Engineering Ultra Low Power System on Chip Sensors

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Scott Hanson – Ambiq Micro
Jim Magos – Cardinal Components
Key Trends Driving Micro SoC Sensors

- New innovative products are smarter, smaller and wireless
- Smart devices with status indications
- There will be billions of new networked smart devices
- Industrial, Medical, Security, Transportation, Environmental...
EH-Powered Autonomous Wireless Sensor Block Diagram

**Energy Harvesting Power Supply**

- **EH Transducer Electrical Interface Discrete Components**
- **IC - Energy Conversion Battery Management Power Management**
- **Rechargeable Energy Storage Device**

**Sensor** (e.g., temperature, pressure, occupancy)

**Energy Manager RTC/Timer**

**MCU + Radio**

**Input Power**

**“Energy Aware” Communications and Control**

- **Light**
- **ΔT**
- **Motion**
- **EM Field**
System on Chip Sensors

**Sensor Types**
- Oxygen Sensor
- Hall Effect
- Soil Moisture
- Speed Sensor
- Water Sensor
- Particle
- Air Speed
- Inclinometer
- Position Sensor
- Seismometer
- Altimeter
- Depth Gauge
- Accelerometer
- Gravimeter
- Gyroscopic

**Components**
- A to D
- D to A
- Micro-C
- Micro-P
- RTC
- TCXO
- VCXO
- GPS
- FPGA
- Crystal
- Solid State Battery
- Level Shifter
- EEPROM
- Bluetooth
- Multiplayer
- Encryption

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[Images and logos for sensors and components]
Trends Driving Need for Innovative Energy Storage

**TRENDS**

- Ultra Low Power Processors
- Smart Devices and Sensors Everywhere
- Wireless is pervasive
- Integration with other components
- Miniaturization
- Eco-Friendly and Renewable Energy

**CURRENT SOLUTIONS**

- Bulky Size/Metal “coin” package
- Cannot be integrated with other electronics
- Low energy for Space used
- Not Eco-Friendly - Toxic Chemicals
- Transportation Safety Issues
Rechargeable solid State Batteries

- EnerChip™ Rechargeable Solid State Batteries are created on Silicon wafers using standard semiconductor fabrication processes and device packaging techniques.
- As the battery is charged, ions move from the cathode through the solid electrolyte to the current collector. As the battery discharges, the reverse is true.
- EnerChips are 150 microns thick – less than two human hairs – and are 1/20th the thickness of a comparable battery.
Key Technical Battery Requirements

High Cycle Life

Flat Output Voltage Profile

Fast and Simple Charge

Low Self-Discharge
Solid State Batteries are Safe

Assembly, Transport, Use and Disposal

Rechargeable solid state batteries are the only energy storage solution that satisfies all the following global environmental and safety regulations and certifications:

- RoHS
- China RoHS
- REACH
- CE Mark
- UL - Underwriters Laboratory
- JEDEC IC Packaging Standards and Tape and Reel EIA Standards
- IEC, NEMA/ANSI
- United Nations Transportation Air Safety Regulations
- WEEE Waste Electrical and Electronic Equipment Directive
- EU Battery Directive
- MSDS and OSHA Information
- Solid State Battery End-of-life Disposal Instructions
- In vitro/In vivo Biocompatibility Test Standards for Cytotoxicity
Packaging Options

- Solid State Batteries are a unique solution for customer applications requiring a small energy storage device integrated directly into the system.

- EnerChips support many different device configurations using standard wire bond or solder bump attachment.

- Applications in the this market include:
  - Sensor Systems on Chip
  - Security and tamper detection devices
  - Electronic fuses for various devices
  - Medical devices – ophthalmic, implantable, patches
EnerChip Solid State Batteries in Bare Die form are the ideal devices for integrating energy storage in emerging System in 3D Packaged Systems. EnerChips using wire bonding, solder bumps for flip chip or eventually Thru Silicon Vias can be integrated into Systems in Package, Package on Package, TSV stacks and other 3D configurations.
Solving the Power Problem

Power must be optimized all levels of the design hierarchy

System Software Architecture
System Hardware Architecture
Hardware Components

The focus of today’s presentation
Building ULP Components with Sub-threshold

Sub-threshold enables energy reductions on the order of $1.8^2/0.5^2=13\times$
The Limits of Sub-threshold

Deep sub-threshold operation is possible, but significant challenges exist.
The Challenges of Sub-threshold

On-to-off current ratio is reduced dramatically

- $V_{dd} = 1.2V, \frac{I_{on}}{I_{off}} \approx 800,000$
- $V_{dd} = 250mV, \frac{I_{on}}{I_{off}} \approx 800$
The Challenges of Sub-threshold

Current is exponentially sensitive to process, voltage, and temperature

- Limited $V_{th}$ sensitivity at high $V_{dd}$
- $\sim 14X$ change in current for $\Delta V_{th} = 100mV$
Addressing the Challenges with SPOT

