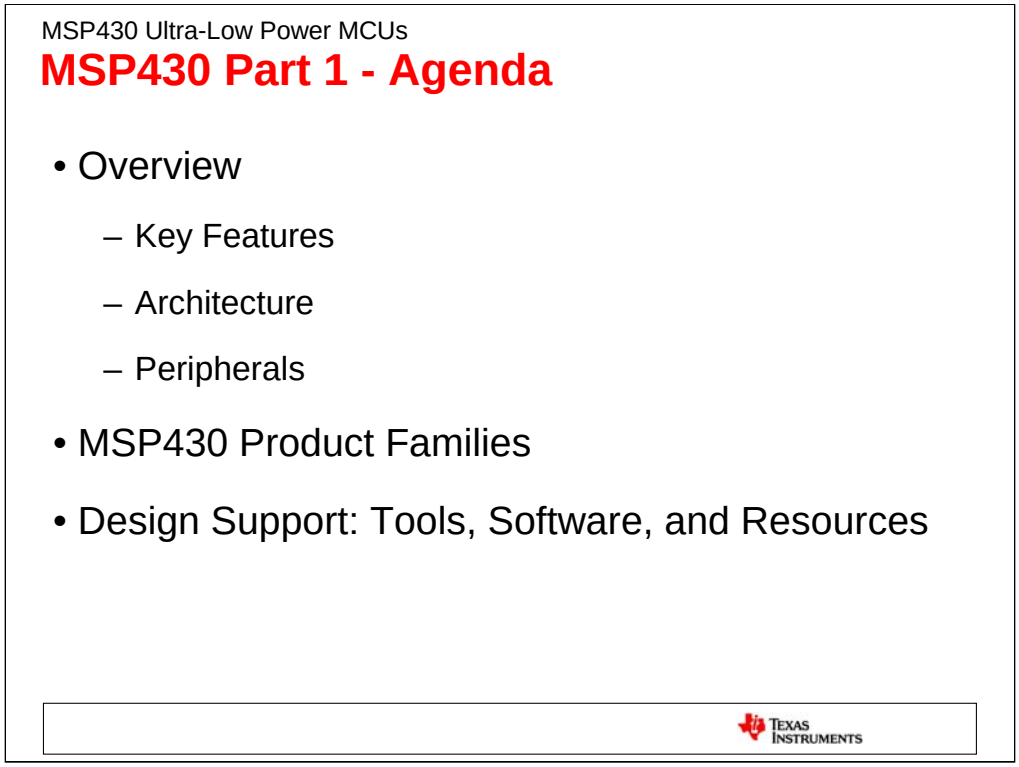
MSP430™ Ultra-Low Power MCUs
Part 1: Overview and Design Support

Technology Day 2009

One Day, Multiple Solutions



These 16-bit MCUs offer a fantastic combination of 3 things: ultra-low-power consumption, high performance analog, as well as a scalable portfolio of devices at competitive price points.

* First, I will share with you what's unique about MSP430's architecture, as well as some of the typical applications that use the MSP430.

* Then, we will discuss our secret sauce for ULP, and how you can take advantage of it in your projects

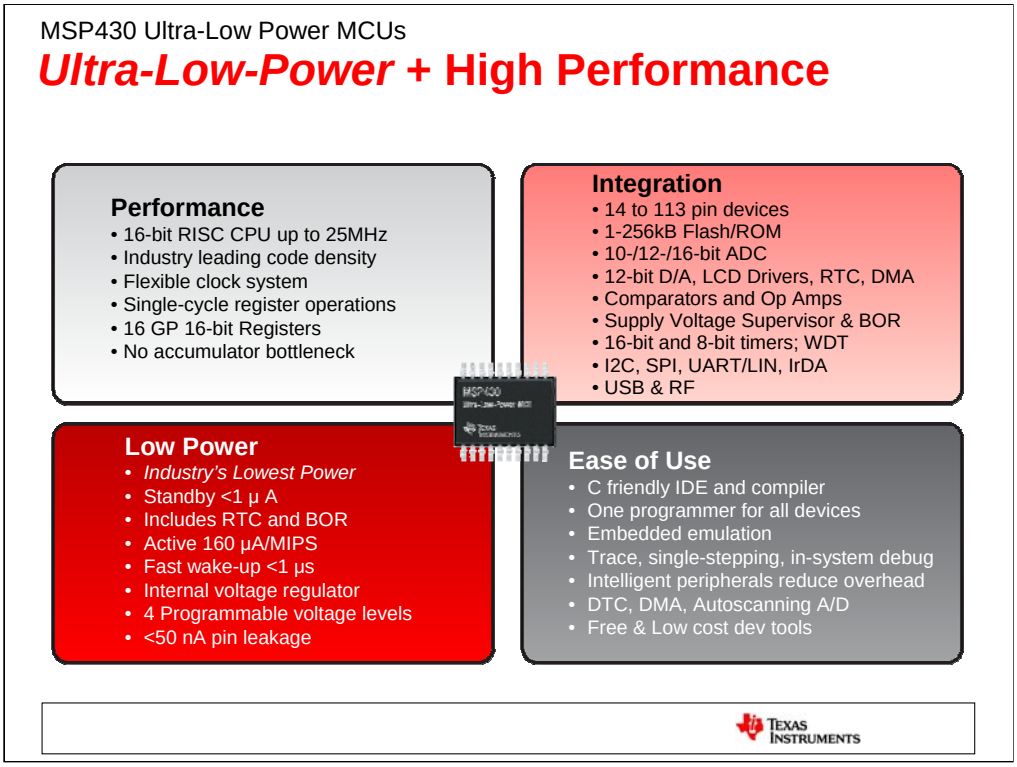
•We will also walk through our peripherals, such as our A/Ds, sigma deltas, DACs, analog comparators and serial communications interfaces

•Next, we will cover what is the most exciting part of the presentation for me, which is new technologies! We have RF, USB, FRAM, and energy harvesting

•then I will show you how our portfolio of 200 products breaks down

•Finally, I think you'll be thrilled to see the new hardware and software tools we've launched for you, and how we have built out our community on the web

MSP430 Overview



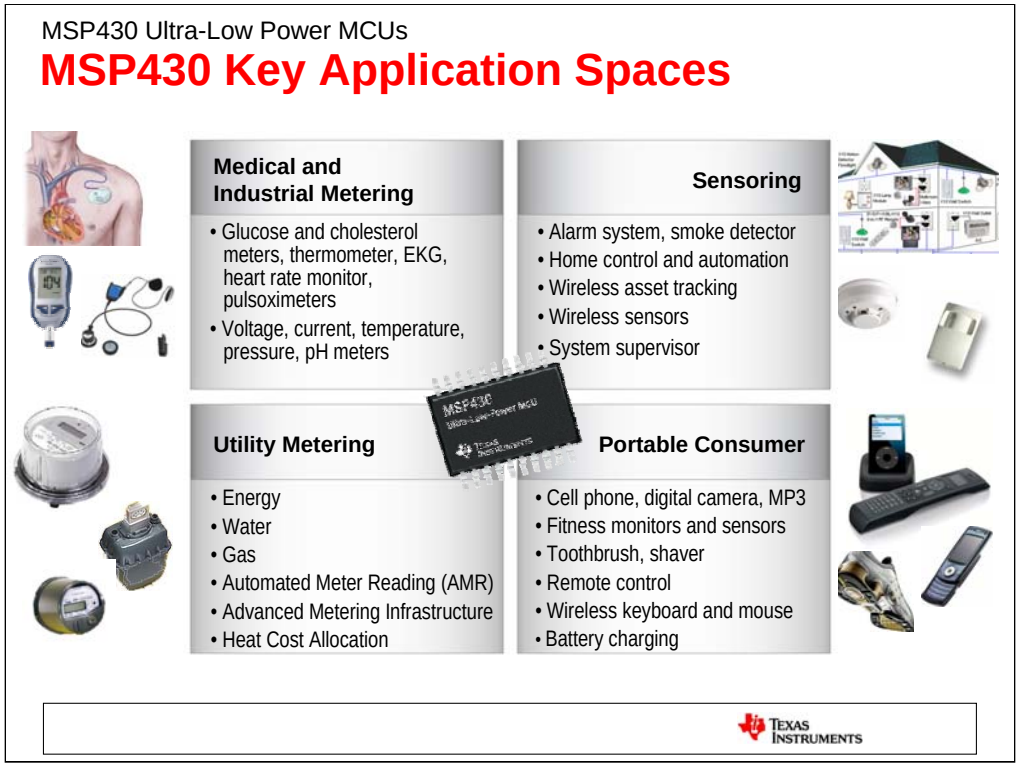
Here are just a few of the features that make MSP430 unique.

Performance**:** From a performance perspective, the original MSP430 architects realized that being "friendly" to C compilers is a way to reduce power consumption; because smaller, faster code means less CPU cycles. And so they designed an orthogonal architecture that allows ordinary tasks to be done with less code. This has allowed to have the highest MCU code density..

Integration: Regarding our integration, we have over 200+ MSP430 devices, with flash ranging from 1KB to 128KB, and packages ranging from 14 to 113 pins. There are high performance analog blocks for applications that require a high degree of accuracy, and there are also nimble devices under $1 and even $0.50 for cost sensitive applications. Our intelligent peripherals including 10-16-bit ADC's, comparators, DACs, LCD drivers and supply voltage supervisors support precision measurement. This allows applications to get implemented faster, using less code and power at lower cost.

Ease of Use: For ease of use, our embedded emulation allows designers to eliminate an external emulator as the device emulates itself. JTAG is used to communicate unobtrusively with the MSP430 in-application. This means that all development is done under the same condition that will be seen in the final product. Using embedded emulation projects are developed faster, with few errors and at a lower cost

Ultra-low Power; On to ultra-low-power, the MSP430 architecture is designed specifically for ultra-low power and this makes it it ideal for battery-powered applications. We offer specific operating modes to reduce power consumption and extend battery life. The real-time clock mode uses as little as 0.8µA and can transition to active mode in less than 1µs.
There are many other important low-power features, just one of example is the brown-out reset (BOR) that is zero power. Another one is extremely low pin leakage, a metric often overlooked. These features have enables MSP430 customers to develop battery-based products that will last for *over 20-years* from the original battery! This is a first in the industry!



These are the four major application spaces which require our balance of analog, and low power and economical prices. However, the ways an MSP430 can be used is only limited by the design engineers' imagination! We have seen smart cards, solar panels and, believe it or not, even an MSP430 mounted on the back of a flying insect!

Medical and Industrial Metering

But putting that aside, the MSP430 has functions designed specifically for medical equipment. The actual physiological signals are analog and they require signal conditioning techniques, such as amplification and filtering, before they can be measured, or displayed. The MSP430 MCU supports applications such as blood pressure monitors, pulsoximeters, and heart rate monitors. You can imagine that in the pioneering field of implantable medical devices, battery life is crucial. It can mean the difference between a patient having invasive surgery ever 20 years instead of every 5-10, and it's here that the MSP430 is must-have.

Sensoring

Sensoring is a fascinating field as energy conservation becomes a greater concern, and it seems everyone wants to go green. All applications, and this includes the industrial markets, are looking for ways to save power. Applications such as smoke detectors, thermostats and glass breakage systems are ideal for the unique combination of ultra-low power consumption and integrated high-performance analog on a MSP430.

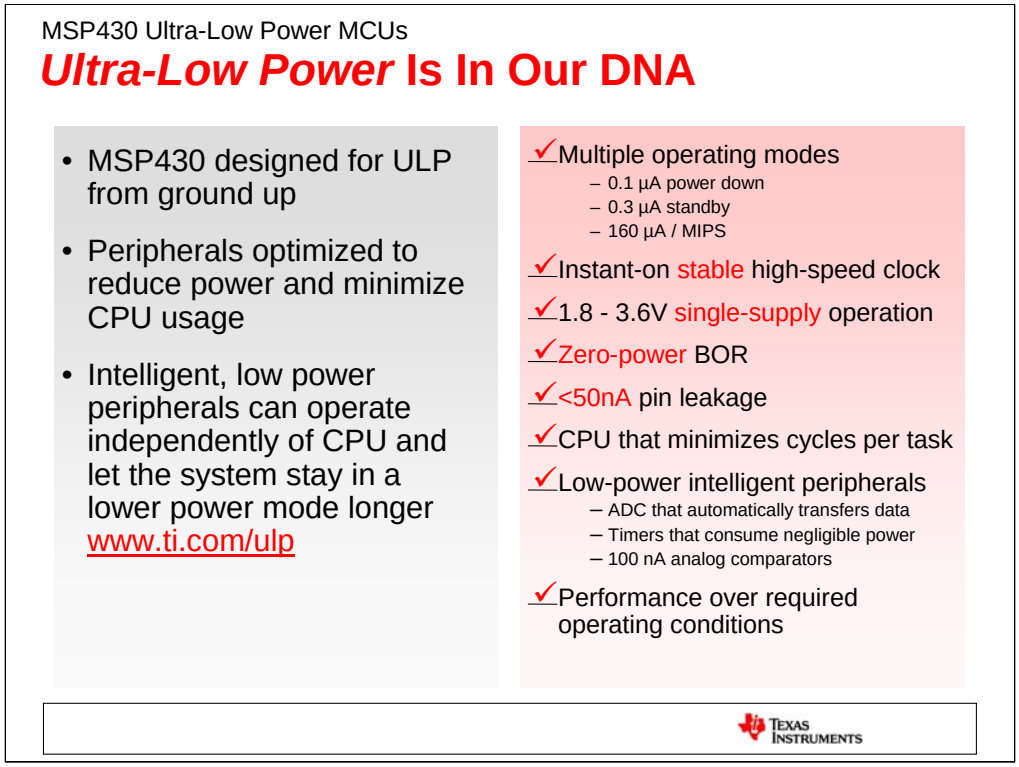
Portable Consumer

Within consumer, portability is the name of the game, and manufacturers want to cut the power cord. In addition, with the built in LCD controller in the 4xx family, the MSP430 MCUs can be used for portable consumer applications requiring a display.

Utility Metering

To address the utility metering market, MSP430 offers devices for one- to three-phase electricity, water and gas metering. In addition, we have integrated wireless radios for automated meter reading (AMR). Check out our extensive ecosystem of solutions at ti.com/metering

Now that we can see how important low power is in all of these applications, Jennifer is going to explain how we have managed to achieve the world's lowest power microcontroller.



Ultra-low power is in our DNA: As the world's lowest power microcontroller, the MSP430 was designed from the ground up with low power in mind. We've woven low power into every aspect of the MSP430 from the architecture, to the smart integrated peripherals, to our easy-to-use tool chain. The MSP430's power consumption is unmatched in the industry – it's so low, it's ridiculous.

* MSP430 is the leading ultra-low power MCU, providing faster wake-up ("burst mode operation"), low-power oscillators and memory designs, lowest power analog components, real-time clock operations down to 1uA and less.

* Originally designed with low power in mind, the MSP430 offers a wide range of integrated peripherals that allow designers to create cutting edge, energy-efficient and ultra-low power applications quickly and easily.

The MSP430 is designed specifically for battery-power measurement applications.

The **clock system** allows many low-power modes with no compromise in performance.

Because of a wide operating voltage range, the MSP430 can often be powered directly from a battery.

The MSP430 **BOR** implementation is truly ultra-low power, in the nA range and practical for all applications. The MSP430 BOR function is so low power that this functions is always active, even in all low-power modes. This ensures the most reliable performance possible. Competitor's BOR protection is in the µA range and not usable in ultra-low power battery powered applications, which leave the application vulnerable to BOR conditions.

The **port pins** have very low leakage when connected to external signals. This is very important as many MCUs have several µA of input leakage on each port pin.

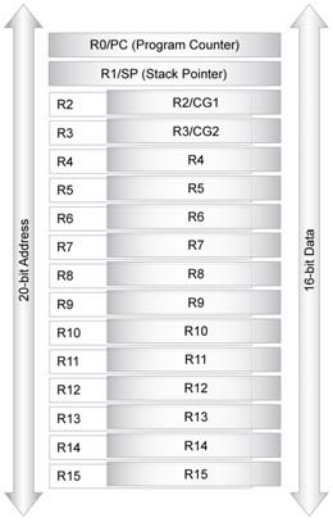
The overall MSP430 **architecture** including a 16-bit CPU with 16 registers and 16-bit data and address buses minimize power-consuming fetches to memory. A fast vectored-interrupt structure reduces the need for wasteful CPU software flag polling.

Many **intelligent peripheral** features are provided that allows tasks to be completed independent of the CPU and far more efficiently. These include the autoscan feature in the ADC12 and the available DMA. With the intelligent peripherals, the CPU does not need to be over clocked to deliver the required system performance.

Always review manufactures worst case or maximum values. Many specifications are dramatically effected over **temperature**.

MSP430 Ultra-Low Power MCUs

16-bit Orthogonal RISC CPU



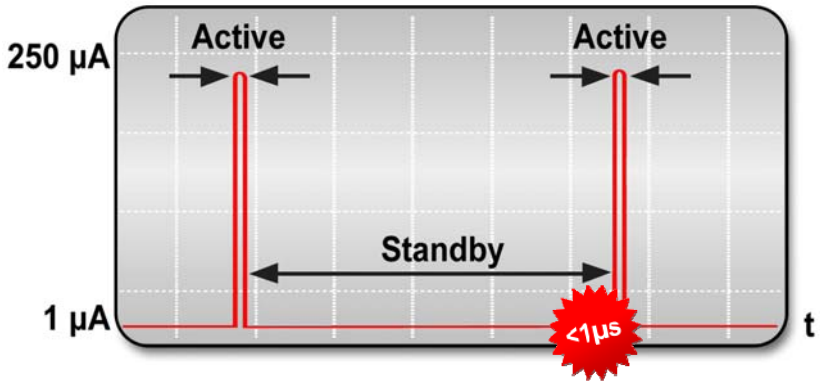
- Efficient, ultra-low power CPU
- C-compiler friendly
- RISC architecture
  - 27 core instructions
  - 24 emulated instructions
  - 7 addressing modes
  - Constant generator
- Single-cycle register operations
- Memory-to-memory atomic addressing
- Bit, byte and word processing
- 20-bit addressing on MSP430X for Flash >64KB

Texas Instruments

Modern 16-bit RISC CPU is optimized for modern programming techniques.
The MSP430's architecture provides the flexibility of 16 fully addressable, single-cycle 16-bit CPU registers. The large CPU register file eliminates what is typically a single working file or accumulator bottleneck. The CPU registers are fully accessible including the program counter, stack pointer, status register and 12 working registers. The modern Reduced Instruction Set (RISC) design of the CPU offers versatility through simplicity using only 27 easy-to-understand instructions and 7 consistent addressing modes. All memory spaces – Flash, RAM, peripherals and CPU registers - use the exact same instructions and addressing modes. All instructions can also be used in a 16-bit word (.w) or 8-bit byte (.b) format. The MSP430 is an orthogonal design because all instructions and addressing mode are used consistently though all areas of the device.
The CPU also integrates a constant generator to automatically generate the six most used immediate values. The constant generator has the effect of reducing code size by generator this common constants (or literals) using hardware, eliminating what would be immediate values embedded in code.
To support real-time programming and save code space, the CPU also supports atomic – uninterruptible – memory-to-memory operations with the full instruction set. No intermediate register operation is required.
Up to 16 MIPS of performance is available today on the newest 2xx family, and 25 MIPS on the new 5xx family. The result is a 16-bit, ultra-low power CPU that has more effective processing throughput, is smaller in size, and more code-efficient than other 8/16-bit microcontrollers. When using the MSP430, this results in programmers writing less lines of code. Now it's possible to develop ultra-low power, high-performance applications at a fraction of the code size previously possible.

