Automating the industry
with low power microcontrollers

William Cooper, Product Marketing Engineer, MSP Microcontrollers
Agenda

• Trends in the industrial market
• An example system and the place of low-power microcontrollers
• The latest from the MSP family of microcontrollers: FRAM and MSP432™ MCUs
• Related reference designs from TI for
  • Industrial Communications
  • Flow Metering
  • Equipment Monitoring
  • Compute Through Power Loss (CTPL)
Challenges in Industrial Automation Systems

- Lower Power
- Higher Resolution Analog
- Wider Operating Temperatures
- Reduced System Size
Key Applications

- Field transmitters facilitate automation and process control:
  - Temperature
  - Pressure
  - Flow
  - Vibration
Industrial Sensing and Communications
TI’s Low-Power Microcontroller Solutions

16-bit MSP430™ MCUs
- The industry leader in ultra-low-power, rich peripherals and analog integration.
- World’s only portfolio of ultra-low-power embedded FRAM MCUs.
- Growing portfolio of more than 500 ultra-low-power MCUs across 13,000+ customers.

32-bit MSP432™ MCUs
- Industry’s lowest power ARM® Cortex®-M4F MCUs. Period.
- High performance MCUs without sacrificing power consumption.
- Pin-for-pin platform planned; sampling 256KB today.

Wireless MCUs
- Focused on ease of use and low power.
- Support for 14 standards including Bluetooth® Smart, Wi-Fi®, Sub-1 GHz, 6LoWPAN, ZigBee® and more.
- Portfolio includes SimpleLink™ Wi-Fi, SimpleLink ultra-low power and CC430 platforms.
MSP MCUs: Continued Low-Power Leadership

Leverage the EnergyMonitor tool to evaluate MCU power using your application code.

See for yourself: ULPBench Scores

MSP MCUs: Industry's lowest power
16-bit MCUs and 32-bit Cortex-M4F MCUs.
Introducing the FRAM Advantage

The lowest power

• Because you spend so much time in **standby**, current consumption as low as **350 nA**

• When your application wakes up, **100µA/MHz** active mode current for efficient operation

• Write quicker to save power; **13 KB in milliseconds**, not seconds

The smartest designs

• Adjust to changing memory requirements with flexible non-volatile FRAM; store your application, data or both

• Restore your system state after power failure with two lines of code and **no backup power source**

• Update your system over the air with **on-the-fly, bit level data writes** and no buffering or pre-erase required

The highest reliability

• Log data continuously with **$10^{15}$ write endurance** and proven 10 year data retention at **85° C**

• Prevent unauthorized memory and data communication access with IP encapsulation and hardware AES

• Diminish data loss with **undetectable soft error rates** and other inherent security advantages of FRAM
# All-in-one: FRAM MCUs Deliver Max Benefits

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<th>Specifications</th>
<th>FRAM</th>
<th>SRAM</th>
<th>EEPROM</th>
<th>Flash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-volatile</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td><em>Retains data w/o power</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Write speed</td>
<td>10ms</td>
<td>&lt;10ms</td>
<td>2 secs</td>
<td>1 sec</td>
</tr>
<tr>
<td><em>(13 KB)</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average active Power [μA/MHz]</td>
<td>100</td>
<td>&lt;60</td>
<td>50,000+</td>
<td>230</td>
</tr>
<tr>
<td><em>16 bit word access by the CPU</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Write endurance</td>
<td>10¹⁵</td>
<td>Unlimited</td>
<td>100,000</td>
<td>10,000</td>
</tr>
<tr>
<td>Soft Errors</td>
<td>Below Measurable Limits</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Bit-wise programmable</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Unified Memory</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><em>Flexible code and data partitioning</em></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Learn more at: [TI.com/FRAM](https://www.ti.com/FRAM)
Ultra-Low-Power MSP FRAM MCU Portfolio

- Broad portfolio
  - 100s of device options
  - 4 – 128 KB FRAM
  - More than 10 packages
  - Integrated smart analog

- MSP430FR6x
  - Up to 128 KB FRAM
  - ADC12
  - 256-bit AES accelerator
  - Scan interface
  - Integrated LCD
  - 64-100 pins

- MSP430FR5x
  - Up to 64 KB FRAM
  - ADC12
  - 256-bit AES accelerator
  - 40-48 pins

- MSP430FR2x
  - Up to 16 KB FRAM
  - ADC10
  - Up to 60 I/O
  - 48-64 pins

- MSP430FR4x
  - Up to 16 KB FRAM
  - Integrated LCD
  - ADC10
  - Up to 60 I/O
  - 48-64 pins
MSP432 – Low-power + Performance

MORE PERFORMANCE FOR MSP430™ MCU DEVELOPERS
Advance to higher levels of computing and analog performance, while maximizing your ultra-low-power MSP430 MCU investment and expertise