- SPOT: Sub-threshold Power Optimized Technology
- Standard manufacturing process
- Circuit, architecture, and test methodology that enables robust sub-threshold operation
- Proven over 8 years of development

2005 2006 2007 2009 2010

2012
AM18XX: A SPOT-Based RTC

SPOT enables unprecedented power of only 15-55nA
A Typical Use Case

SPOT enables a 5X increase in battery life

<table>
<thead>
<tr>
<th></th>
<th>Incumbent System</th>
<th>SPOT-Based System</th>
</tr>
</thead>
<tbody>
<tr>
<td>EnerChip Power Management Current</td>
<td>35nA</td>
<td>20nA</td>
</tr>
<tr>
<td>RTC Current</td>
<td>150nA</td>
<td>21nA</td>
</tr>
<tr>
<td>Life for 12µAh battery*</td>
<td>4 days</td>
<td>20 days</td>
</tr>
</tbody>
</table>

* EnerChip CBC012 battery under 41nA load is an 18uAh equivalent
Sensor SoC - What’s Needed?

- Looking for reduction in system size
- Systems incorporating energy harvesting techniques
- Low power small wireless systems
- Wireless sensor nodes
- Short time back up power
- Self powered systems
- Embedded power systems needing time logs, datalogs
- Embedded processing systems
- Any system that maintains RTC during power outage
Real Time Plus Concept

- Real Time Clock
- Solid State Battery
- Integration
- Configuration Options
- Battery Recharging Circuit
- I²C
- RTC Crystal
Real Time Plus – RTC + Battery + XTAL

Traditional Design Approach

Real Time Plus Solution

78% smaller surface area

<table>
<thead>
<tr>
<th>Type</th>
<th>Length</th>
<th>Width</th>
<th>Square mm Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCB with CR2032</td>
<td>30.0</td>
<td>32.0</td>
<td>960</td>
</tr>
<tr>
<td>CRTP</td>
<td>12.4</td>
<td>17.4</td>
<td>216</td>
</tr>
</tbody>
</table>

78%
RTPlus SoC Components

**Real Time Clock**
- Temperature Compensation
- Industrial Temperature Range -40 to +85°C
- RoHS Complaint
- Calendar tracks year and leap year
- Clock tracks seconds, minutes and hours in 24 hour format
- Interrupt Output
- Programmable Alarm and Universal Timer
- Extremely Accurate i.e., @25°C, ± 2 PPM
- 8 Bytes of Ram and 2 Bytes EEPROM for Customer Application

**Battery**
- Solid State Battery
- RoHS Compliant
- Rechargeable with on board trickle charge circuit

**Package**
- SMD
  - 10.3 x 12.7 mm
  - 12.4 x 15.1 mm
  - 12.4 x 17.8 mm
- High quality Crystal
- I2C Interface Bus

**Application Examples**
- Wireless sensors and RFID tags
- Consumer appliances
- Energy Harvesting
- Time Keeping
- Metering
- Telemedicine
- Time stamping
- Smart energy
- Military surveillance

**CRTP Series Power Holdover**
- CRTPN05  4 days
- CRTPA12  20 days
- CRTPA50  90 days
Creating a Sensor SoC – Modu-Flex™ Example

**Typical System Before Modu-Flex™**

- Battery Backup
- Recharging Circuit
- Power
  - Micro P, or Micro C
  - Memory
  - Control Logic
  - Analog Processing (ADC)
  - Analog Processing (DAC)
  - Output Driver, switches
  - RTC
  - Crystal
  - Oscillator

**After Modu-Flex™**

- Modu-Flex
  - Analog Processing (ADC)
  - Analog Processing (DAC)
  - Output Driver, switches
Sensor SoC Package Innovation

Diagram showing the components of a Sensor SoC Package:
- uC
- RTC
- EEPROM
- Temp Sensor
- D/A
- A/D
- Output Driver
- Switch
- Osc
- Battery
- Charge
- Crystal

Image from sensors expo & conference.
Sensor SoC Integrated Package

Modu-Flex is a RoHS compliant (including the battery), CMOS low-power, real-time clock/calendar module with built-in Thermometer, Digital Temperature Compensation circuitry (DTCXO), a solid-state battery back up for the RTC, and single or dual output oscillator circuit (1 to 200 MHz)

**Applications:**
- **Automotive:** Car Radio / GPS and Tracking Systems / Dashboard / Engine Controller / Car Mobile & Entertainment Systems / Tachometers
- **Metering:** E-meter / Heating Counter
- **Outdoor:** ATM & POS systems / Surveillance & Safety systems / Ticketing systems
- **All Types** Portable and battery operated devices
- **Industrial** Automation, Robotics, Controls
- **Consumer** Gaming, Set top box, Data Storage
- **White goods** Refrigerators, Dishwasher, Washers

**Benefits:**
Integration, any frequency from 1 to 200 MHz, small physical size, simplifies design, custom options available, factory configurable in 48 hours
Sensor SoC Creation Process