MSP430 Ultra-Low Power MCUs

Ultra-Low Power Activity Profile



- Extended *Ultra-Low Power* standby mode
- Minimum active duty cycle
- Interrupt driven performance on-demand

Texas Instruments

The MSP430 is designed specifically for battery-powered measurement applications. The average system power consumption is the absolute lowest, without compromise in performance. The system enters and remains as long as possible in an ultra-low power standby mode and is awoke only to service interrupts as fast as possible.

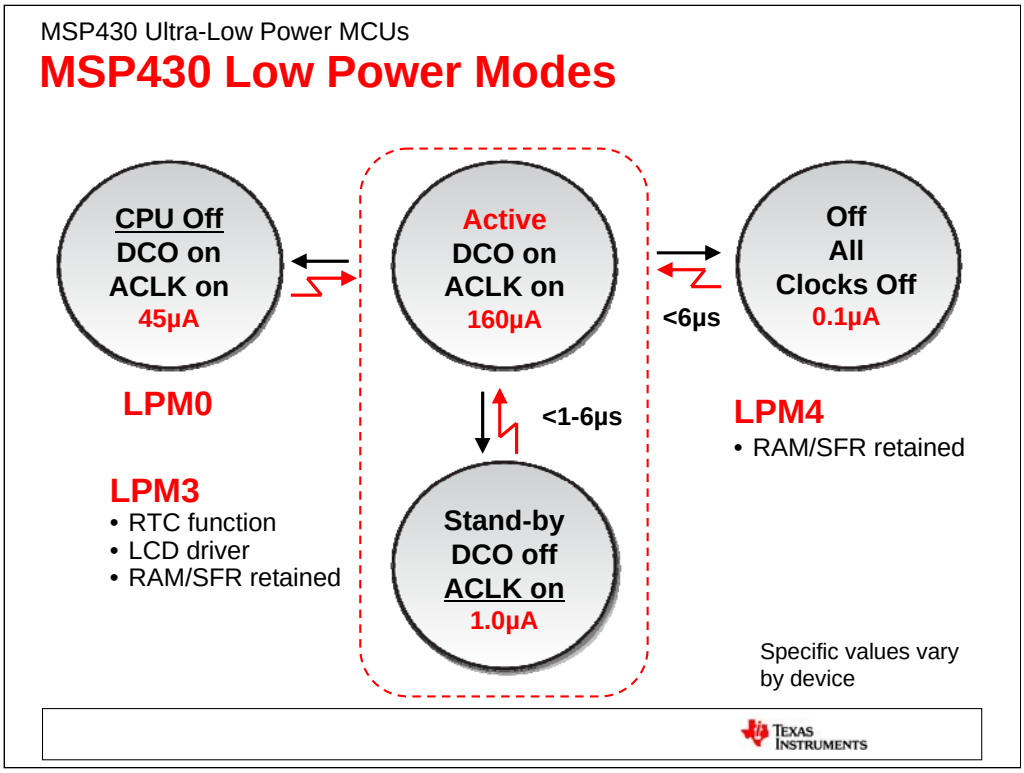
Multiple oscillators are utilized to provide both an ultra-low power standby mode, and “on-demand” high-performance processing. The clock system is very flexible and allows the MSP430 to operate optimally from a single 32KHz crystal – with the internal digitally controlled oscillator (DCO) used for the CPU and high-speed peripherals.

A low frequency Auxiliary Clock (ACLK) is driven directly from a common 32KHz watch crystal with no additional external components. The ACLK enables the MSP430’s ultra-low-power standby mode (LPM3) and an embedded real-time clock function. In LPM3, the MSP430 typically consumes in the 1uA range.

The integrated high-speed DCO can source the master clock (MCLK) used by the CPU and high-speed peripherals. By design, the DCO is active and fully stable in less than 6 µs with no intermediate steps. This enables “instant on” high-performance processing – no long start-up for a second crystal or 2-speed start-up required. Because the DCO is digitally adjustable with software and hardware, stability over time and temperature are assured.

To service interrupt driven events, the software efficiently uses the 16-bit RISC CPU’s performance in very short, “burst” intervals. Transition from standby to full active is less than 6us. This results in a combination of ultra-low power consumption and very high-performance immediately when needed.

To support non-low power applications, a high-speed crystal up to 16Mhz can also be used. The device can also operate with no external crystal using only the internal DCO



The 1xx and 4xx families will serve as the baseline for comparison of families

First explain why LPM1 and LPM2 are not included in discussion.

Functionality ranges from only the CPU off to Everything Off except Core

Power savings ranges from 0.1uA to ~55uAuA

Discussion of LPM will primarily center on LPM3, sometimes referred to as LPM3 mode, and LPM4.

In addition to power another key care about is time. One of the common phrases associated with the MSP430 is performance on demand.

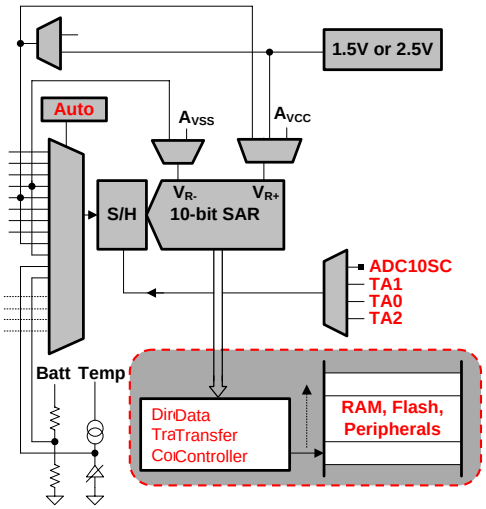
Additional cost of LPM5 is return path through BOR/POR/PUC

3V, 25C, typical values in datasheet

MSP430 Ultra-Low Power MCUs

Fast Flexible 10- and 12-bit ADCs

- 10-bit & 12-bit ADCs
- 200ksps+
- Autoscan
- Single
  Sequence
  Repeat-single
  Repeat-sequence
- Int/ext ref
- TA SOC triggers
- Data Transfer Controller (DTC)
- DMA Enabled



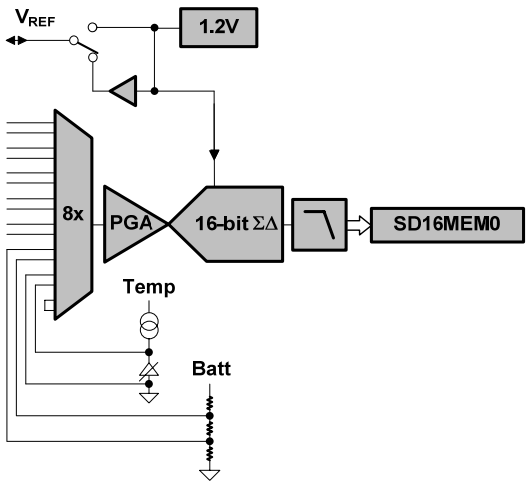
TEXAS INSTRUMENTS

The ADC10 is a fast, flexible 10-bit ADC.
Up to sixteen inputs are available to measure external signals. The complete sample/conversion time is under 5µs supporting greater than 200ksps. The sample time is programmable to allow engineers to account for the impedance of external sensors.
An independent temperature sensor and low-battery detect channel are also integrated. The 1.5V/2.5V internal voltage reference, VCC or an external reference can be used. The output from the ADC can be in binary or signed format.
The ADC10 offers several features to reduce CPU loading, improve performance, and lower current consumption. A sample start can be triggered with software, or, by using an output from a timer for a precise start independent of CPU activity (SOC = Start Of Conversion). User software does not have to be burdened to start a conversion. It can be done more precisely, using less code, with timer hardware.
Auto-scan allows channels to be sequenced automatically (for example A3-A2-A1-A0 A3-A2-A1-A0) without CPU intervention. Again, this relieves the software from performing this basic, but important task in many multi-channel applications.
The Data Transfer Controller (DTC) is used to automatically transfer ADC10 conversion results directly to memory without CPU intervention. This feature allows fast conversion throughput (200ksps+) to run continuously without the software intervention. The DTC transfers the output of the ADC10 directly to any memory location, which can be configured as a buffer, up to 256 bytes. The DTC can transfer continuously into the buffer, automatically incrementing, and interrupt the CPU when the buffer is full, or ½ full. For each DTC memory transfer, one bus cycle is required, in which the CPU is automatically halted to avoid and bus contention. The CPU and software can focus on higher-level data processing and not on basic data movement. More advanced products can be designed using the ADC10 that use less power and less code space.

MSP430 Ultra-Low Power MCUs

High-Precision SD16

- 16-bit Sigma Delta ADC
- Differential inputs
- 4.096ksps
- 85dB SINAD
- 32x PGA
- 18ppm 1.2V ref
- Temp sensor
- Battery input



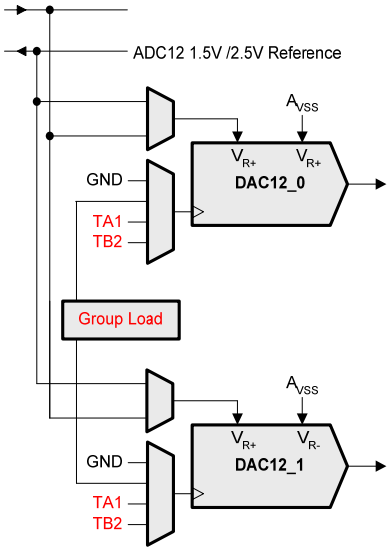
Texas Instruments

The SD16 is a very high precision integrated ADC especially impressive in a low pin-count device.
The SD16 has up to 8 fully differential multiplexed inputs and includes a built-in temperature sensor. The converter is based on a second-order oversampling sigma-delta modulator and digital decimation filter. With user a selectable low-power conversion mode. The decimation filter is a comb type filter with selectable oversampling ratios of up to 1024.
Other features of the SD16 include:
- Software selectable internal or external reference including a precision on-chip reference voltage generation (1.2V)
- Programmable gain amplifier
- Built-in temperature sensor and battery monitor

MSP430 Ultra-Low Power MCUs

DAC12

- 12-bit monotonic
- 8/12-bit voltage output
- Programmable settling time versus power
- Int/ext reference
- Binary or 2's compliment
- Self-calibration
- Group sync load
- DMA enabled



Texas Instruments

The DAC12 module is a 12-bit, voltage output DAC. The DAC12 can be configured in 8- or 12-bit mode and may be used in conjunction with the DMA
controller. When multiple DAC12 modules are present, they may be grouped together for synchronous update operation.

DAC12 Reference

The reference for the DAC12 is configured to use either an external reference voltage or the internal 1.5-V/2.5-V reference from the ADC12 module with the
DAC12SREFx bits. When DAC12SREFx = {0,1} the VREF+ signal is used as the reference and when DAC12SREFx = {2,3} the VeREF+ signal is used as the
reference. To use the ADC12 internal reference, it must be enabled and configured via the applicable ADC12 control bits.

DAC12_xDAT Data Format

The DAC12 supports both straight binary and 2s compliment data formats. When using straight binary data format, the full-scale output value is 0FFFh
in 12-bit mode (0FFh in 8-bit mode) When using 2s compliment data format, the range is shifted such that a DAC12_xDAT value of 0800h (0080h in 8-bit mode) results in a zero output voltage, 0000h is the mid-scale output voltage, and 07FFh (007Fh for 8-bit mode) is the full-scale voltage output

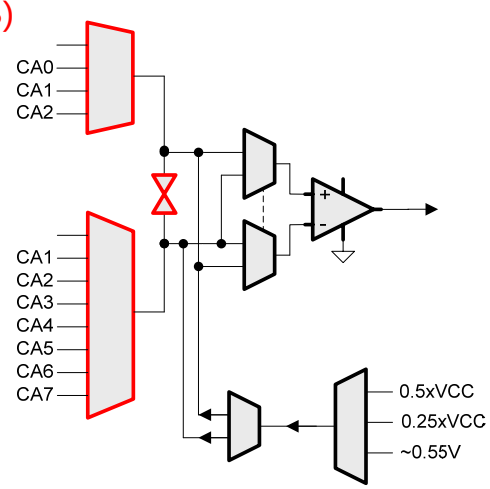
Reference Input and Voltage Output Buffers

The reference input and voltage output buffers of the DAC12 can be configured for optimized settling time vs power consumption. Eight
combinations are selected using the DAC12AMPx bits. In the low/low setting, the settling time is the slowest, and the current consumption of both buffers is
the lowest. The medium and high settings have faster settling times, but the current consumption increases. See the device-specific data sheet for
parameters.

MSP430 Ultra-Low Power MCUs

Analog Comparators

- ~100nA operation (Comp_B)
- Hysteresis generator (B)
- Input multiplexer
- Reference generator
- Low-pass filter
- Battery detect
- Interrupt source
- Timer_A capture
- Multiplexer short for sample-and-hold



The Comparator_A+ module supports precision slope analog-to-digital conversions, supply voltage supervision, and monitoring of external analog signals.
Features of Comparator_A+ include: Inverting and non-inverting terminal input multiplexer, Software selectable RC-filter for the comparator output, Output provided to Timer_A capture input, Software control of the port input buffer, Interrupt capability, Selectable reference voltage generator, Comparator and reference generator can be powered down, Input Multiplexer

Voltage Reference Generator
The voltage reference generator is used to generate VCAREF, which can be applied to either comparator input terminal. The CAREFx bits control the output of the voltage generator. The CARSEL bit selects the comparator terminal to which VCAREF is applied. If external signals are applied to both comparator input terminals, the internal reference generator should be turned off to reduce current consumption. The voltage reference generator can generate a fraction of the device's VCC or a fixed transistor threshold voltage of ~ 0.55 V.

Output Filter
The output of the comparator can be used with or without internal filtering. When control bit CAF is set, the output is filtered with an on-chip RC-filter. Any comparator output oscillates if the voltage difference across the input terminals is small. Internal and external parasitic effects and cross coupling on
and between signal lines, power supply lines, and other parts of the system are responsible for this behavior as shown in Figure 19–3. The comparator output oscillation reduces accuracy and resolution of the comparison result. Selecting the output filter can reduce errors associated with comparator Oscillation.

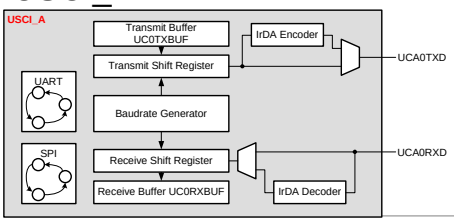
Comparator_A+ Interrupts
One interrupt flag and one interrupt vector are associated with the Comparator_A+. The interrupt flag CAIFG is set on
either the rising or falling edge of the comparator output, selected by the CAIES bit. If both the CAIE and the GIE bits are set, then the CAIFG flag generates an interrupt request. The CAIFG flag is automatically reset when the interrupt request is serviced or may be reset with software.

Input Short Switch
The CASHORT bit shorts the Comparator_A+ inputs. This can be used to build a simple sample-and-hold for the comparator

MSP430 Ultra-Low Power MCUs

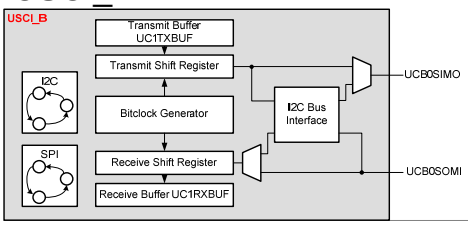
USCI: Serial Communication I/F

USCI_A



- UART with IrDA/LIN support or SPI
- Baud-rate generator with auto-baud rate detect
- *Double buffered TX/RX*

USCI_B



- I2C master/slave up to 400kHz or SPI
- Bit clock generator
- *Double buffered TX/RXs*

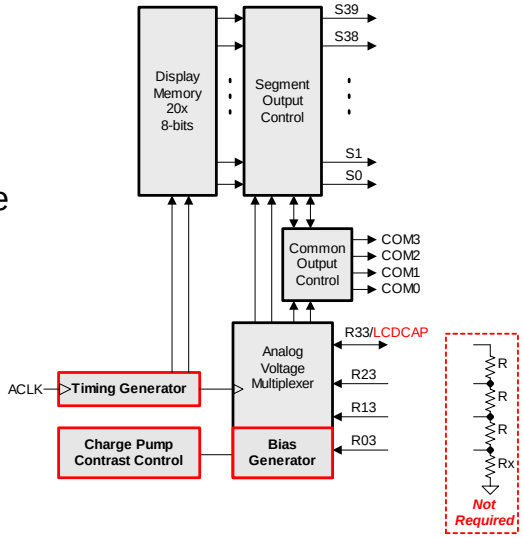
TEXAS INSTRUMENTS

The universal serial communication interface (USCI) modules support multiple serial communication modes. Different USCI modules support
different modes. Each different USCI module is named with a different letter. For example, USCI_A is different from USCI_B, etc. If more than one identical
USCI module is implemented on one device, those modules are named with incrementing numbers. For example, if one device has two USCI_A modules,
they are named USCI_A0 and USCI_A1. See the device-specific data sheet to determine which USCI modules, if any, are implemented on which devices.
The **USCI_Ax** modules support:
UART mode
Pulse shaping for IrDA communications
Automatic baud rate detection for LIN communications
SPI mode
The **USCI_Bx** modules support:
I2C mode
SPI mode

MSP430 Ultra-Low Power MCUs

LCD Controllers

- Ultra-low power
- Fully automatic
- 4/3/2/1 mux
- Up to 160-bit display
- Internal regulated voltage generator
- Internal or external bias generation
- Contrast control
- 1/2 bias for 3 or 4 mux
- Internal clock generation
- Auto segment blinking



TEXAS INSTRUMENTS

The LCD_A controller directly drives LCD displays by creating the ac segment and common voltage signals automatically.

The MSP430 LCD controller can support static, 2-mux, 3-mux, and 4-mux LCDs.