LOWER POWER FOR ARM® DEVELOPERS
Slash power consumption and boost performance with the world’s lowest power Cortex®-M4F microcontroller

NO COMPROMISES
Get low-power and performance with a scalable portfolio of 16-bit and 32-bit MSP microcontrollers in a variety of applications
MSP432 MCU: PERFORMANCE AT ITS CORE

Selecting the high-performance ARM® Cortex®-M4F core

Highest Coremark score: 3.41/MHz

48MHz ARM® Cortex®-M4F
- Full ARM instruction set
- DSP extensions
- FPU engine

Industry-leading ultra-low-power
- Active power: 95 µA per MHz
- Sleep mode: 850 nA (with RTC)
- ULPBench score: 167.4

Incorporating high-performance peripherals and features
- Simultaneously read and erase from flash
- Execute up to 200% faster with DriverLib in ROM vs. Flash
- 14-bit 1MSPS ADC with 13.2ENOB, differential mode & 2 window comparators
MSP432 MCU: LOW-POWER AT ITS BEST

48MHz ARM® Cortex®-M4F
- Full ARM instruction set
- DSP extensions
- FPU engine

Industry’s best ULPBench score

Optimizing the architecture for ultra-low power

Industry’s lowest power ARM Cortex-M MCU

Industry-leading ultra-low-power
- Active power: 95 μA per MHz
- Sleep mode: 850 nA (with RTC)
- ULPBench score: 167.4

Wide voltage range: 1.62-3.7V

Integrated LDO & DC/DC

Selectable RAM retention

Independent flash banks

Driver Lib in-ROM

128-bit Flash buffer & pre-fetch

14-bit ADC

8 channel DMA

NVIC with tail-chaining

Peripheral & SRAM memory bit-band

Optimizing peripherals for ultra-low power
- Save 40% more power with the integrated DC/DC vs. LDO
- Save 30nA per RAM bank with selectable RAM retention
- Consume minimal power (375uA) when sampling sensors at 1MSPS with 14-bit ADC
- DriverLib in ROM consumes up to 35% less power than Flash
Analog Integration Highlight

- High degree of analog integration makes system design simpler and easier
- Many MSP MCUs have on-chip integrated ADCs, DACs, and Op Amps
- MSP430i2xx family features on-chip 24-bit Sigma Delta ADC
- MSP432P401R features a high resolution 14-bit SAR ADC

24-bit Sigma-Delta Benefits

- Differential inputs - good for AC measurements and eliminates need for level shifting
- Simultaneous conversions - no inherent delay between voltage and current samples means SW compensation not required
- Built-in PGA - when shunt resistors or Rogowski coils are used, complete dynamic range can be used with any external gain amplifiers
Extended Operating Temperatures

- System processes often require an MCU to operate at temperatures beyond the standard 85°C
- MSP430F2xx and MSP430i2xx MCU families offer chipsets with operating temperatures up to 105°C

- MSP430F2xx: 150°C - 125°C - 105°C - 45°C - 55°C
- MSP430i2xx: -45°C - -55°C
Small Package Size Options

- Often sensors on com links need to be as thin as wires that link them
- Some sensors require a package size that is less than 3mm wide
- **MSP430FR57xx** MCU family includes packages as small as 2mm x 2mm
Single Chip HART Protocol and Modem Solution

Features

- **Physical media**: Same as 4-20 mA wiring (no terminators needed)
- **Max devices**:
  - Point-to-point recommended
  - Can multi-drop up to 15 devices for some applications
- **Max distance**: 3000 meters (can use repeaters)
- **Communication method**: Analog 4-20 mA, plus two-way digital master/slave
- **Cycle time**: 500 ms for digital
- **Transmission properties**: Analog 4-20 mA (which is instantaneous, always present, with no transport lags or synchronization time)
- **Data Packet size**: Four process variables in IEEE floating point values, plus engineering units for them, plus device status in one packet

Learn more at: [HART Transmitter TI Design](#)
Flow Metering Solutions

- **Challenge**: Continuously measure flow while consuming as little energy as possible
- MSP430FR6989 MCU
  - Ultra-low-power flow sensing with Extended Scan Interface
  - 320 Segment LCD Display Driver
  - 128kB of Unified FRAM

LC Water Meter TI Design
Ultrasonic Flow Meter Reference Design
Smart Peripheral Highlight

Extended Scan Interface (ESI) – MSP430FR69x

- Standalone module, operational in LPM3
- Measures rotation with 4 input channels
- Two unique analog front ends ensure parallel rotation measurement and calibration
- Dedicated 12-bit DAC, RAM and internal connections to 32kHz clock and timer output
- Orders of magnitude lower power than software-based approach
- Suitable for water, gas and heat meter flow measurement (induction, magnetic, or optical sensors)

