + IIR stage
- Programmable Low Pass Filter (LPF), configuration shared with voltage measurement channel
- Shunt open detect sensing feature
- Triggered sampling during low power mode with programmable wake up conditions
Voltage Measurement

Feature Summary:
- Dedicated 16 Bit Sigma Delta (ΣΔ) ADC
- Four external voltage inputs with individual resistor divider VSENSE[3..0]
- Five external voltage inputs with direct access (no divider) to Sigma Delta PTB[4..0]
- Fixed high precision and calibrated divider for each VSENSEX input
- Simultaneous sampling with current channel
- Gain and offset compensation
- Optional chopper mode with moving average
- SINC3 + IIR stage
- Programmable Low Pass Filter (LPF), configuration shared with current measurement channel
Temperature Measurement

Feature Summary:

- Internal on chip temperature sensor
- Five optional external temperature sensor inputs: PTB[4..0]
- Dedicated PTB5 input for connection to GND of external temperature sensors and disconnection in Sleep and Stop modes
- Dedicated 16-Bit Sigma Delta ADC
- Programmable gain and offset
- Optional external sensor supply (VDDA) with decoupling capacitor
- Optional measurement during low power mode to trigger recalibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement Range</td>
<td>$T_{\text{RANGE}}$</td>
<td>-40</td>
<td>–</td>
<td>150</td>
<td>°C</td>
</tr>
<tr>
<td>Accuracy</td>
<td>$T_{\text{ACC}}$</td>
<td>-2.0</td>
<td>–</td>
<td>2.0</td>
<td>K</td>
</tr>
<tr>
<td>• $-40 , ^\circ \text{C} \leq T_A \leq 85 , ^\circ \text{C}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• $85 , ^\circ \text{C} &lt; T_A \leq 150 , ^\circ \text{C}$ (22)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resolution</td>
<td>$T_{\text{RES}}$</td>
<td>–</td>
<td>8.0</td>
<td>–</td>
<td>mK</td>
</tr>
<tr>
<td>Max Calibration Request Interrupt Temperature Step</td>
<td>$T_{\text{CALSTEP}}$</td>
<td>-25</td>
<td>–</td>
<td>25</td>
<td>K</td>
</tr>
</tbody>
</table>
Timers, I/O & Communications
Timers: 4 Channel 16-bit Timer Module

- General purpose timer
- 4 independent channels
- Input capture
- Output compare
- Interrupts
  - 1 per channel
  - Timer overflow
- Clock prescaler (1-128)
- 16-bit counter
- Normal mode clock:
  - D2DCLK / 4 (8 MHz max.)
- Low power mode clock:
  - ALFCLK (0.125 – 1 kHz)

- Optional timer counter reset on channel 3 output compare event
- Optional wake-up over PTB0-3 (GPIO)
Timers: Life Time Counter

- Flexible up-counter running in normal and low power mode
- ALWAYS based on ALFCLK
- Overflow interrupt and wake-up
GPIO: General Purpose Input Output

- 4 pins (PTB0-3)
  - PTB0-2
    - 5V
    - Input / output
  - PTB3
    - High voltage capable (42 V)
      - Input only
- Wake up detection
- SCI Rx/Tx
- Timer 0-3 IC/OC
- LIN Tx/Rx
- PIN direct control
- Optional pull-up (PTB0-2)
- Optional pull-down (PTB3)
Interrupts

- Common vector on S12 for all analog die interrupts
  - INT_VECT register shows individual source
- Interrupt mask register for each source
- All interrupts are nestable
- Fixed priorities