The LCD_A controller features are:

- Display memory
- Automatic signal generation
- Configurable frame frequency
- Blinking capability
- Regulated charge pump
- Contrast control by software
- ½ bias and 1/3 bias supported for 3-mux and 4-mux LCDs

Support for 4 mux rates of LCDs;

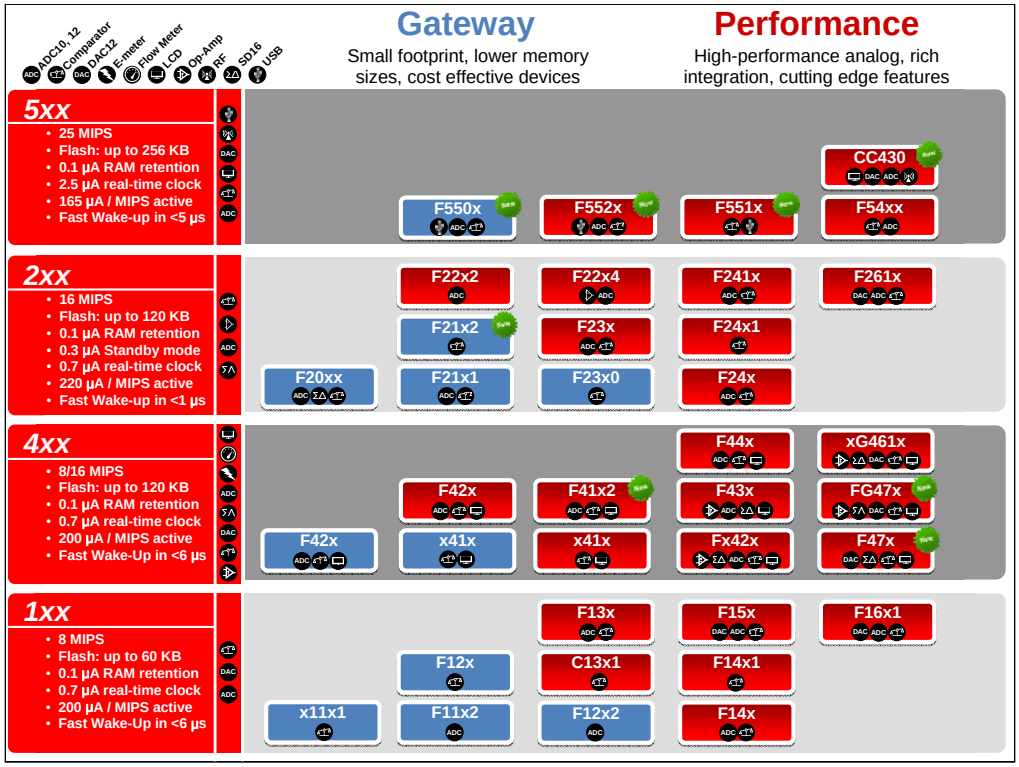
- Static
- 2-mux
- 3-mux
- 4-mux

The LCD_A module is available today on the MSP430x42x0 devices and is implemented on the MSP430FG461x devices sampling soon.

MSP430 Product Families

1xx | 2xx | 4xx | 5xx

Gateway | Performance



- **Broken down into two device families**
  - **Gateway** – Affordable yet capable, cost efficient, lower memory sizes.
    - Scalable portfolio provides many (currently 8) sub-$1 devices and growing
  - **Performance** – high performance analog, new technologies at fullest capabilities (USB, FRAM, RF)

- *Devices are organized depending on memory size (up and to the right = higher memory size)*

- **4 device families**
  - **5xx** fastest device family at 25 MIPS
    - Lowest active mode power consumption @ 165 uA/MIPS
    - Uniquely provides integrated USB and RF
    - Many new devices in both Gateway and Performance Line
    - F550x (mini USB) – Gateway option with USB capabilities
    - L092 – provides 0.9 voltage operation
    - CC430 – provides RF capabilities
    - New FRAM devices in both Gateway and Performance Line
    - FR1000 device provides 16 kb of FRAM
  - **2xx**
    - Capable of 16 MIPS
    - Lowest power consumption devices in Low Power Mode
    - Fastest wake up time at < 1 us
  - **4xx**
    - Capable of 8/16 MIPS
    - Provides integrated LCD drivers
    - Integrated with analog components specifically aimed for metering (electric and flow)
  - **1xx**
    - 8 MIPS operation

MSP430 Ultra-Low Power MCUs

MSP430x1xx Series: 31 Unique MCUs

Family	ROM	RAM	I/O	16-bit Timers	ADC	Comm.	Other Peripherals	Price 1k USD
x11x1	1-4KB	128B	14	A3, WDT	Slope	-	Comp	$1.00 – $1.40
F11x2	4-8KB	256B	14	A3, WDT	ADC10	-	Temp Sensor	$1.65 – $2.00
F12x	4-8KB	256B	22	A3, WDT	Slope	USART	Comp	$1.65 – $1.80
F12x2	4-8KB	256B	22	A3, WDT	ADC10	USART	Temp Sensor	$1.80 – $2.05
F13x	8-16KB	256-512B	48	A3, B3, WDT	ADC12	USART	Comp, Temp Sensor	$2.65 – $2.85
C13x1	8-16KB	256-512B	48	A3,B3, WDT	Slope	USART	Mask ROM, Comp	$2.00 – $2.30
F14x1	32-60KB	1-2KB	48	A3, B7, WDT	Slope	2 USART	Comp, MPY	$3.50 – $4.30
F14x	32-60KB	1-2KB	48	A3, B7, WDT	ADC12	2 USART	Comp, MPY, Temp Sensor	$3.85 – $4.65
F15x	16-32KB	512B-1KB	48	A3, B3, WDT	ADC12	2 USART w/I2C	Comp, MPY, BOR, SVS	$4.25 – $4.75
F16xx	32-60KB	1-10KB	48	A3, B7, WDT	ADC12	2 USART w/I2C	Comp, MPY, BOR, SVS	$5.60 – $7.95

USART: SPI + UART

Texas Instruments

Correct 1ku pricing

1xx sill strong, note pricing, 31 device options

MSP430 Ultra-Low Power MCUs

MSP430x4xx w/ LCD: 94 Unique MCUs

Family	Flash	RAM	I/O	LCD Seg.	16-bit Timers	ADC	Comm.	Other Integrated Peripherals	Price USD 1kU
x41x	4-32KB	256B-1KB	48	96	A3,A5, WDT	Slope	-	Comp, SVS	$1.60 – $2.10
F41x2	8-16kB	512B	56	144	A2, WDT	ADC10	1 USCI	SVS, Comp	$1.70 – $1.90
F42x	8-32KB	256B-1KB	14	128	A3, WDT	SD16	USART	MPY(16 X16), SVS	$2.40 – $2.90
FW42x	8-32KB	128B-1KB	48	96	A2, WDT	Slope	-	Flow-meter	$2.50 – $3.10
FE42xx	8-32KB	256B-1KB	14	128	A2, A3, WDT	SD16	USART	E-meter	$2.35 – $2.75
F42x0	16-32KB	256B	32	56	A2, A3, WDT	SD16	-	DAC12	$3.10 – $3.65
FG42x0	16-32KB	256B	32	56	B3, A3, WDT	SD16	-	DAC12, OPAMP	$3.30 – $4.00
F43x	16-32KB	512B-1KB	48	160	B3, A3, WDT	ADC12	USART	SVS, Comp	$3.75 – $4.30
F43x1	16-32KB	512B-1KB	48	160	B3, A3, WDT	Slope	USART	SVS, Comp	$2.90 – $3.95
FG43x	32-60KB	1-2KB	48	128	B3, A3, WDT	ADC12	USART	DAC12, OPAMP	$5.15 – $6.60
F44x	32-60KB	1-2KB	48	160	B7, A3, WDT	ADC12	2 USART	SVS, Comp, MPY	$4.60 – $5.15
xG461x	48-120KB	4-8KB	80	160	B7, A3, WDT	ADC12	2 USART	DAC12, OP-AMP, MPY (32 x32)	$7.45 – $8.35
FG47x	32-60kB	2kB	48	128	A1, B1, WDT	(1)SD16	2 USCI	DAC12, Op-Amp,	$4.75 – $6.20
F47x	32-60kB	2kB	48	128	A1, B1, WDT	(1)SD16	2 USCI	DAC12	$4.70 – $5.35
F471xx	92-120KB	4-8KB	72	160	B3, A3, WDT	(7)SD16	2 USCI	RTC, MPY (32x32), DMA, Comp	TBD

Texas Instruments

USCI_A: UART + SPI

USCI_B: I2C + SPI

USI: I2C + SPI

MSP430 Ultra-Low Power MCUs

MSP430F2xx Series: 39 Unique MCUs

Family	Flash	RAM	I/O	16-bit Timers	ADC	Comm.	Other Integrated Peripherals	Price USD 1kU
F20x1	2 KB	128 B	10	A2, WDT	Slope		Comp	$0.55 – $0.80
F20x2	2 KB	128 B	10	A2, WDT	ADC10	USI		$0.80 – $0.95
F20x3	2 KB	128 B	10	A2, WDT	SD16	USI		$1.20 – $1.30
F21x1	8 KB	256 B	10	A2, A3, WDT	Slope		Comp	$0.65 – $0.95
F21x2	8 KB	512 B	10	A2, A3, WDT	ADC10	USCI		$1.20 – $1.50
F22x2	32 KB	1 KB	10	B3, A3, WDT	ADC10	USCI		$1.75 – $2.20
F22x4	32 KB	1 KB	10	B3, A3, WDT	ADC10	USCI	2 Op Amp	$2.00 – $2.65
F23x0	32 KB	2 KB	10	B3, A3, WDT	Slope	USCI	Comp, MPY	$1.80 – $2.25
F23x	16 KB	2 KB	10	B3, A3, WDT	ADC12	USCI	SVS, Comp, MPY	$2.15 – $2.45
F241x	120 KB	4 KB	48	B7, A3, WDT	ADC12	2 USCI	SVS, Comp, MPY	$4.70 – $5.30
F24x	56 KB	4 KB	10	B7, A3, WDT	ADC12	2 USCI	SVS, Comp, MPY	$3.40 – $4.60
F24x1	60 KB	2 KB	10	B7, A3, WDT	Slope	2 USCI	SVS, Comp, MPY	$3.15 – $3.80
F261x	120 KB	4 KB	48	B7, A3, WDT	ADC12	2 USCI	SVS, Comp, MPY, 2 DAC12, 3 DMA	$5.85 – $6.65

USCI_A : UART + SPI USCI_B: I2C + SPI USI: I2C + SPI USART: SPI + UART

Texas Instruments

USCI_A: UART + SPI

USCI_B: I2C + SPI

USI: I2C + SPI

MSP430 Ultra-Low Power MCUs

MSP430F5xx Series Summary

Family	Flash	RAM	IO	16-bit Timers	ADC	Comm.	Other Integrated Peripherals	Price USD 1kU
F541x 18 MHz	128 KB	16 KB	67,87	A5,3,B7,WDT	ADC12	2,4 USCI	DMA, UCS, MPY(32X32)	$3.30 - $3.65
F541xA 25 MHz	128 KB	16 KB	67,87	A5,3,B7,WDT	ADC12	2,4 USCI	DMA, UCS, MPY(32X32)	$3.30 - $3.65
F543x 18 MHz	192-256 KB	16 KB	67,87	A5,3,B7	ADC12	2,4 USCI	DMA, UCS, MPY(32X32)	$3.90 - $4.85
F543xA 25 MHz	192-256 KB	16 KB	67,87	A5,3,B7	ADC12	2,4 USCI	DMA, UCS, MPY(32X32)	$3.90 - $4.85
F551x	64 KB	6-8 KB	48,60	A5,3,3, B7	_	USCI	USB, DMA, UCS, MPY(32X32)	$3.25 - $3.35
F552x	64-128 KB	6-8 KB	48,60	A5,3,3, B7	ADC12	2 USCI	USB, DMA, UCS, MPY(32X32)	$3.55 - $4.10

USCI_A : UART + SPI USCI_B: I2C + SPI

Texas Instruments

USCI_A: UART + SPI

USCI_B: I2C + SPI

USI: I2C + SPI

MSP430 Design Support: Tools, Software, and Resources

MSP430 Ultra-Low Power MCUs

Embedded Emulation

- Real-time, in-system debug
  - No application resources used
  - Full speed execution
  - H/W breakpoints
  - Single stepping
  - Complex triggering
  - Trace capability
- Powerful, easy to use tools
- Spy Bi-Wire
  - 2-wire debug interface
  - No pin function impact
- Only 1 tool required for *all* devices

Texas Instruments

Embedded Emulation with the MSP430

Development is in-system and subject to the exact same characteristics of the final application

Non-obtrusive especially in portable and high-pin count situations

Common user software and physical interface

Today's applications operating at lower voltages, with tighter packaging and higher-precision analog, benefit greatly from the MSP430's in-system emulation approach. The MSP430's dedicated embedded emulation logic resides on the actual device itself and is accessed via industry standard JTAG using no additional system resources.

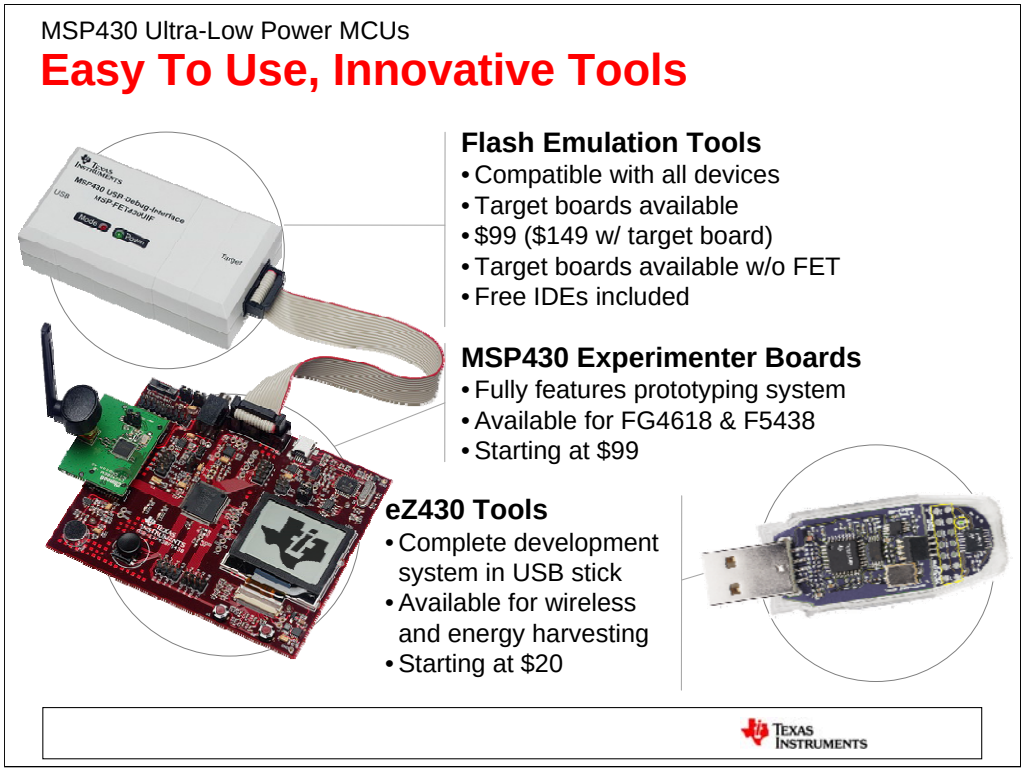
From the first day of development, firmware engineers can now unobtrusively develop and debug their embedded code with full-speed execution, breakpoints, and single steps in an application.

Embedded emulation becomes even more important with high performance mixed-signal systems that must maintain the integrity of microvolt analog signals. Signal integrity is virtually impossible with cumbersome in-circuit emulators that are sensitive to cabling crosstalk. And unlike abstract background debuggers, no time-sharing of system serial communication resources is required with embedded emulation on the MSP430.

By combining the flexibility of in-system programmable Flash memory, unobtrusive embedded emulation, and a common user interface, development time is reduced. And, should the situation arise, last minute code updates as well as remote scheduled and unscheduled upgrades can also be made.

Access to the JTAG port can be permanently disabled using a non-erasable fuse.

Spy Bi-Wire which is only available on new small pin count devices, such as the F20xx and F22xx, give you the same real time embedded emulation support but only uses two wires instead of the usual four. This allows for more pins to be used for other functioning instead of being dedicated for debugging support.



Flash Emulation Tools for the MSP430 – A common user software and physical interface is used for all MSP430s. This means only one tool needs to be learned for any device. The Flash Emulation Tool – or FET – is a complete JTAG based real-time emulation device. The FET comes with a universal USB JTAG interface, a target board, cables and all documentation on a CD-ROM for $149. Stand alone debugging and programming interfaces without a target board (MSP-FET430UIF) are available for $99. All USB FETs include support for both the standard 4-wire JTAG and 2-wire Spy Bi-Wire

The CD-ROM includes both the IAR Kickstart Embedded Workbench IDE with 4kB C-compiler and TI Code Composer Essentials IDE with 8kB C-compiler. Code Composer Essentials V2.0 is available for purchase from Texas Instruments for only $499. It is built on the open source Eclipse based platform which allows user created plug-ins, supports all MSP430 devices, and provides unparalleled debugging performance. Currently, CCE provides best-in-case code speed optimization relative to all others compilers available for the MSP430 (IAR, MSPGCC, CrossWorks, etc). Code execution speed is vital for low power applications since every single cycle required to complete a task consume a part of your battery life that you will never get back.

The FET supports complete in-system development for all Flash based MSP430's. Programming, assembler/C-source level debugging, single stepping, multiple hardware breakpoints, full-speed operation and peripheral access are all fully supported in-system using JTAG.

The FET comes with everything required to complete an entire project! Customer wishing to purchase unlimited C-compilers can do so from IAR or TI directly.

A parallel port JTAG interface is also available

In addition, many third parties vendors provide development tools for the MSP430 – please see www.ti.com/msp430

MSP430 Ultra-Low Power MCUs

eZ430-Chronos: CC430 Dev Tool

- CC430-based *wireless* development tool in a watch
- 915/868/433 MHz versions available
- Custom LCD driven directly by CC430
- Features:
  - 3-axis accelerometer
  - Altimeter
  - Temperature sensor
  - Buzzer
- **Only $25 for MCU Day Attendees**

Texas Instruments

Remember, it's always 430 somewhere.

The eZ430-Chronos is the world's first wearable development tool. Based on the CC430F6137 <1 GHz RF SoC, the eZ430-Chronos is a complete CC430-based development system contained in a watch. This tool features a 96 segment LCD display and provides an integrated pressure sensor and 3-axis accelerometer for motion sensitive control. The integrated wireless feature allows the Chronos to act as a central hub for nearby wireless sensors such as pedometers and heart rate monitors. The eZ430-Chronos offers temperature and battery voltage measurement and is complete with a USB-based CC1111 wireless interface to a PC and a programming interface to create custom applications.

The Chronos will retail for $49 and will be available around MCU Day (Sep 9).

Chronos can be used to control or display data with any system that includes a <1GHz RF transceivers such as the CC430 or CC11xx devices from TI. Custom solutions such as exercise equipment, heart rate monitors or pedometers can be paired with the Chronos to get real time information back to it's user.