FR69x current per sample for 2 Sensors < 9nA
FW42x current per sample for 2 Sensors < 17nA
Equipment Monitoring

• A pervasive ULP wireless motor monitoring solution
  • 10+ Year Coin Cell Battery Life (100mAh Coin Cell)
    – No wired power
    – Hourly to daily measurements
    – Local data processing
  • Wireless Communication
    – Bluetooth Smart (BLE) Communication
  • Temperature & Vibration Sensing
    – Investigate precision piezoelectric vibration sensor
    – Co-packaged modular solution (sensor + AFE)
  • Small form factor
    – Target final solution size similar to a matchbox

Motor Condition Monitor TI Design
Compute Through Power Loss (CTPL)

• Compute Through Power Loss (CTPL) is a software utility designed to:
  • Save the CPU and several peripheral states in non-volatile memory
  • Use LPMx.5 or handle complete power loss
    – Supported MCUs
      • MSP430FR5xxx MCU, MSP430FR6xxx MCU
  • Restores the CPU and peripheral states
  • Returns the application where it last executed
  • Available now in MSPWare
  • No extra hardware required

  • Program Stack
  • Global variables linked in non-volatile memory
  • System Resets, Interrupts, and Operating Modes, System Control Module (SYS)
  • Power Management Module (PMM)
  • Clock System (CS)
  • 32-Bit Hardware Multiplier (MPY32)
  • FRAM Controller (FRCTL)
  • Memory Protection Unit (MPU)
  • RAM Controller (RAMCTL)
  • Digital I/O (PORT, PORT_INT)
  • Watchdog Timer (WDT_A)
  • Real-Time Clock B (RTC_B)
  • Real-Time Clock C (RTC_C)

Compute Through Power Loss Library
CTPL | Makes LPMx.5 Easy to Use

- Reduces the complexity and makes it easier to use LPMx.5

```c
// Check if a wakeup from LPMx.5 was detected and use a dedicated dev
// previous program execution in that case.
if (SYSSTIV == SYSSTIV_LPMxWS) {
    mode = APP_ULP_ADC;
    select = SEL_ADC_LPMxS_MODE;
    setClock = 1; // After exiting from LPM3.5, set up date and time
    SystemInitFromLPMxS();
} else {
    // Start up normally
    SystemInit(); // Initialize board

    // Display TI Logo
    LCD_drawPicture(1);
    TAI_sleep(2192); // 2s

    // Display Wolverine Slash
    LCD_drawPicture(2);
    TAI_sleep(2192); // 2s

    // Write "Wolverine User Experience" on LCD
    LCD_introWrite();
    TAI_sleep(2192); // 2s
}
```

One simple function call saves state of your system…

```c
void ctpl_enterLpm35(bool restoreOnReset);
```

Similarly, one function call restores the state upon waking up!
CTPL | Save Processor State on Power Loss

- Gracefully enter and exit shutdown on power loss using VCC monitoring
- Ensure enough energy through system capacitance

```
void ctpl_enterShutdown()
```

VCC Monitor TH ~ 2.6V

0V

Device State

Application Runs

Saves State on Power-Loss

Shutdown

Restores State on Power-Up
Compute Through Power Loss (CTPL)

System counter implementation on startup

Context save on power failure

Application resume on power restore

MSP-EXP430FR6989 LaunchPad Development Kit
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<td>4-20mA</td>
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<td>NFC logger with FRAM</td>
<td>TIDA-00230</td>
<td>Communications and Data Logging</td>
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<td>Proximity</td>
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<td>TIDA-00244</td>
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<td>Proximity &amp; SIO</td>
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<td>Linear Hall based Proximity Sensor with SIO Interface</td>
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<td>IO-Link Device with SPI Sensor IF</td>
<td>TIDA-00339</td>
<td>Sensors &amp; Communication</td>
<td>Any sensor w/ SPI &amp; IO-Link</td>
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<td>Water Meter Reference Design for two LC Sensors</td>
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<td>Water Meter Reference Design for Optical Sensors</td>
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<td>Optical Sensors</td>
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<tr>
<td>Ultrasonic Flow Meter Design</td>
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<td>Flow Metering</td>
<td>Ultrasonic Sensors</td>
<td>MSP430FR6989</td>
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<tr>
<td>Intelligent System State Restoration after Power Failure</td>
<td>TIDM-FRAM-CTPL</td>
<td>Control Systems</td>
<td>N/A</td>
<td>MSP430FR6989</td>
</tr>
</tbody>
</table>
Summary in Industrial Automation Systems

- Lower Power
- Higher Resolution Analog
- Wider Operating Temperatures
- Reduced System Size
Thanks for Joining!

Will Cooper – will@ti.com