<table>
<thead>
<tr>
<th>IRQ</th>
<th>Description</th>
<th>IRQ</th>
<th>Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>-</td>
<td>No interrupt pending or wake-up from Stop mode</td>
<td>0x00</td>
<td></td>
</tr>
<tr>
<td>UV1</td>
<td>Under-voltage interrupt or wake-up from Cranking mode</td>
<td>0x01</td>
<td>1 (highest)</td>
</tr>
<tr>
<td>HT1</td>
<td>High temperature interrupt</td>
<td>0x02</td>
<td>2</td>
</tr>
<tr>
<td>LT1</td>
<td>LIN driver over-temperature interrupt</td>
<td>0x03</td>
<td>3</td>
</tr>
<tr>
<td>CH0</td>
<td>TIM channel 0 interrupt</td>
<td>0x04</td>
<td>4</td>
</tr>
<tr>
<td>CH1</td>
<td>TIM channel 1 interrupt</td>
<td>0x05</td>
<td>5</td>
</tr>
<tr>
<td>CH2</td>
<td>TIM channel 2 interrupt</td>
<td>0x06</td>
<td>6</td>
</tr>
<tr>
<td>CH3</td>
<td>TIM channel 3 interrupt</td>
<td>0x07</td>
<td>7</td>
</tr>
<tr>
<td>TOV</td>
<td>TIM timer overflow interrupt</td>
<td>0x08</td>
<td>8</td>
</tr>
<tr>
<td>ERR</td>
<td>SCI error interrupt</td>
<td>0x09</td>
<td>9</td>
</tr>
<tr>
<td>TX</td>
<td>SCI transmit interrupt</td>
<td>0x0A</td>
<td>10</td>
</tr>
<tr>
<td>RX</td>
<td>SCI receive interrupt</td>
<td>0x0B</td>
<td>11</td>
</tr>
<tr>
<td>CVMI</td>
<td>Acquisition interrupt</td>
<td>0x0C</td>
<td>12</td>
</tr>
<tr>
<td>LTC</td>
<td>Life time counter interrupt</td>
<td>0x0D</td>
<td>13</td>
</tr>
<tr>
<td>CAL</td>
<td>Calibration request interrupt</td>
<td>0x0E</td>
<td>14 (lowest)</td>
</tr>
</tbody>
</table>
Window Watchdog

- Can be used as conventional or window watchdog
- Clocking based on low power oscillator (independent from S12 MCU)
- Active after reset or wake-up
- Disabled during low power mode
  - During stop mode, the S12 watchdog can be used instead (inactive by default)
- Configurable timeout (4 ms – 2048 ms)
Serial Communication Interface (SCI)

- Digital part of serial communication (e.g. for LIN)
- Full-duplex, standard non-return-to-zero (NRZ) format
- Double-buffered transmitter and receiver with separate enables
- Programmable baud rates (13-bit modulo divider)
- Interrupt-driven or polled operation:
  - Transmit data register empty and transmission complete
  - Receive data register full
  - Receive overrun, parity error, framing error, and noise error
  - Idle receiver detect
  - Active edge on receive pin
  - Break detect supporting LIN
- Hardware parity generation and checking
- Programmable 8-bit or 9-bit character length
- Receiver wake-up by idle-line or address-mark
- Optional 13-bit break character generation / 11-bit break character detection
- Selectable transmitter output polarity
- Single wire mode
Operating Modes & Wakeup
Operating Modes Overview

- **Normal Mode**
  - All device modules active
  - MCU fully supplied, D2DCLK active analog die clock source
  - Window watchdog clocked on independent clock

- **Stop Mode**
  - MCU in low power mode, MCU-regulator supply reduces current capability, D2D interface supply disabled (VDDH=OFF)
  - Unused analog blocks disabled, watchdog disabled
  - Optional: Wake-up capabilities
  - Optional: Current and temperature measurements

- **Sleep Mode**
  - MCU powered down (VDDH and VDDX = OFF)
  - Unused analog blocks disabled
  - Watchdogs = OFF
  - Optional:醒来-up capabilities
  - Optional: Current and temperature measurements

- **Intermediate Mode**
  - Transition from Stop/Sleep to normal mode

- **Reset Mode**
  - Reset state (driven by both analog and MCU)

- **Power On Reset Mode**
  - Indicate a loss of internal state

- **Cranking Mode**
  - Special mode implemented to guarantee the RAM content is valid though very low power conditions
Differences Between Sleep And Stop Mode
(Software Perspective)

• Differences between sleep and stop mode:
  - Starting point for the software after wake-up
  - Current consumption (different values for analog and MCU die)

• Sleep mode
  - MCU is not powered (disconnected from the supply)
  - First instruction is fetched from power-on reset vector
  - All hardware and software initialization code is executed
  - Longer wake-up time but less current consumption compared to stop mode
    (see next slides for details)