Contents:

1 Chronos Watch

1 Small Screwdriver to dissemble watch

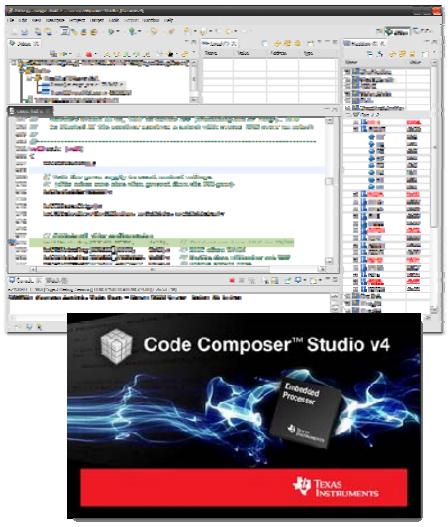
1 CC1111 RF Access Point

1 eZ430 emulator to reprogram the watch

MSP430 Ultra-Low Power MCUs

CCE is now Code Composer *Studio* v4

- Code Composer Studio v4:
  A single development platform for all TI processors
- CCE users will feel at home
- Enhancements since CCE:
  - Speed
  - Code size improvements
  - Auto-updating
  - License manager
  - Support for all TI MCUs
- Only $495 for MCU Edition
  - $249 for MCU Day attendees
- FREE 16KB-limited edition



http://tiexpressdsp.com/wiki/index.php?title=Category:Code_Composer_Studio_v4

Texas Instruments

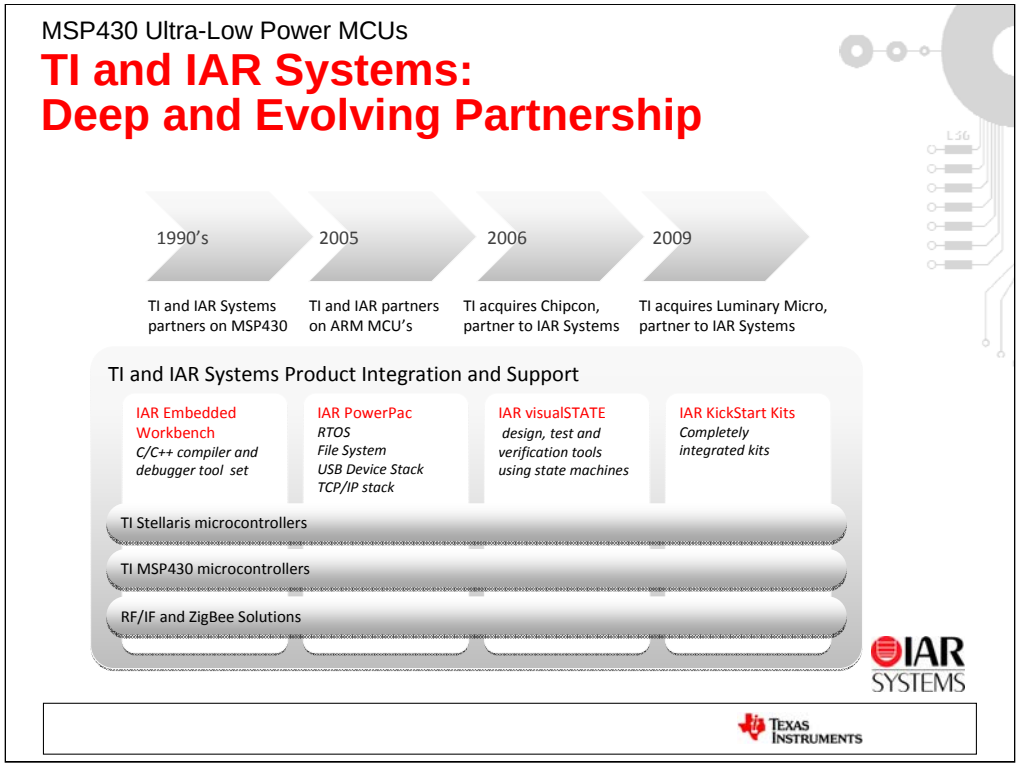
Code Composer Essentials, TI's IDE for MSP430 is now Code Composer **Studio** v4. This will bring all TI embedded processors under one IDE based on Eclipse. Since CCE was also based on Eclipse, CCS v4 will feel familiar as CCE v3, however, we have added lots of features to greatly improve the performance and ease of use of CCS. The compiler (code generation tools) have been improved to reduce the overall code size and execution speed of your project. CCS also features an auto-updated feature that will automatically download the latest service packs from the web to make sure that you're using the latest version.

CCS v4 Platinum edition supports all TI Embedded Processors and will sell for $1,995 USD.

CCS v4 MCU Edition supports MSP430 & C2000 and will sell for $495. Support for the Stellaris family of MCUs will be added in the next v4.1 (4Q09) and will not require a separate purchase. All users who purchased CCE v3 within the last 12 months will receive a free upgrade

Several new ordering options have been added including:

- Traditional, Single user license - $495 (Half price for MCU Day)
- Downloadable purchase (NO DVD) - $50 discount ($445)
- Floating network licenses (1, 3, 5, 10, 25 users) - $795 - $1,995
- University Edition - FREE



- TI and IAR Systems work in close partnership on all TI's microcontroller architectures
- The partnership has evolved and grown stronger over the years
- IAR Systems offers broad support in development tools and software for MSP430, ARM Cortex-M3 Stellaris, TI Chipcon products, and RF/IF and ZigBee Solutions

MSP430 Ultra-Low Power MCUs

Third Party Development Resources

- Rowley CrossWorks
  - Complete IDE solution
  - High code density
  - Simulator
  - Windows, Linux, Mac

  www.rowley.co.uk

- Elprotronic
  - MSP430, CC Chipcon, C2000 Programmers
  - Fastest download speed
  - Production programmers

- RTOS Options
  - µC/OS-II™
  - CMX-Tiny+™
  - embOS
  - FreeRTOS™
  - IAR PowerPac
  - QP™
  - Salvo™
  - TinyOS

- MSPGCC Tool Chain
  - Free
  - Open Source
  - GNU C Compiler, Assembler/ Linker, GDB Debugger
  - Windows, Linux, Unix

  http://mspgcc.sourceforge.net

- Amber Wireless
  - Drop in wireless modules
  - <1GHZ eZ430-RF target boards
  - CC430 Development boards

- USB Stacks
  - IAR
  - HCC

MSP430 Ultra-Low Power MCUs

www.ti.com/msp430

- User's Guides
- Datasheets
- TI Community Forum
- 100+ Application Reports
- 1000+ Code Examples
- Product Brochure
- MCU Selection Tool
- Latest Tool Software
- 3rd Party Listing
- Silicon Errata

TEXAS INSTRUMENTS

The 430 is very well supported including a dedicated TI website www.ti.com/msp430.

For detailed technical information on device peripherals, TI has up-to-date MSP430 Family User's Guides available.

Chip specific electrical and pin information is available in device-specific datasheets.

Over 100+ application reports and 500+ downloadable code examples are available from the MSP430 website.

The product brochure provides a description and an overview of all available MSP430 devices.

A listing of 3rd parties is provided.

Any known silicon errata is available.

A FAQ system (Knowledge Base) and regional technical support phone lines also are available.

The most current MSP430 documentation is always available on the MSP430 website.

MSP430 Ultra-Low Power MCUs

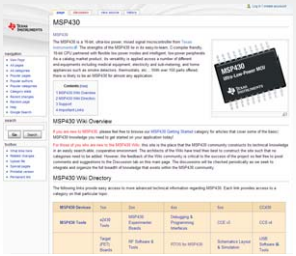
Extensive Community Support

E2E Community

- Videos, Blogs, Forums
- Extensive community support and idea exchange
- Global customer support
- http://e2e.ti.com

Processor Wiki

- Growing collection of technical wiki articles
- Tips & tricks, common pitfalls, and design ideas
- http://wiki.msp430.com



Texas Instruments

Wiki:

•Same look and feel of internet Wikipedia. It leverages the concept and is subject based. For example, there are articles on VIDs and PIDs for USB, also, what type of antenna should you use with our RF CC430? How do you rate the ESD?

•Another way for you to get technical support. You can mine data. It will be populated with cc430, USB, search tied into external web site

E2E Community:

•Conversation oriented. You can post a question and get answers within a community. We have MSP430 experts participating in the threads.

MSP430 Part 1 - Summary

- Ultra-low Power
- Broad portfolio
  - Access for size and cost constraints
  - Performance for precision and speed
- Ease of Use
  - HW and SW Tools
  - Community
  - Order a tool with your discount code!

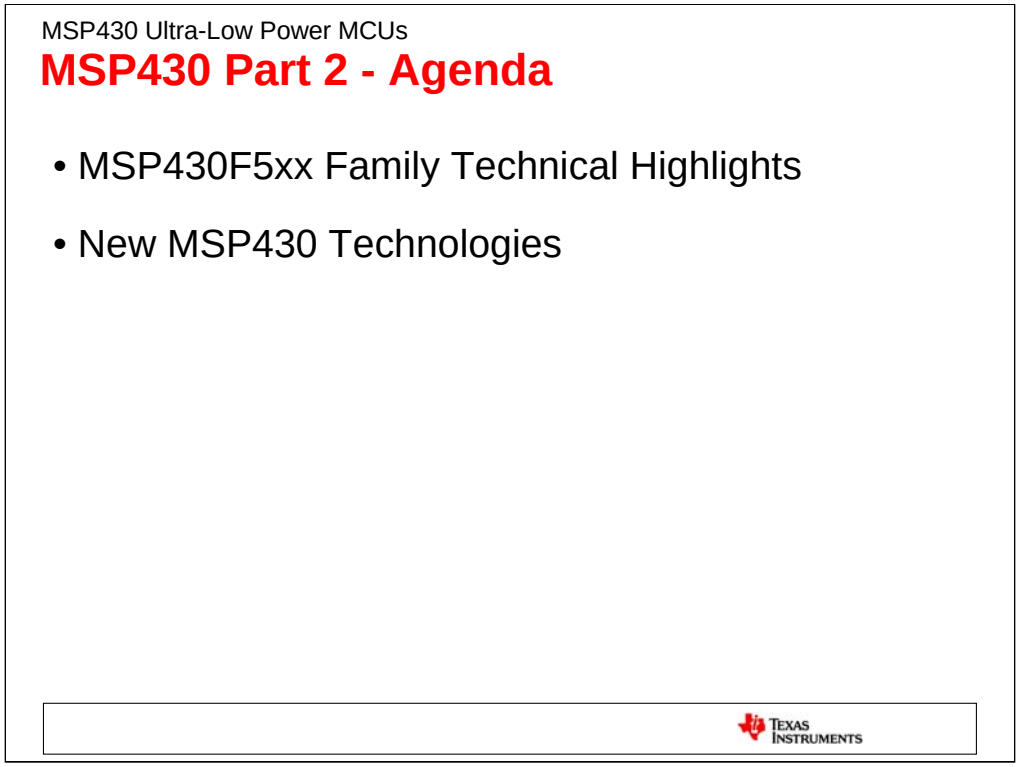
Thank you.

Don’t forget the 2nd MSP430 session!

‘5xx Family Technical Highlights and New Technologies

MSP430™ Ultra-Low Power MCUs
Part 2: ‘5xx Family Technical Highlights and New Technologies

Technology Day 2009
One Day, Multiple Solutions



These 16-bit MCUs offer a fantastic combination of 3 things: ultra-low-power consumption, high performance analog, as well as a scalable portfolio of devices at competitive price points.

* First, I will share with you what's unique about MSP430's architecture, as well as some of the typical applications that use the MSP430.

* Then, we will discuss our secret sauce for ULP, and how you can take advantage of it in your projects

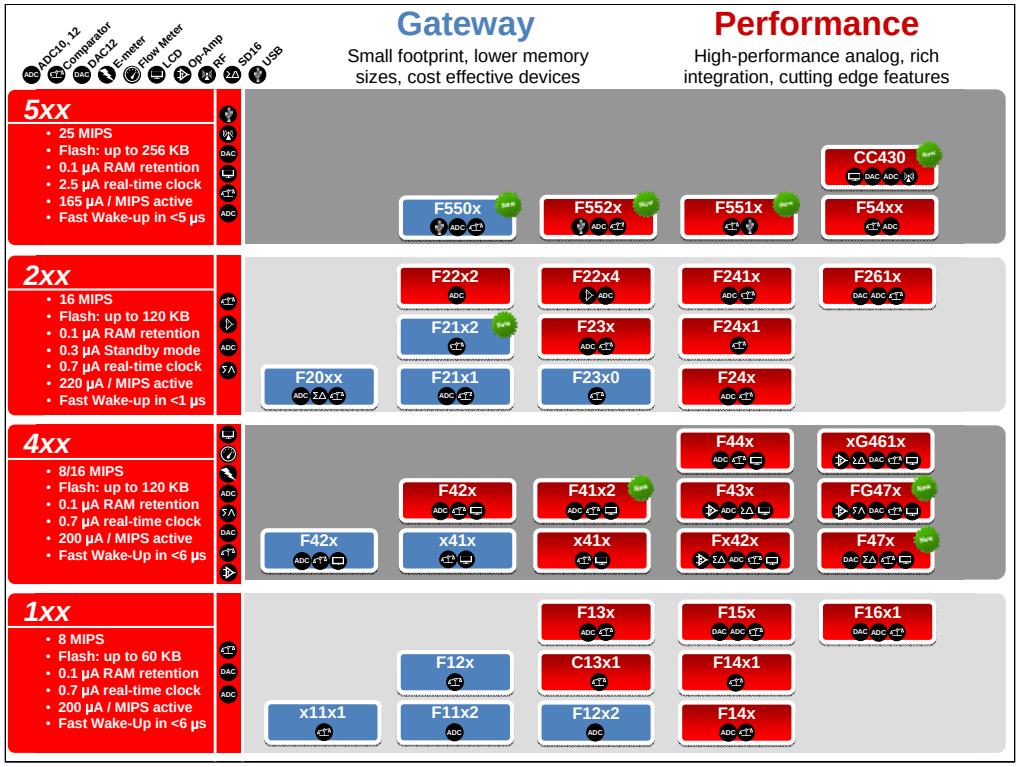
•We will also walk through our peripherals, such as our A/Ds, sigma deltas, DACs, analog comparators and serial communications interfaces

•Next, we will cover what is the most exciting part of the presentation for me, which is new technologies! We have RF, USB, FRAM, and energy harvesting

•then I will show you how our portfolio of 200 products breaks down

•Finally, I think you'll be thrilled to see the new hardware and software tools we've launched for you, and how we have built out our community on the web

MSP430F5xx Family: Technical Highlights



- **Broken down into two device families**
  - **Gateway** – Affordable yet capable, cost efficient, lower memory sizes.
    - Scalable portfolio provides many (currently 8) sub-$1 devices and growing
  - **Performance** – high performance analog, new technologies at fullest capabilities (USB, FRAM, RF)

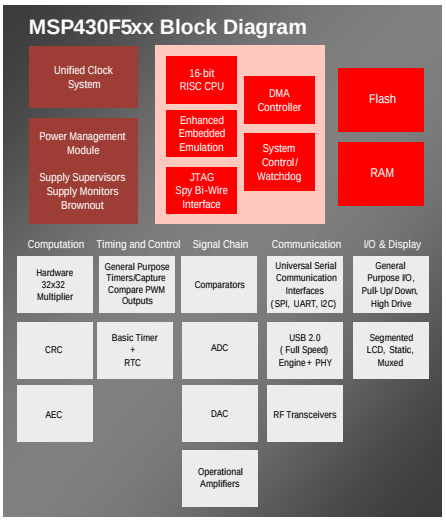
- *Devices are organized depending on memory size (up and to the right = higher memory size)*

- **4 device families**
  - **5xx** fastest device family at 25 MIPS
    - Lowest active mode power consumption @ 165 uA/MIPS
    - Uniquely provides integrated USB and RF
    - Many new devices in both Gateway and Performance Line
    - F550x (mini USB) – Gateway option with USB capabilities
    - L092 – provides 0.9 voltage operation
    - CC430 – provides RF capabilities
    - New FRAM devices in both Gateway and Performance Line
    - FR1000 device provides 16 kb of FRAM
  - **2xx**
    - Capable of 16 MIPS
    - Lowest power consumption devices in Low Power Mode
    - Fastest wake up time at < 1 us
  - **4xx**
    - Capable of 8/16 MIPS
    - Provides integrated LCD drivers
    - Integrated with analog components specifically aimed for metering (electric and flow)
  - **1xx**
    - 8 MIPS operation

MSP430 Ultra-Low Power MCUs

5xx Key Features

- Ultra-Low Power
  - 160 µA/MIPS
  - 2.5 µA standby mode
  - Integrated LDO, BOR, WDT+, RTC
  - 12 MHz @ 1.8V
  - Wake up from standby in <5 µs
- Increased Performance
  - Up to 25 MHz
  - 1.8V ISP Flash erase and write
  - Fail-safe, flexible clocking system
  - User-defined Bootstrap Loader
  - Up to 1MB linear memory addressing
- Innovative Features
  - Multi-channel DMA supports data movement in standby mode
  - Industry leading code density
  - More design options including USB, RF, encryption, LCD interface



TEXAS INSTRUMENTS

The MSP430F5xx is the next generation technology platform for the MSP430 family. The F5xx will continue & expand on MSP430's industry leadership in the ultra-low-power 16-bit MCU space. In addition to improved ULP performance and features, the F5xx also offers increased performance, significantly higher levels of integration, many new features designed for customer ease of use, all while remaining completely compatible with existing MSP430 families.

MSP430F5xx takes ultra-low-power (ULP) performance to completely new levels by significantly lowering active mode current, & significantly expanding the performance range, while still maintaining "MSP430 typical" LPM3 (standby mode) performance (even for devices as large as 256KB Flash & 16KB RAM).

F5xx will set a new active current consumption benchmark for 16-bit MCUs with less than 200uA/MHz consumed. This means the increased performance (25 MHz) of the F5xx can be utilized by even the smallest battery powered devices.

With new capabilities such as in system FLASH write and erase and 12MHz CPU performance both available all the way down to 1.8V, useful battery life of many applications will be significantly extended.

The F5xx family of devices will include many new exciting capabilities:

-Integrated USB 2.0 optimized for ULP battery powered equipment.

-Integrated RF transceivers. Utilizing TI's acquisition of Chipcon technology, sub-1GHz & 2.4GHz radios will be available integrated on F5xx devices.

-Growing with the needs of our customers, larger memory devices (e.g. 256KB Flash & 16KB RAM) will be available through F5xx.

-In-System-Programmable (ISP) Flash down to 1.8V extends the available useful battery life.

-"Blocked" Flash allows the capability to read one section of Flash while erasing another section.

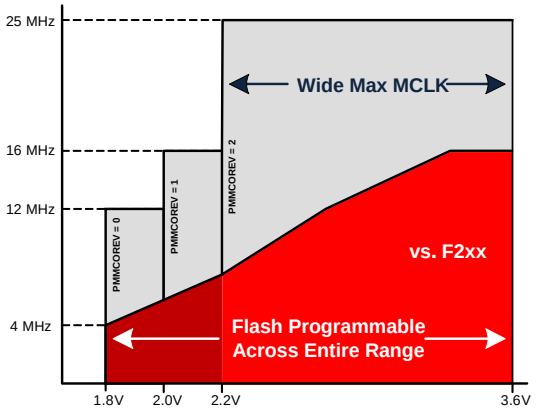
-The new Unified Clock System (UCS) module supports low system cost and ultra-low power consumption. From three internal clock signals, customers can select the best balance of performance and low power consumption. The UCS module can be configured to operate without any external components, with one or two external crystals, or with resonators, under full software control. The UCS module includes up to five clock sources & three clock signals. With high levels of flexibility and programmability, the UCS helps customers manage and optimize the typically conflicting clocking requirements in battery-powered applications. The UCS also incorporates new oscillator-fault fail-safe features.

-The enhanced F5xx bootstrap loader (BSL) enables customers to communicate with embedded memory during the prototyping phase, final production, and in service. All memory mapped resources, Flash, RAM, and the peripherals, can be modified by the BSL as required. Customers can define their own BSL-Code for Flash based devices to protect them against erasure and unintentional or unauthorized access.

