WHITE PAPER

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TEXAS INSTRUMENTS

Ultra-Low Power Comparison: MSP430 vs. Microchip XLP Tech Brief

A Case for Ultra-Low Power Microcontroller Performance

Introduction

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 highly agile instant-on clock architecture, the modern 16-bit orthogonal CPU, to the smart integrated peripherals, to our easy-to-use tool chain.

The MSP430's power consumption is unmatched in the industry.

All MSP430 internal peripherals are carefully designed to be intelligent and with features that reduce CPU load. For example the internal ADC converters offer an automatic channel scanning feature and a direct transfer controller or DMA for off-loading basic data movement tasks from the CPU. This enables higher system performance and reduces power consumed. The transparency of the MSP430 architecture is first experienced with it's revolutionary 16-bit orthogonal CPU that has more effective processing, is smaller-sized, and more code-efficient than other 8-/16-bit microcontrollers. In addition to a common instruction set there is a strict memory-mapped peripheral library for easy migration.

The MSP430 is a true family concept offering consistent performance. For example, in the MSP430F2xx family of general-purpose devices, both the simplest 14-pin MSP430F2001 device with only 1kB Flash and the most complex 80-pin MSP430F2619 with 128kB Flash offer ultra-low power performance figures that are extremely close for these very different devices. This enables an engineer to select just the right device for their application from a wide and scalable portfolio of compatible devices.

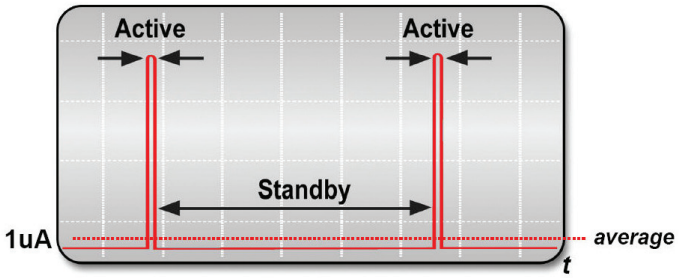
MSP430 development is in-system and subject to the exact same characteristics of the final application. Today's applications operating at lower voltages, with tighter packaging and higher-precision analog, benefit greatly from the MSP430 MCU's in-system emulation

MSP430: World's Lowest-Power MCU

- **Ultra-low power by design**
  - 100nA storage mode, <500nA standby, <1µA RTC mode
  - 0–16MIPS <1µs, agile instant-on clock system
  - Intelligent peripherals reduce CPU load, improve performance
- **A modern transparent family architecture**
  - Compatibility top-to-bottom
  - Consistent performance throughout
  - True embedded emulation
- **Mixed signal processor**
  - 10-, 12-, 16-bit ADC
  - 12-bit DAC, op-amps, comparator
  - Enabling higher performance, low total cost systems

approach. The MSP430 MCU's dedicated embedded emulation logic resides on the actual device itself and is accessed via JTAG or Spy-Bi-Wire 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 stepping in an application. The MSP430 offers a variety of high-performance mixed-signal peripherals that enable high-performance system solutions, at a lower total cost using few external components. Designing with an MSP430 in many cases allows a single-chip solution for a specific application. For example the MSP430FW42x is designed specifically to implement a single-chip water/flow meter. The MSP430FG4xx integrated peripheral set, including ADC, op-amps, and DACs, is ideal for portable medical devices or glucose meters. The MSP430F2xx MCUs on the other hand are designed for more general-purpose ultra-low power applications with the same system-on-chip capabilities.

Ultra-Low Power Activity Profile



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

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 in an ultra-low power standby mode for as long as possible, and is awakened 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 current in the 1µA 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 is 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 fully active is less than 6 µs. 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 at all using only the internal DCO.

Application Report AN1267A?

- 1.8V?
- No BOR?
- RAM?
- Deep Sleep wakeup?
- Crystal included?
- Clock source included?
- Add together what?
- Most ULP systems are 3V battery powered

	PIC24F16KA102	TI MSP430F21X1/ MSP430F21X2/ MSP430F22X2/4
Deep Sleep (nA)	20	—
Sleep (nA)	25	100
WDT (nA)	420	300-700
32 kHz Oscillator/RTCC (nA)	520	700
I/O Port Leakage (nA)	±50	±50(2)
1 MHz Run (µA)	195	200-270
Minimum VDD	1.8	1.8