Customer Concept → Design → Flexible Manufacturing → Integrated Solution

- Flip Chip
- Stack Die
- Hard PCB
- Flex PCB
- Hard PCB

Prototype-Small Volume
Volume Packaging

sensors expo & conference
CARDINAL COMPONENTS
# Customizable System Options

<table>
<thead>
<tr>
<th><strong>Reference clock</strong></th>
<th><strong>Communications Interfaces</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• RTC</td>
<td>• Wireless radio control</td>
</tr>
<tr>
<td>• Crystal</td>
<td>• LIN bus</td>
</tr>
<tr>
<td>• Single Oscillator</td>
<td>• Optical cable conversion</td>
</tr>
<tr>
<td>• Dual Oscillator</td>
<td>• Dual Tone Multi-Frequency -DTMF Dialer</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Batteries</strong></th>
<th><strong>Power Control</strong></th>
<th><strong>Other</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Solid State Battery 5uAh</td>
<td>• Battery charging</td>
<td>• Magnetic read/write</td>
</tr>
<tr>
<td>• Solid State Battery 12 uAh</td>
<td>• Voltage &amp; current</td>
<td>• Mechanical buttons</td>
</tr>
<tr>
<td>• Solid State Battery 50uAh</td>
<td>• System power</td>
<td>• LCD display/drive control</td>
</tr>
<tr>
<td>• Multi-Batteries</td>
<td></td>
<td>• LED drive</td>
</tr>
</tbody>
</table>

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<thead>
<tr>
<th><strong>Environmental Sensing</strong></th>
<th><strong>ADCs</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Pressure</td>
<td>• Delta-Sigma 6- to 14-bit</td>
</tr>
<tr>
<td>• Humidity</td>
<td>• Incremental 6- to 14-bit</td>
</tr>
<tr>
<td>• Current</td>
<td></td>
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<tr>
<td>• Airflow</td>
<td></td>
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<tr>
<td>• Acceleration</td>
<td></td>
</tr>
<tr>
<td>• Tilt</td>
<td></td>
</tr>
<tr>
<td>• Pyroelectric Infrared (PIR)</td>
<td></td>
</tr>
<tr>
<td>• Light</td>
<td></td>
</tr>
<tr>
<td>• Voltage</td>
<td></td>
</tr>
<tr>
<td>• Temperature</td>
<td></td>
</tr>
<tr>
<td>• Inductive</td>
<td></td>
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<tr>
<td>• Gas</td>
<td></td>
</tr>
<tr>
<td>• Liquid level</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th><strong>Power Management</strong></th>
<th><strong>Sensor AFE</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Voltage Sequencer</td>
<td>• Thermistor</td>
</tr>
<tr>
<td>• Fan Controller</td>
<td>• Gas sensor</td>
</tr>
</tbody>
</table>
# Customizable System Options

## Touch Sensing
- CapSense capacitive sensing (buttons, sliders)
- Touchscreens
- Trackpads
- Proximity sensing

## Other sensing
- Position
- Accelerometer
- Water
- Speed
- Inclinometer
- UV
- Pressure

## Fan/Motor Control
- AC motor
- DC motor
- Fan
- Fuel pump
- Instrument gauges

## DACs
- 6-, 8-, and 9-bit
- 6- and 8-bit multiplying

## Filters
- 2-pole low-pass
- 2-pole band-pass

## Amplifiers
- Programmable gain
- Instrumentation
- Comparators

## Timers/Counters
- 8-, 16-, and 24-bit

## Pulse-Width Modulators
- 8-, 16-, and 24-bit

## Coming soon
- GPS
- Bluetooth
- Zigbee
- IrDA

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Modu-Flex is a flexible module that Integrates peripherals into a single component

A fast, reliable way for companies to take their design and integrate for production with a low NRE custom offerings and solutions.
Combining IC Bare Die into SoC

Cymbet EnerChip RTC CBC34803 example

- Integrate Ambiq AM0803 (I2C) with Cymbet EnerChip CBC005 and CBC910 power mgmt IC
- Miniature Land Grid Array (LGA) module or possibly BGA package
- Wire bond in this case, but could also use flip chip style attachment using bumped bare die
- CBC34813 uses AM0813 (SPI)
RTPLUS and EnerChip RTC

Integrated Solutions Examples

Ambiq RTC + 5uAh EnerChip + PMIC + Xtal Oscillator using Packaged parts – 8 mm x 10 mm

Ambiq RTC + 5uAh EnerChip + PMIC using bare die – 5 mm x 5 mm
Summary

• Key Industry Trends and Application Requirements are driving the need for highly integrated Sensor Systems on Chip designs
• Ultra-low power electronics with Sub-threshold Power Optimized technologies are now available
• Solid State Batteries provide ideal energy storage
• Innovative packaging techniques enable optimized footprint and volume
• Optimized Sensor SoCs are available today