MSP430 Ultra-Low Power MCUs

MSP430F5xx Operating Range

- 25 MHz peak performance
- More performance across V_{CC} range
  - Flash ISP @ 1.8V
  - 12MHz @ 1.8V
  - 25MHz @ 2.4V-3.6V



This slide highlights the Vcc vs. CPU freq relationship of the 5xx family as compared to the existing 2xx. All MSP430 devices, including the F5xx operate in the wide range of 1.8 to 3.6V. Fundamental improvements were made to the F5xx including Flash programming at the minimum Vcc of 1.8V, increased CPU clock at both the upper and lower Vcc ends & a widened max CPU clock range of 25MHz at 2.2 – 3.6v. 12 MHz operation is possible even at the lowest Vcc of 1.8V.

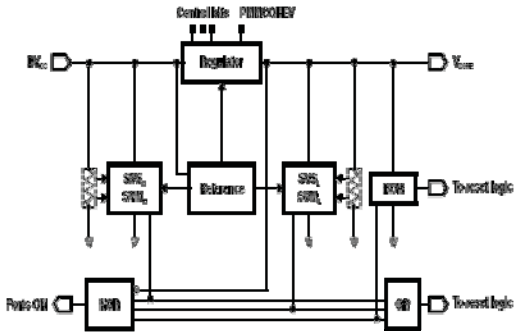
Compared to the F2xx, only 4MHz operation is possible at the min Vcc of 1.8v, and the min Flash programming voltage was 2.2V (vs. 2.7V on the 4xx). On the 2xx, full speed 16MHz operation is only possible at 3.3v or higher.

Also shown is the core voltage programmability that the regulator in the PMM has enabled. This provides the user the ability to optimize the Vcore level to the performance needed by the given application for maximum power efficiency.

MSP430 Ultra-Low Power MCUs

F5xx: Power Management Module

- Integrated LDO
- V_{CORE} level programmable
- Flexibility in processing performance vs. power
- Integrated *supervision & monitoring*
- *Zero-power* BOR
- Five integrated supervisors
  - SVSH, SVSL, SVMH, SVML & BOR



Texas Instruments

The Power Management Module (**PMM**) on the new MSP430F5xx, allows you to your application to the optimal amount of processing power vs. power consumption. To save power, the main digital logic of the MSP430 device runs at a voltage is lower than DVCC. The PMM incorporates an integrated low-dropout voltage regulator (LDO) that generates a secondary core voltage rail, VCORE, that is programmable in four steps to allow power consumption optimization without the need for an external LDO.

The PMM also provides several monitoring and supervision mechanisms for reliable operation. Both supervision and monitoring detect when a voltage has fallen under a specific threshold. Usually, ***supervision*** results in a power-on reset (POR) event, while ***monitoring*** results in the generation of an interrupt.

On the MSP430F5xx Brown Out Reset (BOR) is always on and consumes zero additional power.

5 integrated mechanisms are in places: SVSH (Supply Voltage Supervisor High Side), SVSL (Supply Voltage Supervisor High Side), SVMH (Supply Voltage Monitor High Side) , SVML (Supply Voltage Monitor Low Side), & BOR (Brown out Reset)

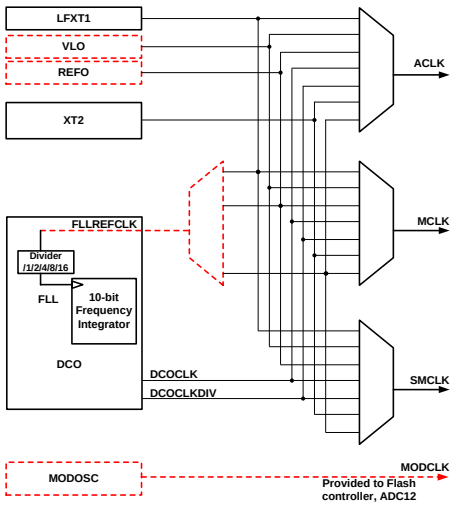
The PMM features include:

· Wide supply voltage (DVCC) range: 1.8 V to 3.6 V
· Core voltage (VCORE) generation: 1.4 V, 1.6 V, 1.8 V, and 1.9 V (typical)
· Brown-out-reset (BOR)
· Supply voltage supervisor for DVCC and VCORE
· Supply voltage monitor for DVCC and VCORE with eight programmable levels
· Software accessible power-fail conditions
· Software selectable power-on-reset at power-fail condition
· I/O protection at power-fail condition
· Software selectable supervisor or monitor state output (optional)

MSP430 Ultra-Low Power MCUs

F5xx: Unified Clock System

- Orthogonal clock system
  - Any source can drive any clock signal
- 2 Integrated clock sources:
  - REFO: 32kHz, trimmed osc.
  - VLO: 12kHz, ultra-low power
- DCO & FLL provide high frequency accurate timing
- MODOSC provides bullet proof timing for Flash
- Crystal pins muxed with I/O function



TEXAS INSTRUMENTS

The Unified Clock System (**UCS**) module supports low system cost and ultra-low power consumption. Using three internal clock signals, the user can select the best balance of performance and low power

consumption. The Unified Clock System module can be configured to operate without any external components, with one or two external crystals, or with resonators, under full software control. The DCO can be on and stable from a low power standby mode within 5us.

The crystal pins being muxed with I/O requires the user software to enable the oscillator function.

Internal Clock Sources:

REFO – A 32kHz trimmed oscillator that is calibrated at the factory. Automatic source for FLL at power-up.

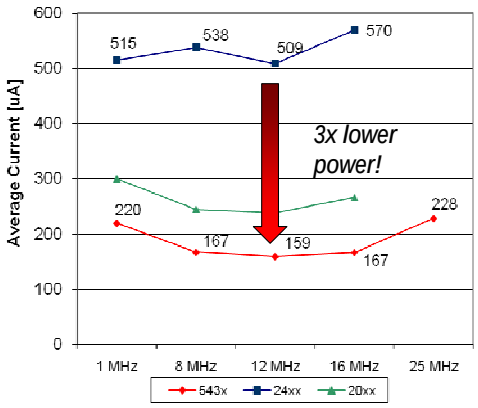
MODOSC – this is a general purpose oscillator for automatic use by peripherals, for instance the flash controller & ADC12. With the MODOSC sourcing the flash you now don't have to modify the FCTL2 register and change the operating speed of the system when doing in system programming of the flash.

VLOCLK: Internal very low power, low frequency oscillator with 12 kHz typical frequency

MSP430 Ultra-Low Power MCUs

F543x: Real World Power Comparison

- MSP430F5x's ultra-low active power dramatically lowers average power consumption
- For a 1 MIPS task occurring every second:
  - ~3x lower power than F24xx (largest 2xx device)
- F5438 Advantages
  - 12MHz over Vcc: 1.8-3.6V
  - ~150uA/MHz @ 12MHz
  - <2mA active current @ 12MHz
  - 2.6uA standby current



Lower average power than F20xx, the smallest MSP430 device!
– 256K vs. 2K Flash, 16K vs. 128B RAM

Texas Instruments

For a real world application, which spends most of it's time in standby mode and will wake up periodically to process a task, the F5438 will have the lowest average system power of any existing MSP430 ultra-low-power MCU.

For example, if we take a generic 1 MIPS task, meaning that it will required 1 million clock cycles worth of processing every second, the system only needs to be awake while its processing the task. So if the system running at 1MHz, it will be active 100% of time or if the system operates at 25MHz, it will be active only 4% of the time (1M/25M) and will be in standby mode the remaining 96% of the time.

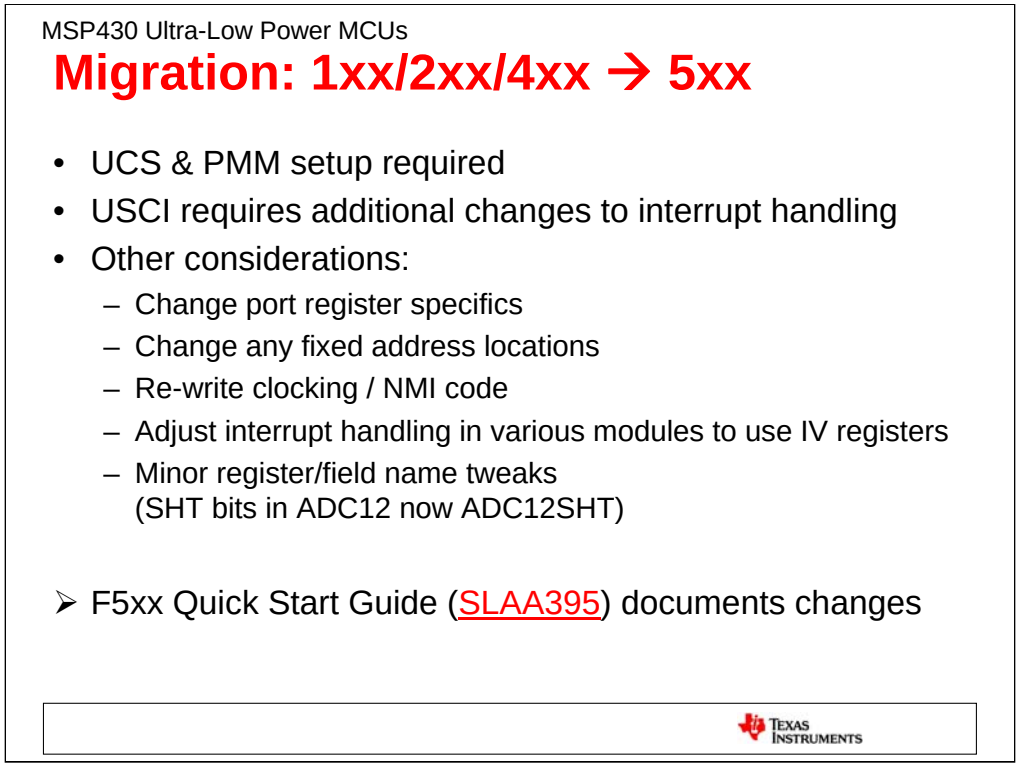
If we compare the F5438 with F2418, the largest, comparable 2xx device, which is already ultra low power, the average current consumed is more than 3x lower on the F5438 than the F24xx across it's entire operating range. This is mainly due to the fact that the active mode current is significantly lower on the F5xx (150uA/MIPS @ 12MHz) than all existing MSP430 devices.

What's even more impressive, is that if we compare the F5438 to the smallest device in MSP430 portfolio with the lowest standby power, the F20xx, the average current on the F5xx is still about 30% lower! Considering that the F5438 has 128x more flash, 128x more flash and tons of other digital peripherals, this is great example of how the F5xx will drastically reduce the power consumption in most real world applications.

How does the F5xx achieve such low power consumption? At 12MHz, the devices consumes only 150uA/MIPS (<2mA) which is an industry leading number. Also, it can operate at 12MHz, a relatively high speed across the entire Vcc range. Operating at a lower Vcc will reduce power consumption. Despite it's high degree of integration it only consumes 2.6uA in standby mode.

NOTES:

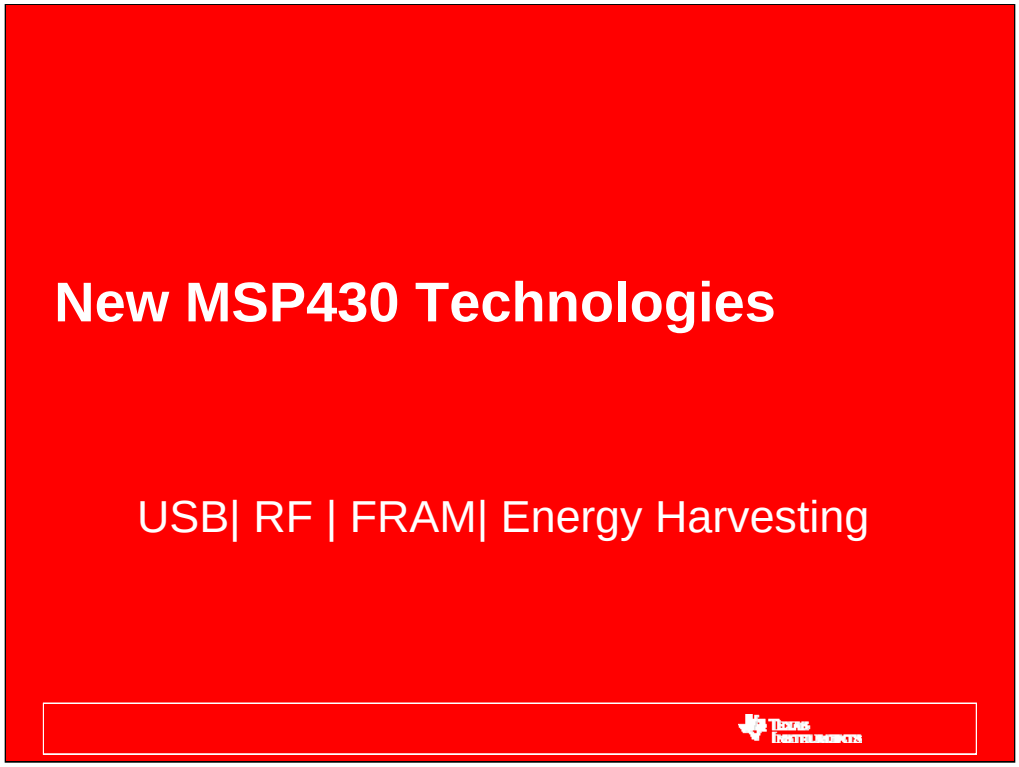
F54xx, F24xx and F20xx current numbers taken from datasheet at 3v. The 16MHz data point is at 3.3v because the devices can't run at 3v at 16MHz. The F5438's 12MHz data point was measured on real hardware because the datasheet did not include this characterization yet.



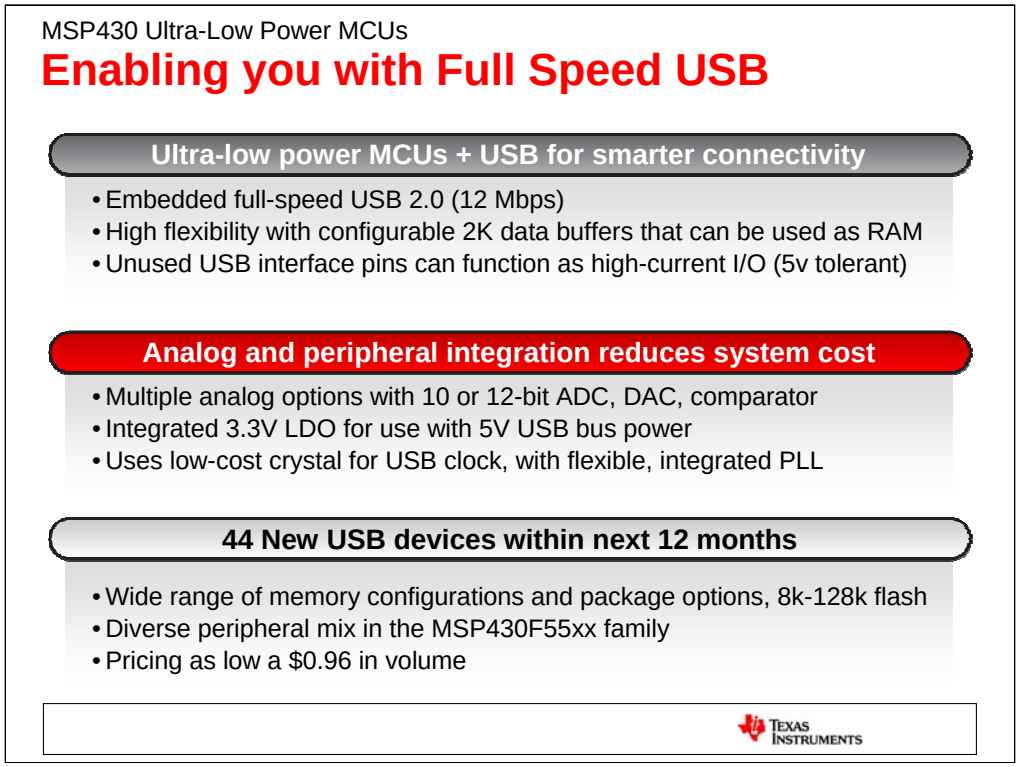
All MSP430 families use the same instruction set and have a similar architecture, which makes porting code from an older device easy. Since the MSP430F5xx has an all new Clock System (UCS) and Power Management Module (PMM), these two systems must be configured for any application.

Also, the way that most peripherals handle interrupts has also been tweaked so care must be taken when porting code. All absolute memory locations and pin outs must also be modified for the new devices.

All the required changes to port an existing application are well documented in the F5xx Quick Start Guide (SLAA395) .



As I mentioned, the New Technologies is the most captivating subject matter within MSP430 training, because it takes innovative technologies and makes them easy to implement. This year, will have launched FRAM, a revolutionary non-volatile memory, an integrated RF radio, full speed USB, and energy harvesting systems.



The next enabling technology we have added to MSP430 is USB. There are over 2B new USB devices manufactured every year. Since USB has become so ubiquitous, there is a stronger demand for clever USB solutions. And, many MCU designers are being faced with the prospect of adding USB to their systems. So, in July of 2009, MSP430 launched several families of USB-based products.

* They support full speed USB 2.0, not OTG or host. We designed them to be high flexibility. For example:

    Fully-configurable 2K data buffers that can be used as system RAM when USB module is disabled, in addition,

    Unused USB interface pins can function as high-current I/O pins

* Next, the USB power supply system has some functions new to the MCU industry. One of those is the

    Integrated LDO that is used with 5V USB bus power

    It can actually power entire system, saving the battery. It can even power the system when NO battery is attached so it has mixed power capabilities.

    This device operates at 3.3V to 1.8V, supporting the USB PHY, the PLL, and logic.

* Regarding very cost sensitive applications, these devices use low-cost crystals for the USB clock, and they have a flexible, integrated PLL

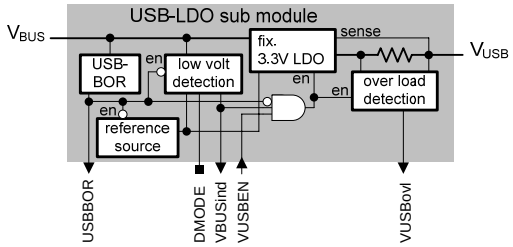
    It's designed so that the same crystal can source non-USB system clocks

    Last, it has detection of physical (not electrical) USB cable connection

    * There a an astonishing 22 new USB devices for MSP430, we have already launched more than half of them, They range in flash size starting at 8k and going up to 128k. There are 5 difference package options, with pin compatibility as you migrate between the USB families. These are aggressively priced, starting at under $1.

USB Module -- Power System

- Integrated LDO with 5V input and protection/monitoring functions, for use with USB bus power
- Outputs 20mA for MSP430 and system use
- Current limiting capability to $IDET_{max}$=60mA on VUSB(3.3V output)
- Independent from 5xx's power management module (PMM)
- Can be powered from USB upon device connection, even if no battery power available (low/no battery condition)



- Prepared for operation with USB battery chargers
- Concept prevents battery drainage to an unpowered, low-resistive USB network
- Controlled through the USB configuration registers

MSP430 Ultra-Low Power MCUs

USB Made Easy

- USB Bootstrap Loader (USB)
  - Supporting device programming
  - Field Firmware updates
- USB Descriptor Tool
  - Configures stack functions via GUI
- Free USB stacks available:
  - Communication Device Class (CDC)
  - Human Interface Device (HID)
  - Mass Storage Class (MSC)
- Additional stacks available from third parties

MSP430F5529 Sample Kit

FREE
Vendor ID/ Product ID sharing program

VID
Request for embedded USB products

Texas Instruments

But , we know it's not just about the numbers, it's about the use experience. Within minutes a developer can have a functioning USB system using TI's support packages.