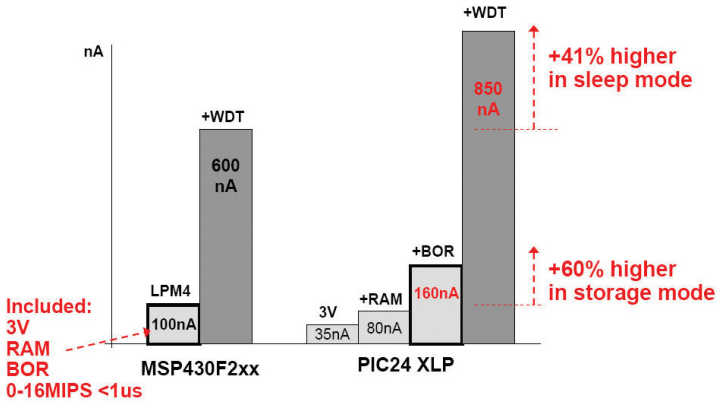
Microchip's application report and video compares the PIC24F XLP specifically to the MSP430. The fundamental claim is that the PIC24F XLP is lower power compared to the MSP430F2xx – this is also demonstrated in a video using a special Microchip measurement board. What is misleading and causes error are the unrealistic use-case conditions. For example, testing at 1.8V is unusual with few real-world sources – perhaps two discharged alkaline batteries? Most ultra-low power systems are powered directly from a 3V lithium coin-cell battery for low cost and a long run time because of its very low leakage. Another common battery solution is two fully charged alkaline batteries at 3.3V. The benchmark needs to be shifted closer to a real-world 3V supply. In the report and in the video, modes of operation are shown that disable BOR protection and remove power to RAM – these techniques will reduce power but are both a dangerous and an inconvenient practice. The importance of brown out is clear for any application in which batteries could be replaced or power could be disrupted for any reason. In the example where RAM is de-powered and the content lost, this lost data would likely be stored temporarily into on-chip Flash. With the PIC24F XLP, this would be a Flash program operation that needs 10mA for 2ms for each 96-Byte block – this adds significant power consumption that is never mentioned.

It is important also to note that all XLP modes of operation require summing various adders together to get the total current for any mode – this is confusing and can be misleading. For example, the mentioned 195µA for PIC24F XLP "1MHz run" is just for the CPU with an external square wave clock source. Because of a /2 divider to the CPU, the CPU clock is running at only 500kHz at 1.8V and does not include the internal clock

generator. At a real 1MIPS CPU clock, with internal clock generation at a realistic 3V operation, the PIC24F XLP's total active 1MIPS power consumption is calculated at well over 1mA. This is 2–3× more than any MSP430F2xx under the same conditions.

The PIC24F XLP 32kHz oscillator specification does not include the power required for the must-have crystal and load capacitors – this adds on the order of 200nA. All MSP430F2xx ultra-low power figures include an always-on BOR for safety and fully powered RAM. MSP430 active mode includes the entire device and active on-chip DCO clock system. LPM3 includes the crystal and load capacitors in the device datasheet specification as is needed in the real world.

Storage versus Sleep Mode



The XLP 20nA "deep sleep" mode is enabled under the restrictive conditions of no BOR, no RAM and at 1.8V. This is more like a literal off mode. The only exit from deep sleep is an external pin interrupt that actually resets the entire device – this is not a useful mode in most microcontroller applications. Moving to a more typical 3V node increases power and restoring RAM and BOR protection increases PIC24 XLP power to 160nA – this is 60% higher than the MSP430F20xx in LPM4 which is an equivalent storage mode. By definition, without the ability of self wakeup, this mode is considered storage and not a sleep mode. Sleep requires the ability to self-wake.

Adding a self-wakeup feature using an internal watchdog timer and oscillator to enable a real sleep mode, the PIC24F XLP power increases to over 800nA – this is 41% higher compared to the MSP430F2xx in LPM3_VLO an equivalent sleep (also called standby) mode.

PIC24F XLP figures used in this analysis are adjusted to 3V by taking the 3.3V datasheet value * 0.8. MSP430 figures are at 3V directly from the device datasheet.

The low power scorecard on the following page summarizes the low-power modes of the PIC24F XLP, MSP430F20xx and MSP430F26xx devices. Both the device datasheet figures for all devices and actual bench measurements are shown.

Low Power Scorecard

	PIC24F16KA102		MSP430F2001		MSP430F2619	
	Datasheet	Bench	Datasheet	Bench	Datasheet	Bench
Standby WDT	0.8uA	*0.7uA*	0.6uA	*0.4uA*	0.6uA	*0.5uA*
Standby 32kHz	0.9uA	*0.8uA*	0.9uA	*0.5uA*	1.1uA	*0.7uA*
Startup 1MIPS	?	*3us*	<1us	*0.4us*	<1us	*0.4us*
Startup 16MIPS	1000us	*1000us*	<1us	*0.4us*	<1us	*0.4us*
Active 1MIPS	1110uA	*1110uA*	300uA	*300uA*	515uA	*515uA*

Notes:

1. PIC24F = Datasheet 3.3V * 0.8, MSP430 = datasheet 3.0V
2. PIC24F Standby WDT = 0.870 (D31E) + 0.095 (D70E) +0.105 (D60E)
3. PIC24F Standby 32kHz = 0.730 (D62E) + 0.095 (D70E) +0.105 (D60E) + 0.2 crystal and load caps
4. PIC24F Active = estimated using ratios of (DC22E+27E+42/44E) + 0.095 (D70E)
5. RAM and BOR active, all GPIO pins configured as output, no load
6. Bench measurements for all devices made at 25C, 3.0V CR2032 powered

For the lowest overall power, the system stays in standby as the normal mode and as long as possible. Transition to active is by interrupt as quickly as possible and stays in active mode for as short a period as possible. In general, overall power can approach that of standby by keeping the active period as short and low as possible. To achieve this, the lowest possible standby, fastest wakeup to active, and the lowest active power are all important and required.