• Stop mode
  - MCU is in stop mode but still supplied
  - First instruction is fetched from the wake-up ISR. After the ISR, the first
    instruction after the STOP command (to go to stop mode) is executed in the
    main program
  - No software initialization, minor hardware initialization
    (mainly wait for PLL-lock)
  - Faster wake-up but more current consumption compared to sleep mode
Reduced Average Current Consumption Due to Embedded Low-power Features

• Device is put into stop/sleep mode most of the time to decrease current
• The system wakes up regularly and updates SoC/SoH
• Cyclic measurements allow Coulomb counting and detect any activity in the car (typically every second)
### MM9Z1_638 Intelligent Battery Sensor

**Low Power - Performance**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ.</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MM9Z1_638 COMBINED CONSUMPTION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normal mode current measured at $V_{SUP}$ excluding external load current, $(3.5 \leq V_{SUP} \leq 28 \text{ V}, -40 \degree C \leq T_A \leq 125 \degree C)$ parameter tested up to $T_A = 85 \degree C$</td>
<td>$I_{RUN}$</td>
<td>–</td>
<td>35</td>
<td>40</td>
<td>mA</td>
</tr>
<tr>
<td>Normal mode current measured at $V_{SUP}$ - analog die contribution - excluding mcu and external load current, $(3.5 \leq V_{SUP} \leq 28 \text{ V}, -40 \degree C \leq T_A \leq 125 \degree C)$ parameter tested up to $T_A = 85 \degree C$</td>
<td>$I_{NORMAL}$</td>
<td>–</td>
<td>1.5</td>
<td>4.0</td>
<td>mA</td>
</tr>
<tr>
<td>Stop mode current measured at $V_{SUP}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Continuous base current (6)</td>
<td>$I_{STOP}$</td>
<td>–</td>
<td>105</td>
<td>125</td>
<td>µA</td>
</tr>
<tr>
<td>$T = 40 \degree C$</td>
<td>–</td>
<td>110</td>
<td>195</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T = 85 \degree C$</td>
<td>–</td>
<td>210</td>
<td>450</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T = 125 \degree C$ (7)</td>
<td>–</td>
<td>110</td>
<td>135</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Stop current during Cranking mode (6)</td>
<td></td>
<td>–</td>
<td>130</td>
<td>235</td>
<td></td>
</tr>
<tr>
<td>$T = 40 \degree C$</td>
<td>–</td>
<td>235</td>
<td>500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T = 85 \degree C$</td>
<td>–</td>
<td>235</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T = 125 \degree C$ (7)</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleep mode measured at $V_{SUP}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Continuous base current (6)</td>
<td>$I_{SLEEP}$</td>
<td>–</td>
<td>65</td>
<td>85</td>
<td>µA</td>
</tr>
<tr>
<td>$T = 40 \degree C$</td>
<td>–</td>
<td>85</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T = 85 \degree C$</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T = 125 \degree C$ (7)</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pseudo stop current</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T = 40 \degree C$</td>
<td>–</td>
<td>205</td>
<td>225</td>
<td>µA</td>
<td></td>
</tr>
<tr>
<td>$T = 85 \degree C$</td>
<td>–</td>
<td>210</td>
<td>305</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$T = 125 \degree C$ (7)</td>
<td>–</td>
<td>310</td>
<td>550</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Current adder during current trigger event in stop or sleep modes: (typ. 10 ms duration (8), temperature measurement = OFF)</td>
<td></td>
<td>–</td>
<td>1500</td>
<td>1750</td>
<td>µA</td>
</tr>
</tbody>
</table>

**Notes:**

5. Typical values noted reflect the approximate parameter mean at $T_A = 25 \degree C$.
6. From $V_{SUP}$ 6.0 to 28 V
7. Guaranteed by design and characterization
8. Duration based on channel configuration. 10 ms typical for Decimation Factor = 512, Chopper = ON.
Wake-up Sources Overview

- Cyclic current acquisition / calibration temperature check
  - Three wake-up conditions are implemented:
    - Current Threshold Wake-Up
    - Current AmpHour Threshold Wake-Up
    - Calibration Request Wake-Up
- Timed wake up
  - Programmable wake up timer with integrated 4 Channel Timer Module available during both low power modes
- Wake up from LIN/CAN
- Wake up on pin : PBT3/L0 with pin 0 to 1 transition (rising edge)
- Wake up on life time counter overflow
  - The life time counter can be configured to run during low power mode. Once the counter overflows with the life time counter wake up enabled, a wake up is issued
- General Wake Up Indicator
  - To indicate the system has been woken up after power up
Trim and Calibration
Trimming and Calibration Overview