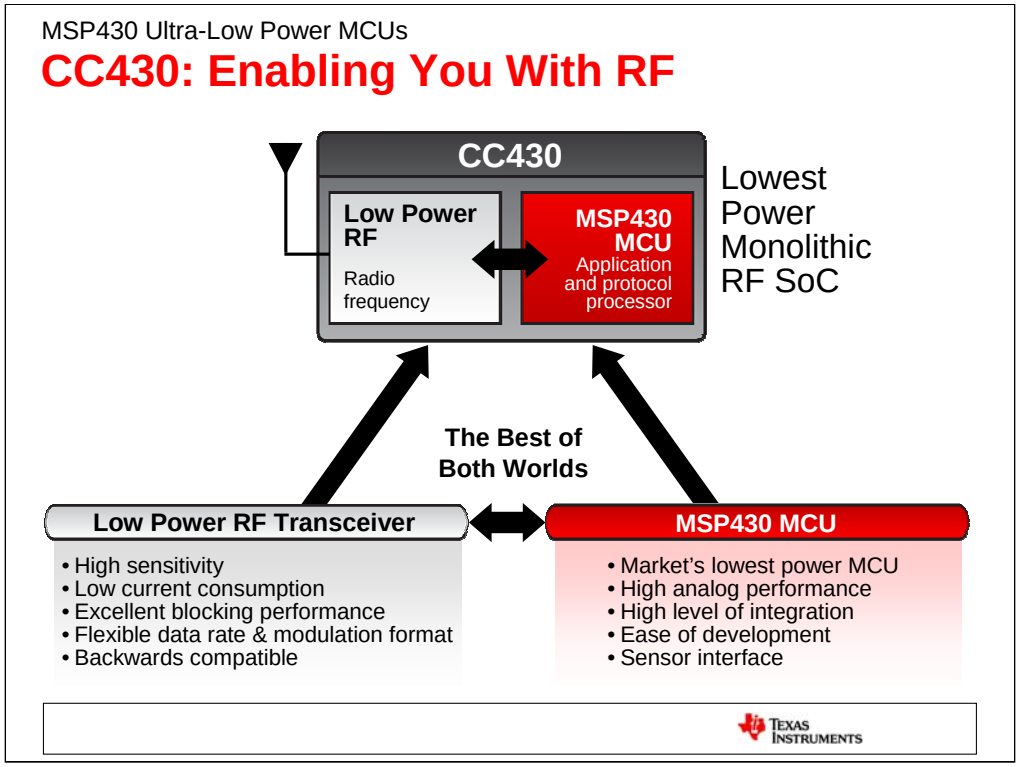
This packages includes:

1. **Sample kit** – Silicon 80 pin QFN, target board, and both the HID and CDC stacks
2. **USB BSL** – allows for field firmware updates… comes with it's own GUI making it very easy to use…. **Same BSL** can be used for device or factory **programming** via the USB as well.
3. **Descriptor tool is a a feature new to USB micros. – It address the problem that *configuring USB code can be very difficult..*** **This task** is made simple with this tool since it abstracts the USB code generation. Specifically,

   - It configures descriptor code for you. More simply put you choose correct the stack, descriptor code generates a USB header files.

   - Automatically and quickly generates descriptors that are reliable…on the 1st pass!
4. **Let me touch upon the VID/PID** Sharing program– allows user to obtain a Free VID/PID from TI. (without having to spend thousands of dollars $2-4K). TI assumes this cost on your behalf.
5. **Last, there is an Application note for** Starting a USB design with MSP430. It Describes tools suite. Section on VIDs and PIDs. Also, walks customer thru which stack they should use. Also, it discusses certification and the needed tools.

Together, all of these items help expedite the development effort and time for your USB project..



Switching now to another exciting set of products that will enable low power wireless applications – making RF design simple for the mass market.

More and more, we are seeing emerging 'remote monitoring' or 'sensing' applications where "no maintenance" is a key concern. You can imagine a situation such as sensors embedded in a bridge to monitor the structural integrity or a building automation application where the devices are too hard to reach once they have been installed, or it is too expensive for frequent service calls/replacements. Couple of key enabling technologies are wireless and ultra-low power, especially in battery operated devices.

Now, we'll discuss the CC430 - how you can enable your system with an integrated low power RF and the MSP430 solution; We have taken the popular CC radios within TIs analog portfolio, and integrated a sub 1GHz radio onto our new generation of MSP430 MCUs. It's the CC1101 RF transceiver for wireless networking integrated with our newest 5xx architecture core.

This allows us to offer our customers the best of both worlds –

The High sensitivity, low radio current consumption, Excellent blocking performance and Flexible data rate & modulation format of the CC1101 radio with all the advantages offered by the market's lowest power MCU family - high analog performance, high level of integration, ease of development (tools etc.), sensor interfaces etc.

The first family of products, the CC430F61xx and CC430F51xx devices, also feature

Wide Supply-Voltage Range, 2.0 V to 3.6 V

Ultralow Power Consumption: ·

– CPU Active Mode (AM): 180 mA/MHz core

– Standby Mode (LPM3 RTC Mode):1.7 mA – same as in CC1101

– Off Mode (LPM4 RAM Retention): 1.0 mA

– Radio in RX: 16 mA, 1.2kbps, 433MHz

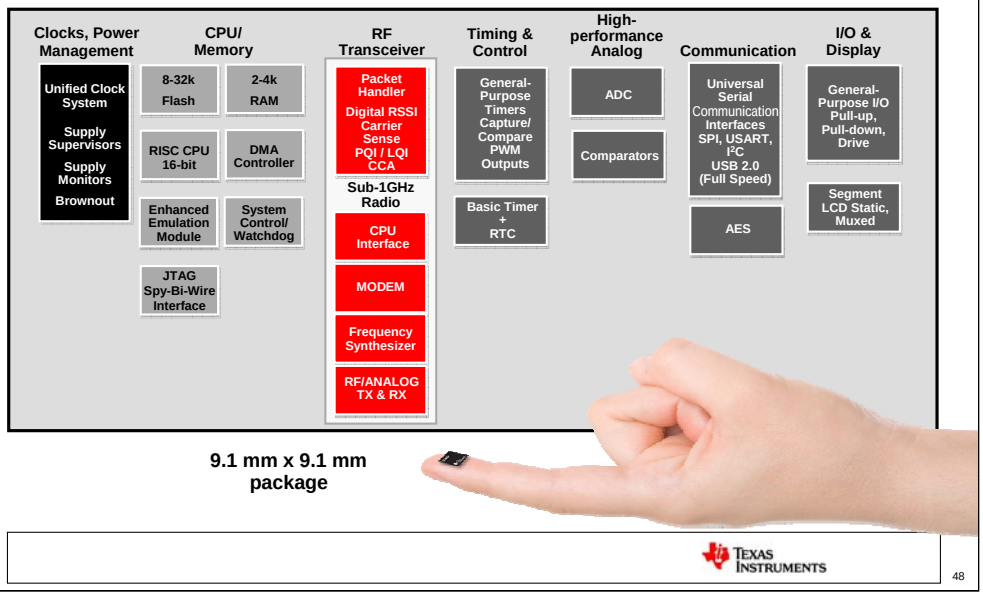
Wake up from Standby in < 5 ms

I would encourage you to visit the CC430 home page - www.ti.com/cc430 - for more information

MSP430 Ultra-Low Power MCUs

CC430: Reduces Complexity

Do more with less



The CC430 MCUs allow designers to tap into peak performance of up to 25 MHz while consuming as low as 160uA/MHz (microamp per megahertz). The full MSP430 peripheral set is available on the CC430 devices including 12-bit ADC, 16-bit DACs and comparators that provide high performance even during RF transmissions and consume no power when not in operation. We have also accelerated design cycles through key modules such as an integrated Advanced Encryption Standard (AES) accelerator that encrypts and decrypts data sent wirelessly . This guarantees more secure solutions, a concern in several wireless communication applications.

So, as you may see, leveraging the 5xx MSP430 core allows the CC430 to work with many of the same peripherals. Looking at this block diagram, you may recognize some of the familiar and innovative 5xx peripheral modules such as the Unified Clock System, Power Management Module, CRC checksum and F5438. In addition, we have implemented several new & innovative modules on the CC430, such as the new Comparator, the AES encryption module I mentioned, and an updated LCD module and, of course, the new RF1A interface to the integrated CC1101 transceiver. We will quickly highlight some of these in our next slide

Looking at the RF transceiver, it supports many of the standard worldwide sub-1 GHz frequency bands including the Industrial, Scientific, and Medical bands of 868 and 915 MHz. Frequency bands supported include the 300-348 MHz, 389-464 MHz and 779-928 MHz. The radio is specifically designed to meet the stringent spurious noise and selectivity requirements of the different regional regulatory groups, such as the FCC and ETSI in the US and Europe, respectively.

It does not support the worldwide 2.4 GHz band of operation. It also does not support the physical layer requirements for the 802.15.4 IEEE standard. However, this in no way limits the applications into which it can be deployed. TI has other chipsets that address the 2.4GHz band of operation.

The CC430 also offers a Port Mapping controller. To simplify the layout and optimize pin-function for a variety of applications, different peripherals have been brought out to multiple pins as specified in the device datasheets. However, each output signal can be mapped to several output pins and the mapping is runtime re-configurable. Pin functionality can be controlled using port mapping registers that are configurable only once per reset, or at runtime when the Port Mapping Reconfigure bit is set in the control registers. Intended for safe and robust behavior in-application, the pin mapping is password protected and locked from write access by either a timeout or an incorrect write to the password register.

The CC430 family has 8 devices that range between $1.47 and $1.97 at high volumes

MSP430 Ultra-Low Power MCUs

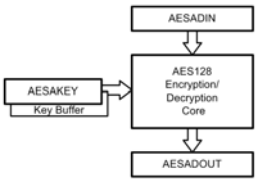
CC430: Innovative Peripherals

LCD_B

- Blinking of individual segments, Programmable frame frequency, Software-driver contrast control
- Regulated charge pump
- Integrated drivers

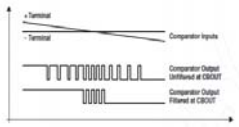
AEC 128

- Encryption and decryption according to AES FIPS PUB 197 with 128-bit keys
- Key expansion for en- and decryption
- Off-line key generation for decryption



Comparator_B

- Selectable reference voltage & voltage hysteresis generator
- High-speed, normal, and ultra-low power 100nA modes
- Internal output to Timer A capture
- Selectable RC filter for comparator output



Texas Instruments

Let's touch on some of the new peripherals.

LCD_B is an evolution of an LCD_A module from previous MSP430 devices, and provides new handy features such as the blinking of individual segments, and programmable frame frequencies to improve the clarity of an LCD display. It does provide automatic LCD signal generation, with an integrated resistor ladder for intermediate voltage generation as well as an integrated charge pump. It also has integrated drivers to decouple the LCD load from the bias generation

The AES encryption module is a completely new peripheral, and implements the encrypt and decrypt functions of the AES-128 bit encryption standard, including dynamic key expansion and interrupt-based processing (via an AES ready interrupt flag) to reduce the CPU load it takes to securely transmit wireless data.

The new comparator B module is nice because of three key differences over its previous incarnation.

•High-speed, normal, and ultra-low power mode settings that allow the user to tradeoff speed for power specific to their application requirements

•A stable, internally generated 1.2 V shared voltage reference is selectable as the comparator reference

•And the fact that the reference is divisible into two separate comparator voltages, a high and a low voltage.

This last point is especially useful when charging or discharging a capacitor, say for a cap touch application, where you need to measure the amount of time it takes to move that charge and attain a specific voltage and those voltage references need to switch automatically and without CPU intervention. Since the comparator output is connected internally to a Timer module, this is all possible in the low power modes of operation where interrupt driven events reduce the active current consumption of the CPU.

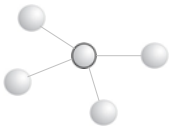
MSP430 Ultra-Low Power MCUs

Wireless Made Easy

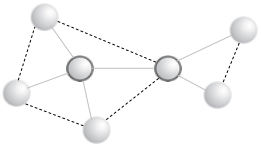
- *Free* RF libraries and stacks
- SimpliciTI (Star Network protocol)
  - www.ti.com/simpliciti
- TIMAC – IEEE 802.15.4 Medium Access Control (MAC)
- Z-Stack – Free ZigBee Stack
  - Compliant with 2006 ZigBee™ spec
  - www.ti.com/zigbee
- Third party partners with mesh network stacks – coming soon!
- SmartRF® Studio
  - Automatically generates register values

Point-to-Point
(MSP430 + RF HAL)

Star Network
(IEEE 802.15.4, SimpliciTI)



Mesh Network
(ZigBee, 6LoWPAN)



Texas Instruments

Once again, it's not just about the specs and hardware, we want to ensure we provide you with RF products that are easy to design in your system. Several software options and tools are freely available from Texas Instruments to test your design and enabling your MSP430 + Chipcon Low Power RF radios to communicate over a number of a different frequencies and network topologies, using both standards-based and proprietary RF stacks.

The TI HAL library sets up the communication between the CC1100(xx) & CC2500(xx) radios and every MSP430 device available. All SPI communication is abstracted. So, simple point-to-point link can be established and the software comes abstracted and ready for use in your application.

SimpliciTI is a TI proprietary low-power network protocol that enables direct device-to-device communication. It is a Simple star with access point for store and forward to end device that supports the use of range extenders to increase range to 4 hop. Its key advantages include a simple 5 command API and the ease-f-use. It is designed for low data rate and low duty cycle applications such as Alarm & Security, Smoke Detectors, Active RFID etc. It is available on our website at http://focus.ti.com/docs/toolsw/folders/print/simpliciti.html

The TI MAC is a free download of the IEEE standards-based implementation of the 802.15.4 protocol for low data rate wireless communication. The Physical Layer and MAC layers (Medium Access Control) are defined allowing a PAN topology (Personal Area Network). The 802.15.4 standard is ideal point-to-point or point-to-multipoint communication in star networks. Battery life may be extended by modifying the user selectable latency options. The TI MAC will run on any MSP430 device and the CC2400(xx) RF devices.

The Z-stack, which is also available for free from TI, is an implementation of the 2006 ZigBee specification and is a Network and Application Layer above the 802.15.4 MAC. It was designed for low power, low data rate communication over a secure channel between multiple low cost nodes through the ISM band (2.4 GHz). So, because ZigBee is a defined standard, it's possible to communicate and not interfere with other existing ZigBee based products within radio range.

We are also working with third party partners on other wireless stacks and we will have a robust and broad solution portfolio (hardware + software) for our customers to choose from.

SmartRF Studio is a free RF design tool offered on our web site – it converts user inputs and performance requirements into register values for the CC devices. Supports quick performance testing and allows users to establish a simple link to the CC devices.

Proprietary solutions are also available which allows for a smaller flash footprint. We have relased SimpliciTI, a star-network stack for use with the MSP430 and Low Power RF devices.

MSP430 Ultra-Low Power MCUs

FRAM: The Future of MCU Memory

- ***Non-volatile, Reliable Storage***
  - Over 100 Trillion write/read cycles
  - Write Guarantee in case of power loss
- ***Fast*** write times like SRAM
  - ~50ns per byte or word
  - 1,000x faster than Flash/EEPROM
- ***Low Power***
  - Only 1.5v to write & erase
  - >10-14v for Flash/EEPROM
- **Universal Memory**

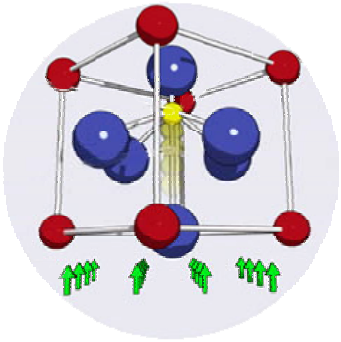


Photo: Ramtron Corporation

Texas Instruments

A wise man once said that to understand where we are going/need to go, its important to know where we have come from

We need to understand that the existing non-volatile memory technologies (Flash and EEPROM) are reaching their limits in some applications. These technologies introduced in the early 1980's have been the work horse of nonvolatile storage. But with every shrink in semiconductor process, Flash and EEPROM have proven more and more difficult to migrate. The combination of specialized process steps that add cost, and the higher voltage (power) required to write data to memory have caused most semiconductor manufacturers to look to other memory technologies such as FRAM as semiconductor geometries shrink.

Also, we are seeing some macro trends in the market place impacting amongst others, embedded microcontroller technologies. **Wireless, Low Power and Security** – coupled with demand for significantly more information, instantaneously - are shaping the need for new technologies

Bottom line: to deliver the benefits that customers are demanding going forward, we need a new technologies. FRAM – Ferroelectric Random Access Memory – is the next generation of embedded memory that the market is waiting for

FRAM has:

FRAM is non volatile like Flash, and it is proven from the robustness and reliability standpoint. FRAM features enhanced Data Reliability – inherent 'write guarantee' protection in case of power loss during a write cycle to FRAM and superior radiation hardness

Because only a small amount of energy is required, all the necessary power for FRAM can be front-loaded at the beginning of a write cycle. This avoids "data-tearing," a partial write of the data which occurs when the smart IC is removed from the RF field power source during a write cycle. EEPROM and Flash are more prone to data tearing.

Fast Write (updates) – less than 50ns – that's 1000x faster than EEPROM

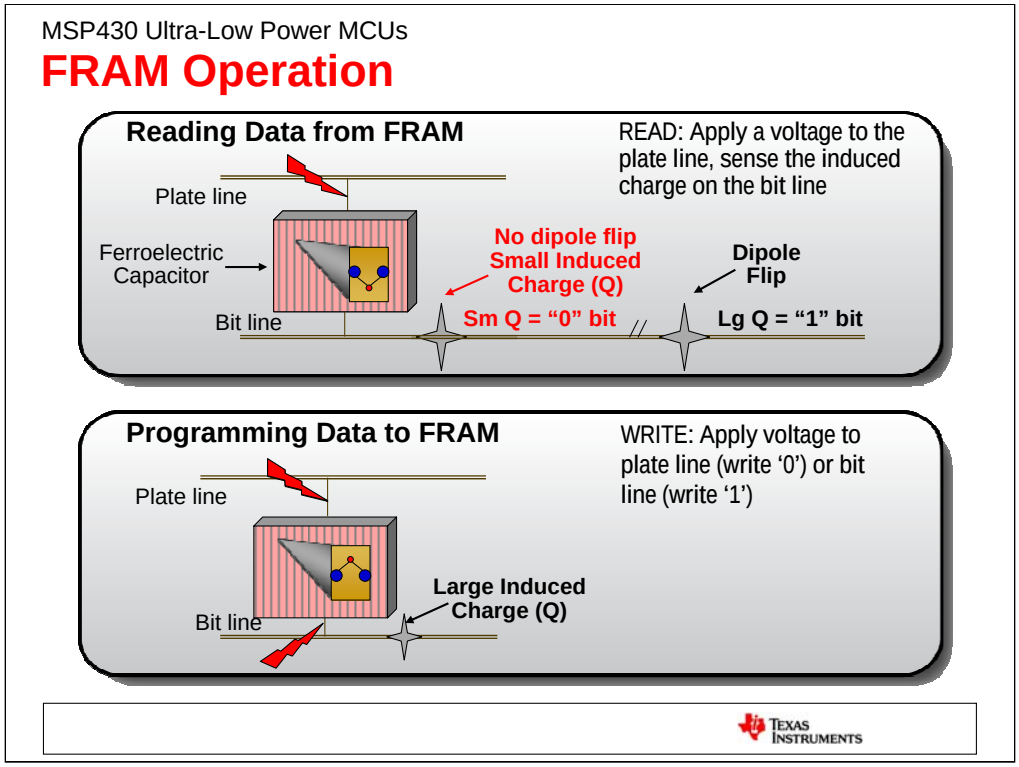
FRAM essentially eliminates the difference between read and write times. This essentially opens the door for a universal memory capability – where the application and software can dynamically partition the device memory into code space or data space or RAM. This brings incredible flexibility to software designers, product manufacturers etc.

Very Low Memory Access Power requirements – 1.5v compared to 10-14v for EEPROM

Low voltage, which translates to low power usage, has the benefit of battery savings in battery operated devices, especially in applications such as datalogging etc. This low power operation also is key in remote data sensing application with battery operated devices.

You look at these features and think about RAM – and you would be correct. Except that again, FRAM is also non-volatile (retains the data stored even when power is shut down).

These features now make the concept of 'universal memory' reality – you now have the desirable features of RAM and Flash in one memory technology, thus gaining tremendous flexibility as a software developer (think dynamic memory partitioning) , improving system performance and reliability by avoiding data transfer between multiple memories, and reducing overall system cost (via inventory management and new product development cost efficiencies).



Now, to share with you a little of how FRAM works. The ease and speed by which data is established within an FRAM memory cell illustrates the shift away from the design complexity of floating gate technology to the **natural** phenomenon that is inherently available within a ferroelectric crystal.

An FRAM memory cell consists of a ferroelectric capacitor – obviously, containing millions of crystals all having dipoles (Ferroelectric capacitor material: PZT- Lead zirconate titanate) connected to the capacitor by a plate line and bit lines.

Intrinsically, the dipole atom within a ferroelectric crystal has either a positive or negative orientation. In contrast to the complex charge storage mechanism used in EEPROM, FRAM stores information through the use of a stable electric dipole found in the ferroelectric crystal. The orientation of the dipole within the ferroelectric crystals that make up the capacitor material can be set and reversed through the application of an external voltage across either line.

To read the data in an FRAM memory cell, a small voltage is placed upon the plate line, the key here is that you are trying to get to a "0" state. If the voltage causes dipoles inside the capacitor to flip orientation, then a large induced charge (Q) is generated on the bit line.

If the orientation of the dipole is already negative prior to applying voltage to the plate line in a read cycle, then there is no change in dipole direction and a small induced charge (Q) is created on the bit line.

So, in reading the data from an FRAM memory cell, a small induced charge is a "0" bit and a large induced charge is a "1" bit.

Writing to FRAM is really just as simple – applying a voltage for example to the bit line changes the orientation of the dipole to a positive "1" bit.

Flipping dipoles is pretty easy – pretty simple and really fast.

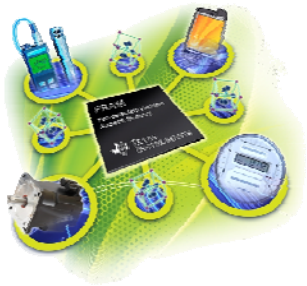
By contrast, Flash / EEPROM uses what is called floating gate technology, where an electrical charge is stored onto an oxide material – not without some effort. Flash memory works by modulating charge (electrons) stored within the gate of a MOS transistor. The gate is constructed with a special "stack" designed to trap charges (either on a floating gate or in insulator "traps"). The presence of charge within the gate shifts the transistor's threshold voltage, higher or lower, corresponding to a 1 to 0, for instance. Changing the bit's state requires removing the accumulated charge, which demands a relatively large voltage to "suck" the electrons off the floating gate. This burst of voltage is provided by a charge pump which takes some time to build up power. General write times for common Flash devices are on the order of one ms (for a block of data), about 100,000 times the typical 10 ns read time, for SRAM for example (for a byte). Flash and EEPROM have many strong characteristics, nonetheless, slow programming time with high power and additional circuitry requirements are some less than stellar attributes.

Other new memory technologies such as Magnetoresistive Random Access Memory (MRAM) and Phase Change Memory (PCM) also suffer from high write currents.

MSP430 Ultra-Low Power MCUs

FRAM in applications

- Battery Backed SRAM Replacement
  - High Write Endurance, Low power
  - Eliminate SRAM quiescent current
- Digital rights management
- Data logging, remote sensing
- Low Power Electronics
- Enables energy harvesting



Texas Instruments

•This revolutionary memory will enable several applications that require low power or a number of write cycles. It also is resistant to radiation, providing greater reliability and security. Here are some examples

•MSP430 will be launching our first FRAM device within months. It is the FR1000 and it is targeted for low end motor-control with several integrated analog peripherals. It will be available late in 2009 and is expected to be about $1.50 in low volumes.

Right now you can check out more information at www.ti.com/fram. We have a FAQ on FRAM, a reliability report, a technical brief, and information about FRAM technology use in the very demanding automotive industry.

MSP430 Ultra-Low Power MCUs

FRAM: Proven, Reliable, Better

- Endurance
  - Proven data retention to 10 years @ 85°C
- Secure
  - Fast access times
  - No charge pump
  - No perceptible difference in read/write processes
- Radiation Resistance
  - Terrestrial Soft Error Rate is below detection limits
- Immune to Magnetic Fields
  - FRAM does not contain iron

Photo: Ramtron Corporation

www.ti.com/fram
For more info on
TI's FRAM technology

Texas Instruments

In addition to the advantages outlined earlier of fast access times, low power and write endurance, a few words now on the reliability and some other unique features of FRAM.

As mentioned earlier, TI has been working with FRAM for over 9 years. We have been exhaustively testing FRAM technology for reliability in this time period. We have proven FRAM data retention to the industry standard 10 years at 85 deg. C.

Addressing a common misconception, although "ferro" means iron, FRAM does not contain iron. The term "ferroelectric" refers to similarity of the

graph of charge plotted as a function of voltage to the hysteresis loop (BH curve) of ferromagnetic materials.

Traditional floating gate non-volatile memories have several deficiencies from a security standpoint – the need for high voltage circuitry including charge pumps for the write process, the storage of data state as charge, long write times, inherent differences (power consumption) between read and write processes. These differences are exploitable in today's technology to access and possibly manipulate sensitive information on the chip (via nanoprobes, laser attacks, power analysis attacks etc). While there exist countermeasures that can be designed in to address these threats, these are time consuming, often power hungry and expensive. Since FRAM is based on dipole position (not charge), is low power, has fast access times and most importantly has similar read and write processes, it simplifies the countermeasures needed in memory operation.

Finally, as traditional floating gate technologies (Flash/EEPROM) have the data state stored as charge, perturbation by alpha particles etc. can cause bits to flip to an opposite state (this is called Soft Error Rate or SER). However in FRAM, the state is stored as a PZT film polarization, an alpha (or other radiation) hit is very unlikely to cause the polarization to change a given cell's state. FRAM's terrestrial SER is below detection limits. This can be potentially very advantageous in medical or space related applications.

MSP430 Ultra-Low Power MCUs

MSP430 Enables *No-Power* Apps

Body warn monitoring devices powered by body heat, movement

Monitor environmental conditions on farm, winery, etc.

Mesh networking for environmental monitoring (e.g. forest fire detection)

Automotive monitoring (e.g. tire pressure gauges powered by vibration)

- Energy harvesting is the process by which energy is captured and stored
- Can substitute batteries that are costly to maintain and can extend system uptime
- Only possible with ultra-low power components
- Solar, kinetic, thermal, RF, salinity gradients, pH difference and other ambient sources available

Texas Instruments

We have spent some time discussing with you the concept of “ultralow-power” systems. Now imagine a “NO” power system.

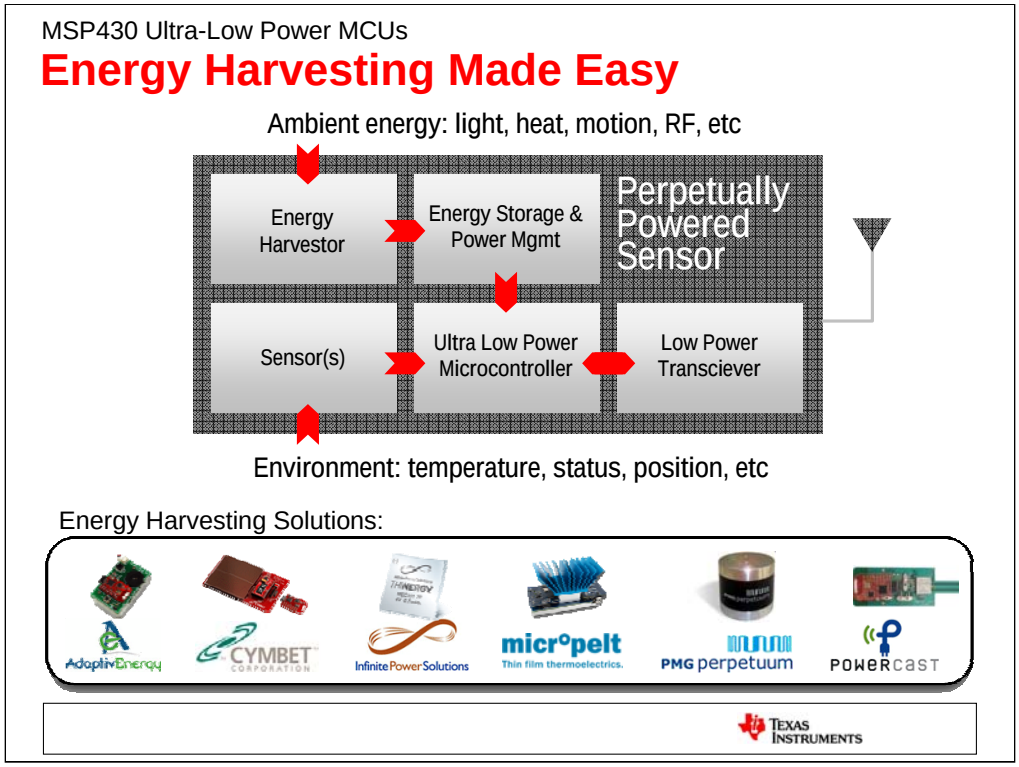
Modern MSP430 ultra-low-power microcontrollers have reached such a level of integration and processing efficiency that

many applications no longer require traditional batteries. These applications include complex and often power intensive

wireless sensor networks that may involve sampling various sensors and communicating wirelessly.

By harvesting the miniscule amounts of ambient energy that would otherwise be waste, ULP applications can be extend their battery life if not completely eliminate the need for a battery.

Several sources of energy exist to harvest from such as solar, vibration, RF, and there are countless other ways to generate power. Whatever is readily available in the applications environment may be a potential source of energy. For example, more esoteric energy sources have been identified such as *tree* energy harvesting or *microbial* fuel cells, ie *dirt* energy harvesting.



At TI, we have not only the MCU to use in energy harvesting applications. We also have all of the other semiconductor parts needed. In addition, we have partnered with the leaders in the EH industry, many of whom have decided to exclusively develop using the MSP430 MCUs. We work hard to be the leaders in energy harvesting. We have technical training, videos, and reference designs available at **ti.com/energy harvesting**

The Energy harvesting solutions listed here are all available from their parties and each feature the MSP430 as the base processor running the application. In many cases, their demos are based on the eZ430-RF2500 development tool featuring the MSP430F2274 and CC2500.

AdaptivEnergy: Adaptive produces a rougedized piezoelectric that generates significant amounts of power from both periodic and random motion. The demo kit featured here is readily available from mouser.

Cymbet: Cymbet is a provider of small thin film rechargeable batteries (~40uAhr batteries) that are packaged in traditional semiconductor packages. TI collaborated with Cymbet to create the eZ430-RF2500-SEH Solar Energy Harvesting Development kit.

IPS: IPS creates high capacity, high power thin film rechargeable batteries (~1mAhr. 50+ mA peak discharge) and they typically call their products micro energy cells. Their cells are packaged in razor thin foil packaging that makes their cells roughly the same size and thickness of a postage stamp!

Micropelt: Micropelt specializes in thermal energy harvesters, and can generate enough energy to run a wireless sensor network from body heat alone.

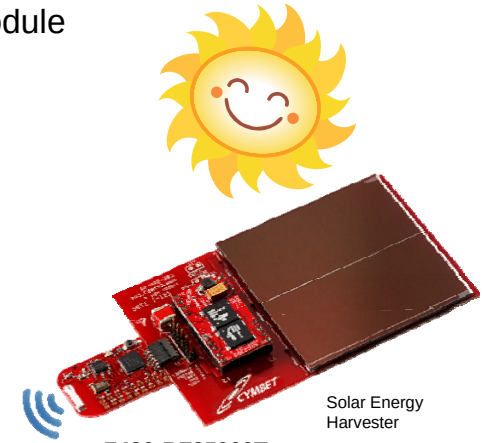
Perpetuum: Perpetuum provides industrial vibrational energy harvesters and have deployed large energy harvesting systems to large manufacturing systems to monitor real-time machinery status and conditions. The MSP430 not only runs a wireless application from the energy harvester but also handles the power management within the system.

Powercast: Powercast develops RF energy harvesting systems that collects energy from out of thin air.

MSP430 Ultra-Low Power MCUs

Self-Powered Solar Energy Harvester

- Solar Energy Harvesting module
- Works in low ambient light
- Negligible self-discharge
- 400+ transmission with no light
- Adaptable to any sensor and RF network



Solar Energy Harvester

eZ430-RF25000T
Wireless Target

Only $110 for MCU Day attendees

Texas Instruments

The eZ430-RF2500-SEH Solar Energy Harvester development kit is available from TI and can serve as a demonstration of energy harvesting from solar power as well as a reference design for your application.

The custom solar panel (from Sanyo) was optimized to work in dim indoor lighting and can provide enough energy to run a wireless sensor network based on the eZ430-RF2500 (MSP430F2274 + CC2500) even in low intensity, office florescent lights. Extra energy is stored in two thin film batteries from Cymbet. These tiny 40uAhr thin film batteries look just like traditional semiconductors and provide enough energy for 400 – 1000 transmissions in complete darkness.

The system is “Energy Aware” so it will automatically switch from solar power when enough light is available and will dynamically switch to battery power when the light is too dim to function. The duty cycle and RF output power can also be automatically adjusted to accommodate for the new power profile.

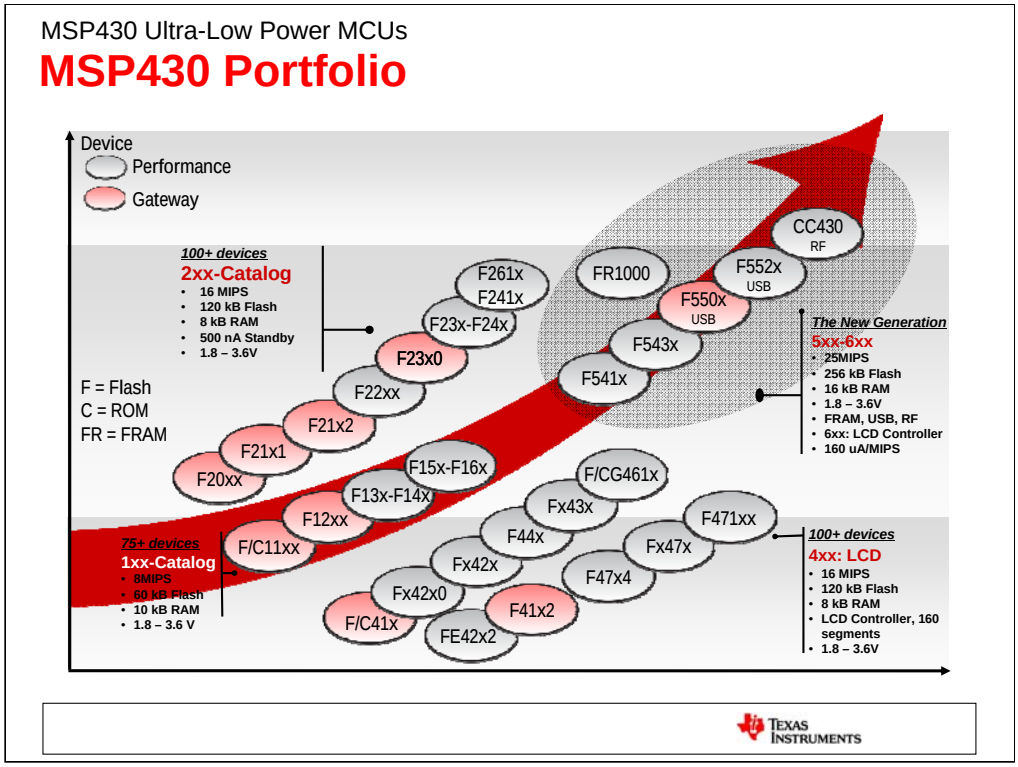
The eZ430-RF2500-SEH samples the MSP430’s on board temperature sensor to create an autonomous wireless sensor network based on SimpliciTI, and the system can be extended to sample other external sensors. Additionally, it may be extended to use any other wireless protocol.

MSP430 Part 2 - Summary

- ‘5xx Family provides
  - Increased performance up to 25 MHz
  - Low operating and flash programming voltages
  - New power management and unified clocking modules
  - New peripherals: USB, DMA
- Enabling Technologies
  - FRAM, USB, RF, energy harvesting

Thank you.

Backup



The MSP430 is designed specifically for battery-power measurement applications.

The **clock system** allows many low-power modes with no compromise in performance.

Because of a wide operating voltage range, the MSP430 can often be powered directly from a battery.