- **Factory Stored Trimming**
  - Trimming will use factory measured and calculated values stored in a special microcontroller information register to be loaded into specific registers in the MCU and analog die at system power up

- **Calibration**
  - Calibration will occur during system operation using internal references or specific measurement procedures
Factory Stored Trimming

- **Microcontroller Chip**
  - **Internal Oscillator Trimming (ICG)**
    - Optimum trim value is determined during final test and stored in the information register block of the MCU FLASH memory. During power on of the microcontroller, the trim value will automatically be stored in the MCU trimming register.

- **Analog Chip**
  - Low Power Oscillator Trimming
  - Band Gap Reference Trimming (BGAP)
  - Temperature Sense Module Trimming (TESENE)
  - LIN Slope Control Trimming

Trim information is determined during final test and stored in MCU flash memory. On every power up, the corresponding trim value needs to be copied into the desired register.
Calibration: Periodic Adjustment during Operation

- Voltage and current sense calibration have to be performed during system operation

- Initiators for re-calibration include:
  - A system power up occurred (to be initiated by the MCU)
  - On a regular basis before or after low power mode - based on application software flow
  - The junction temperature measurement result significantly differs from the “last calibration temperature buffer” content. The analog die constantly compares the “last calibration temperature buffer” vs. the current temperature measurement and issues an interrupt once a significant difference is detected.
  - A significant temperature change was detected during low power current sense2. The analog die compares the “last calibration temperature buffer” vs. the temperature measurement and issues a wake up once a significant difference is detected.
Tools and Enablement
Development Tools Overview

- **Compilers**
  - CodeWarrior
  - Cosmic
- **IDE**
  - CodeWarrior v10.3 (Eclipse-based)
  - Cosmic Win IDEA
  - Eclipse
- **Programmers**
  - P&E PROGS12Z
- **Debugger**
  - CW & P&E S12Z Debugger
  - Cosmic Zap Debugger
- **Debug Interface**
  - P&E USB Multilink Debug Interface
  - Cyclone Pro Programmer
  - Third-party debug interfaces (iSYSTEM/Lauterbach)
Hardware

• Standard EVB - KIT9Z1J638EVM
  - Status: available
KIT9Z1J638EVM – Hardware Features

- MM9Z1_638 Xtrinsic Battery Sensor in a 48-QFN package with wettable flank.
- On-board BDM connection via open source OSBDM circuit using the MC9S08JM60 microcontroller. See www.pemicro.com/osbdm for OSBDM source code
- High-speed CAN interface
- LIN interface
- Customizable GPIOs for voltage and temperature sensing
- LED indicators
- Support for USB Multilink Interface BDM

Block diagram of the KIT9Z1J638EVM design with the primary components
12V Lead Acid IBS Application with MM9Z1_638

Datasheet 12V Application

Application Diagram

Precision Shunt

- Resistance value: 100µΩ +/-5%
- Manufacturer: Isabellenhütte
- PCB is soldered on it
- PCB matches the shunt shape

Measured current
= Vehicle current
+ IC current
MMYMZ1_638 Intelligent Battery Sensor 12V Lead-Acid with LIN - PCB Layout

- Car chassis = IC ground
- Battery minus
- Temperature measurement
- NTC located above shunt for better battery heat transfer
- Current measurement
- Voltage measurement
Final Hardware Solution (PCB + Shunt)
12V Lead Acid IBS: Basic Enablement Drivers

- QuIBS+Z startup
  - MCU die init, analog die init
  - Measurement channel setup for evaluation
- Communication
  - LIN 1.3 slave driver
  - LIN 2.1 slave driver
  - SPI
  - CAN
  - 2-wire serial (UART)
- Runtime software
  - Flash/ EEPROM SW
  - TIMERs SW
  - STOP / SLEEP mode SW, using wake up from LTC, LIN or L0-PTB3
- Startup trimming
  - Complete startup trimming procedure as described in datasheet
  - Including temperature based gain compensation
- Module calibration
  - Test for IBS module calibration (for example, at end-of-line at customer)
  - On-chip & external (in Excel) calculation of compensation values
  - Storage of compensation values in DFLASH
- Test software
  - LIN Master/Slave test using DEMO9S08DZ60 board
Availability