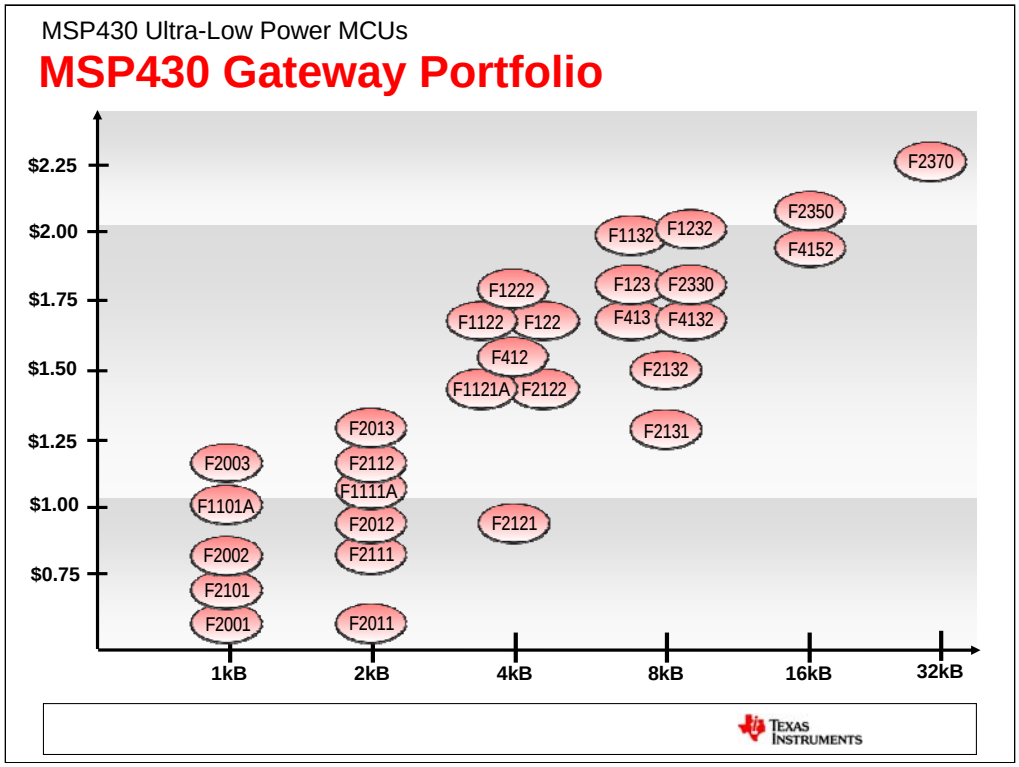
The MSP430 **BOR** implementation is truly ultra-low power, in the nA range and practical for all applications. The MSP430 BOR function is so low power that this functions is always active, even in all low-power modes. This ensures the most reliable performance possible. Competitor's BOR protection is in the µA range and not usable in ultra-low power battery powered applications, which leave the application vulnerable to BOR conditions.

The **port pins** have very low leakage when connected to external signals. This is very important as many MCUs have several µA of input leakage on each port pin.

The overall MSP430 **architecture** including a 16-bit CPU with 16 registers and 16-bit data and address buses minimize power-consuming fetches to memory. A fast vectored-interrupt structure reduces the need for wasteful CPU software flag polling.

Many **intelligent peripheral** features are provided that allows tasks to be completed independent of the CPU and far more efficiently. These include the autoscan feature in the ADC12 and the available DMA. With the intelligent peripherals, the CPU does not need to be over clocked to deliver the required system performance.

Always review manufactures worst case or maximum values. Many specifications are dramatically effected over **temperature**.



The MSP430 Gateway Portfolio offers a growing set of MSP430 devices that are low cost, and come in small form factors. The MSP430 Performance Porfolio offers the more richly integrated devices with high-end analog integration and larger flash sizes up to 256 KB.

MSP430 Ultra-Low Power MCUs

MSP430 Generations

		2xx	1xx/4xx	5xx
CPU Clock (Max)		16MHz	8 & 16 MHz	25MHz
Flash/RAM (Largest comparable device)		120KB / 4KB (F24xx)	120KB / 4KB (FG46xx)	256KB / 16KB (F54xx)
Active Current (3.0V) µA/MIPS	1MHz	515 µA	600 µA	220µA
	8MHz	525 µA/MIPS	600 µA/MIPS	*160 µA/MIPS*
	16MHz	569 µA/MIPS	N/A	188 µA/MIPS
	25MHz	N/A	N/A	224 µA/MIPS
Standby Current (LPM3)		0.3 – 1.1µA	0.7 – 1.3µA	2.6µA (w/ active true RTC)
Power Down Current (LPM4/5)		0.1µA	0.1µA	1.6µA (LPM4) / 0.1µA (LPM5)
Wake-up Time From LPM3		1µs	6µs	5µs
Flash ISP Minimum DV_{CC}		2.2V	2.7V	1.8V
Port I/O Interrupt Capability		P1/P2	P1/P2	P1/P2 (F5438) Add'l pins in future devices
Prog. Port Pin Drive Strength		N/A	N/A	All port pins
Prog. Pull-ups/-downs		All port pins	N/A	All port pins
Available MCLK Sources		DCO, VLO, LFXT1, XT2	FLL, LFXT1, XT2	FLL, VLO, REFO, XT1, XT2
FLL Reference Clocks		N/A	LFXT1	REFO, XT1, XT2

Lowest active power in the industry

Lowest stand-by and fastest wakeup

Write to Flash at min Vcc

Texas Instruments

Although, both of the 2xx and 4xx families are highly integrated, ultra low power families, the 5xx takes the best features from previous generations and improved upon them. By moving to a new ultra-low power technology process, the 5xx has increased the amount of analog and digital integration, increased the processing performance, and managed to be the lowest power MSP430 device for real world applications.

Standby LPM3 Current – This number now has the active RTC included. In past devices, you had to have a wake-up event and then perform the RTC function in software.

LPM4 Current – If you notice LPM4 is a little higher now than the older devices. We now have an regulator on chip that has an associated quiescent current. This requires additional current in LPM4, allowing full device functionality as expected with an MSP430: full RAM retention, fast wakeup on interrupts, etc. With that, note the new LPM5 mode. All other low power modes are the same as the previous families. LPM5 shuts down the regulator so everything is shut down. Exit/wakeup from LPM5 on the first 5xx devices is via reset.

Active Mode Current – the active mode current on the F5xx has been heavily optimized and can sustain <160uA/MIPS which is the best in class active mode current of all MSP430 devices. This enables lower system power in real world applications.

GPIO port pins on the 5xx have also been improved and include programmable pull-ups and pull-downs on all pins, programmable drive strength (normal and high strength), and future 5xx devices will enable more digital ports to be interrupt capable.

The clock system on the 5xx has also been enhanced to be far more orthogonal allowing all clock sources for all clock signals.

Power numbers are for (typical):

F2418, F4618 & F5438

MSP430 Ultra-Low Power MCUs

MSP430 Peripheral Overview

1xx	2xx	4xx	5xx
Basic Clock System	Basic Clock System +	FLL, FLL+	Unified Clock System
Core voltage same as supply voltage (1.8-3.6V)	Core voltage same as supply voltage (1.8-3.6V)	Core voltage same as supply voltage (1.8-3.6V)	Programmable core voltage with integrated PMM (1.8-3.6V)
16-bit CPU	16-bit CPU, CPUX	16-bit CPU, CPUX	16-bit CPUXv2
GPIO	GPIO w/ pull-up and pull-down	GPIO, LCD Controller	GPIO w/pull-up and pull-down, drive strength
N/A	N/A	N/A	CRC16
Software RTC	Software RTC	Software RTC with Basic Timer, Basic Timer + RTC	True 32-bit RTC w/Alarms
USART	USCI, USI	USART, USCI	USCI, USB, RF
DMA up to 3-ch	DMA up to 3-ch	DMA up to 3-ch	DMA up to 8-ch
MPY16	MPY16	MPY16, MPY32	MPY32
ADC10,12	ADC10,12, SD16	ADC12, SD16, OPA	ADC12_A
4-wire JTAG	4-wire JTAG, 2-wire Spy Bi-Wire (Some devices)	4-wire JTAG	4-wire JTAG, 2-wire Spy Bi-Wire

Texas Instruments

UCS – Compare this with the clock system of the past MSP430 devices. With this clock system you can pretty much connect any clock source to any of the clock nets driving the CPU and peripherals (MCLK, ACLK, SMCLK) with more FLL reference capability. A low power, low frequency oscillator has been added that has low accuracy and runs at 12KHz. Good for non-critical applications.

Power Management Module (PMM)- Programmable core voltage conserves power when the CPU frequency can be reduced for the application. Keep in mind there are some external LDOs from TI that allow you to change the output voltage as well for the older devices without the PMM.

CPU – still a 16 bit core but no paging for the extended addressing. Core frequency is also increased.

The **GPIO** is more flexible/capable with the 5xx devices with pull-ups/downs and programmable drive strength. I/Os can be 16 bits wide when combined and also provide interrupt capability.

The **CRC** module has been added and is a separate module. This is a nice feature because it can be used with any peripheral. Compare this with some competing devices where the CRC is integrated with say the SPI module or something.

No more software overhead to wake up and perform the **RTC** function. The 5xx has this as a 32 bit counter. Can also be used as an interval timer.

USB will be added in future devices. This is new for the MSP430 family.

DMA channel capability has been increased to 7. This is device dependent. For example, the F5438 has three channels.

MPY32 – 32 bit operands with a 64 bit result via 4 output registers. Retains backwards compatibility with the lower results registers.

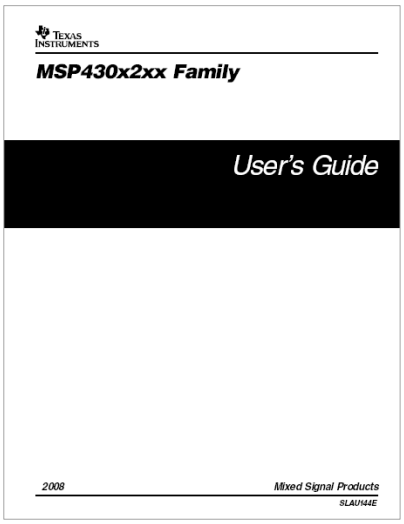
ADC12_A – This is a much lower power ADC now (150µA instead of the 800µA from the 44x ADC). A big improvement is also the reference settling time. The old 44x reference stabilized in 17ms. The new reference is stable in 35us. A huge improvement.

JTAG – all 5xx devices will include a dedicated JTAG port (PJ) that will support both 4-wire JTAG and 2-wire Spy Bi-wire. Unused pins maybe used as general GPIO.

MSP430 Ultra-Low Power MCUs

F2xx Key Features

- <1µA standby LPM3
- <1µs 0-16MHz
- Zero-power BOR
- Failsafe oscillator
- Enhanced watchdog
- Pull-up / down resistors
- Hack proof boot loader
- 2.2V Flash ISP
- Extended temp 105°C
- *Same instruction set architecture*



Texas Instruments

The MSP430F2xx family provides twice the processing performance (16MHz versus 8MHz) in terms of maximum CPU clock speed at half the stand-by power consumption compared to MSP430F1xx devices.

In addition, the F2xx family incorporates a variety of enhancements including zero power brown-out reset protection on all devices, lower power and lower voltage flash programming, an improved failsafe low frequency (LF) and high-frequency (XT) crystal oscillator system. An improved watchdog timer (WDT+) offers protection against run away software, invalid address fetches as well as a protected clock source. The features reduce overall system cost and improve reliability. The digitally controlled oscillator (DCO) is improved with greater stability over temperature and voltage allowing, in most applications, the elimination on an external crystal. All port pins now have programmable pull-up/pull-down resistors eliminating external components. The bootstrap loader is improved including an option that an invalid password will erase the device, which prevents hacking.

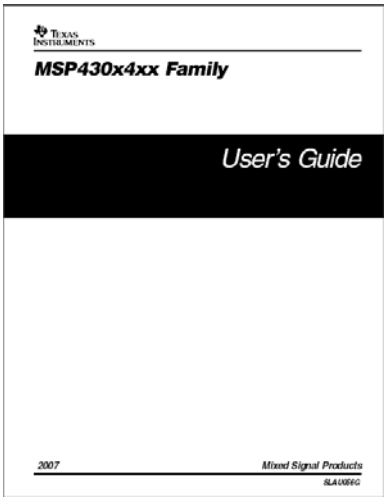
F2xx derivatives are offered with extended 105°C temperature capability. Automotive temperature and qualification will not be offered.

The F2xx family of devices offers many improvements, but shares the same CPU and instruction set as all MSP430's – this means existing code can be completely reused.

MSP430 Ultra-Low Power MCUs

F4xx Key Features

- <1µA standby LPM3
- <1µs 0-16MHz
- 4-120 KB Flash
- Built-in LCD Driver
- Zero-power BOR
- Pull-up / down resistors
- 2.7V Flash ISP
- *Same instruction set architecture*



Texas Instruments

The MSP430F4xx family now provides twice the processing performance (16MHz versus 8MHz) in terms of maximum CPU clock speed at half the stand-by power consumption compared to MSP430F1xx and devices. Now the 47xx devices have the ability to operate @ 16MHz.

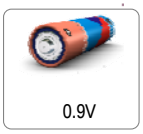
In addition, the F4xx family incorporates a variety of features including zero power brown-out reset protection on all devices, lower power and low voltage flash programming. An onboard LCD controller (up to 160 segments) caters to portable applications.

The features reduce overall system cost and improve reliability. The digitally controlled oscillator (DCO) is improved with greater stability over temperature and voltage allowing, in most applications, the elimination on an external crystal. All port pins now have programmable pull-up/pull-down resistors eliminating external components. The bootstrap loader is improved including an option that an invalid password will erase the device, which prevents hacking.

The F4xx family of devices offers many features and improvements, but shares the same CPU and instruction set as all MSP430's – this means existing code can be completely reused.

MSP430 Ultra-Low Power MCUs

Disruptive Technologies



0.9V

Key Traits
- Low input voltage range

Optimized Analog & Power
- TPS6122x – Input Voltage Down to 0.7V
- TMP112 - Industry's Lowest Power High Accuracy (1°C) Digital Temp Sensor

Key Traits
- Tiny Packaging
- High Integration
- Small External Components

Miniaturization

Optimized Analog & Power
- TPS62600 – 6MHz, Chipscale packaging
- TLC320AIC3254 Lowest power 1.8-V audio codec with miniDSP

Power & Analog

RF

Key Traits
- Low Noise
- High PSRR

Optimized Analog & Power
- TPS717xx – Ultra-high PSRR (67dB @ 100kHz), Very low noise (30uV typ)
- CC2530 - SoC for IEEE802.15.4/ZigBee for RF4CE and Metering (AMI)

Energy Harvesting

Key Traits
- Ultra Low Power
- High Integration
- Small External Components

Optimized Analog & Power
- TPS780xx – 5nA quiescent current
- INA333 – Micro-power zero-drift instrumentation amplifier

Texas Instruments

Amplifier Considerations...

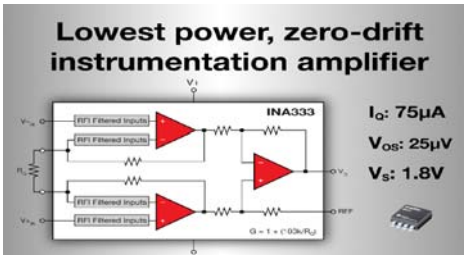
Higher Accuracy Signal Conditioning or Driving an ADC for or Faster Signal Rate

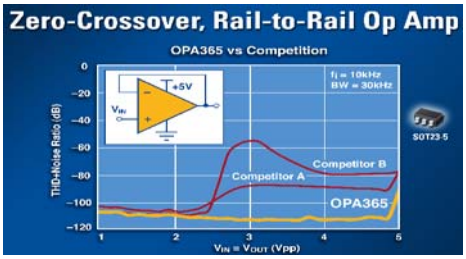
Signal Conditioning Amplifiers

- Instrumentation or Operational Amp?
  - Single Ended or Differential?
- DC Level Specs:
  - Offset Voltage
  - Offset Drift
  - PSRR, CMRR

Choosing a Drive Amp

- Single Supply?
  - Input Common Mode Range for max input signal
- Adequate GBW for
  - RC Filter/Time to Settle
  - Sampling frequency on SAR
  - Sampling cap and series resistance on the input
- Power Requirements
  - Lower power = longer SAR settling time for same resolution





MSP430 Ultra-Low Power MCUs

Choosing an External ADC... Higher Resolution or Faster Signal Rate

Delta Sigma Architectures

- Achieve highest resolution (18-24 bits)
- Best for low input signal frequencies (<50ksps)
- Typically directly samples from the signal source; higher levels of functional integration available
  - PGAs, Comparators, Temp Sensing

SAR Architecture

- Achieve 12-16 bit resolutions
- Highest Data Rate (>100ksps)
- Typically input filter and drive amp needed

- ADS1115
- Will send graphics!

To Learn More About Texas Instruments Low Power Data Converter
Visit http://dataconverter.ti.com`

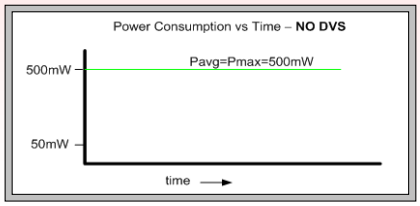
Texas Instruments

MSP430 Ultra-Low Power MCUs

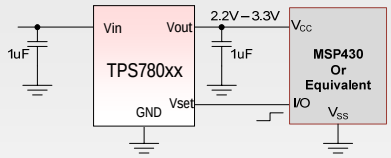
Lowering System Power

Problem

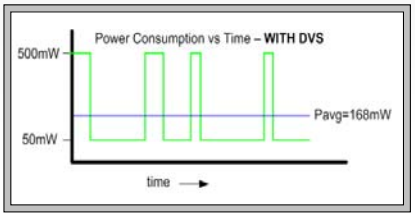
My MCU is only operating a portion of the time, is there a way to lower the overall power consumption of my system?



Solution



Using a LDO with a programmable output voltage yields lower power consumption when your MCU is in an idle state



Texas Instruments

- New LDO's from TI allow the output voltage to be changed between two pre-defined voltages with a logic change to the Vset pin

- Lowering the output voltage/Vcc of the MCU can decrease power consumption when the MCU goes into a low power state

MSP430 Ultra-Low Power MCUs

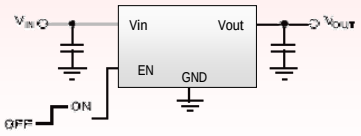
Increasing Power Efficiency

Problem

I want higher efficiency than LDOs, but DCDC's are more complicated, right?

Linear Regulator Efficiency = Vout/Vin
- If Vin = 5V, Vout = 3.3V → Eff = 66%

TPS7xxxx
LDO

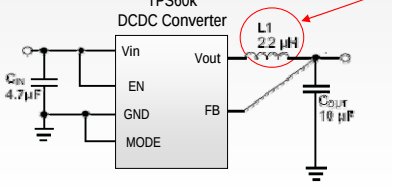


Solution

DCDC Converters with Integrated FETs have low external component count and dramatically reduces complexity with much better efficiency

Switching Regulator Efficiency = 85-95% typ
- varies slightly with Vout & output current
- one additional component vs. LDO solution

TPS60k
DCDC Converter



Translating to Real World Applications:
If LDO eff = 66% & DCDC eff = 90% : DCDC allows your battery to last ~36% longer

Texas Instruments

-These two examples show fixed output voltage versions… adjustable versions will require a resistor divider to set the output voltage.

-Integrated FETs make design much easier & smaller by eliminating the need to choose suitable FETs for your application

-Only one additional component is required for the DCDC converter versus the LDO

-If efficiency/battery life is a key concern, customers should consider using a DCDC Converter as battery life can be extended > 30% versus a LDO.

Questions & Power Resources

Questions

- Basics (Input & Output Voltage, Output Current)
- Care-abouts (Battery Life, Size, Ease of Design)

Power Resources

- Processor Power website (www.ti.com/processorpower)
  - Power specs, Reference Designs, Useful Links
- Power Quick Search (power.ti.com)
- Analog eLAB (http://www.ti.com/home_d_analogelab)
  - Simulation, Design, Education, Quick Search links