- 12V PB IBS- Development Kits (Example Software):
  - Development kit (1st milestone): **Available Now**
    - Reference design hardware (LIN Only)
    - LIN 2.1 driver
    - msCAN driver
  - Development kit (final milestone): **available now**
    - Basic enablement drivers
    - Basic SoC calculation
    - Basic SoF calculation

- AUTOSAR OS (Freescale production software): **Available Now**
- CAN stack (third-party production software): **Available Now**
- LIN stack (third-party production software): **Available Now**

- Low-level drivers (third-party production software) beta release: Q1 2014

- P & E multilink: **Available Now**
- Cosmic WinIDEA (third-party production software): **Available Now**
- CodeWarrior 10.3 (Freescale production software): **Available Now**
14V Four-cell Li-ion BMS Application with MM9Z1_638

Switch terminals to be tied @ GND or @ VDDx
Four-cell Li-Ion Application with MM9Z1_638 Overview

• Features:
  - Current sense input through shunt (±1500A with 100μΩ shunt)
  - 4 cell voltage sensing
  - Cell passive balancing
  - 2 LS and 2 HS switches
  - S12Z microcontroller with 96/128 kByte flash, 8.0 kByte RAM, 4.0 kByte EEPROM
  - CAN and/or LIN bus
14V Four-cell Li-ion BMS: Basic Enablement Drivers

- **Startup**
  - MCU die init, analog die init
  - Measurement channel setup
    (current, 4 voltage, 4 temperature channels)
- **Communication**
  - LIN 1.3 slave driver
  - LIN 2.1 slave driver
  - SPI
  - CAN
  - 2-wire serial (UART)
- **Runtime SW**
  - EEPROM SW
  - TIMERs SW
  - STOP / SLEEP mode SW, using wake up from LTC, LIN or L0-PTB3
- **Startup trimming**
  - Complete startup trimming procedure as described in datasheet
  - Including temperature based gain compensation
- **Module calibration**
  - Test for IBS module calibration (like at end-of-line at customer)
  - On-chip & external (in Excel) calculation of compensation values
  - Storage of compensation values in DFLASH
- **Test software**
  - LIN Master/Slave test using DEMO9S08DZ60 board
Availability

- 14V Four-cell Li-ION BMS Development Kit:
  - Development kit (1st milestone): Available Now
    - Reference design hardware
    - Basic enablement drivers
    - LIN 2.1 driver
    - msCAN driver
    - SoC application (basic)
  - Development kit (2nd milestone): Available Now
    - SoC application (Full)
    - Balancing application software
    - Charge ctrl application software
  - Development kit (final milestone): October 2013
    - SoF application
    - Battery parameter configuration
    - Matlab models
- AUTOSAR OS (Freescale production software): Available Now
- CAN stack (third-party production software): Available Now
- LIN stack (third-party production software): Available Now
- Low-level drivers (third-party production software) beta release: Q1 2014
- P&E multilink: Available Now
- Cosmic WinIDEA (third-party production software): Available Now
- CodeWarrior 10.3 (Freescale production software): Available Now
Useful Links

- **Compilers / Debugger / Debugging Interface**
  - D-Bug12XZ:

- **Freescale Hardware**

- **Freescale Software Drivers and Libraries**
  - LIN Drivers:
    in near future will be also added to [www.freescale.com/LIN](http://www.freescale.com/LIN)
  - NVM Drivers:

- **Freescale Tools**
  - FreeMASTER run time debugger: [www.freescale.com/FreeMASTER](http://www.freescale.com/FreeMASTER)
  - Processor Expert: [www.freescale.com/processorexpert](http://www.freescale.com/processorexpert)
Intelligent Precision Battery Sensors

- Embedded **MCU + precision analog** solutions in a single device
- **Highly integrated** to allow BOM optimization
- Designed to **reduce software complexity** and **current consumption** compared to existing solutions
- **AECQ-100 qualified**, meets **automotive robustness** and **zero defect quality** levels
- Samples available
- EVBs available
- Product demonstrator available