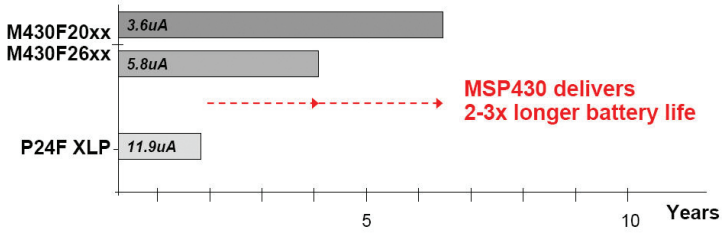
From the scorecard, the MSP430F2xx family is significantly lower power compared to the PIC24F XLP in both the device datasheets and as measured on the bench. From the scorecard, the MSP430 excels in all modes of operation.

The MSP430 is a true family concept offering consistent performance. For example, in the MSP430F2xx family of general-purpose devices, both the simplest 14-pin MSP430F2001 device with only 1kB Flash and the most complex 80-pin MSP430F2619 with 128kB Flash are used for comparison. The low-power figures for these very different devices are extremely close. This enables an engineer to select just the right device for the application from a wide portfolio of compatible devices. All MSP430s are ultra-low power by design. XLP technology is both higher power compared to MSP430 and applied on only a few of Microchip's devices – moving from XLP to other PIC devices within the PIC24F family for example, increases typical power by more than double.

The PIC24F XLP 3V values are the datasheet 3.3V values adjusted to 3V by using an 0.8 multiplier. The MSP430 datasheet values are directly from the device datasheet.

This example on the following page shows a typical ULP application where the system is in standby mode 99% and active 1%. This translates to 14.4 minutes of active time / day – this is similar to what would be experienced in a battery-powered portable consumer medical device or measurement system. Standby mode power is very important but in this example active power has an even bigger impact at over 80% of the total power. Managing active power is a top priority in this example.

Battery Life 1% Active



- *Portable measurement system example*
- *Active power is >80% of the total*
- *Average = Standby + Active*0.01*
- *Used peripherals will impact total Icc*

Also, any used internal and external peripheral power needs to be added to the total power consumption and this will negatively impact the total power used and reduce battery life accordingly. The impact depends on the complete application. All MSP430 internal peripherals are carefully designed to be intelligent and provide features that reduce CPU load and power consumption. For example the internal ADC converters offer an automatic channel scanning feature and a direct transfer controller or DMA offload these tasks from the CPU. This enables a higher performance system and reduces power.

Figures assume a 3V CR2032 with 200mAh usable capacity at 25°C. Total average current is the sum of standby using watchdog with internal oscillator × 0.99 and active power consumption at 1MIPS × 0.01.

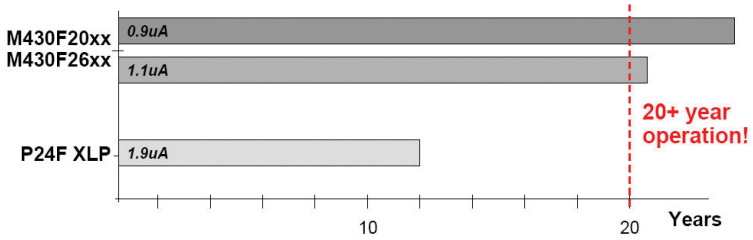
Datasheet specifications are used.

M430F20xx = 0.6µA × 0.99 + 300µA × 0.01, 200mAh/0.0036mA/24/365 = 6.34 years

M430F26xx = 0.6µA × 0.99 + 515µA × 0.01, 200mAh/0.0058mA/24/365 = 4.0 years

P24F XLP = 0.8µA × 0.99+1110µA × 0.01, 200mAh/0.0119mA/24/365 = 1.9 years

Battery Life 0.1% Active



- *Wireless sensor network example*
- *Standby & Active power are equally important*
- *Average = Standby + Active*0.001*
- *Used peripherals will impact total Icc*

This example shows a typical ULP application where the system is in standby mode 99.9% and active 0.1%. This translates to 1.4 minutes of active time / day which is 4k active cycles every 4 seconds, at 1MHz CPU clock. This scenario is similar to what would be experienced in a wireless sensor network for example. Standby mode power consumption is very important but so is active mode power.

In this example, active power ~30 – 60% of the total power depending on the device used. Also, any used internal and external peripheral power needs to be added to the total power consumption and this will negatively impact the total power used and reduce battery life accordingly. The impact depends completely on the application. All MSP430 internal peripherals are carefully designed to be intelligent and provide features that reduce CPU load. For example the internal ADC converters for an automatic channel scanning feature and a direct transfer controller or DMA offload these task from the CPU. This enables higher performance system and reduces power.

After 20 years of operation the self leakage of the battery has a significant impact as well as the overall reliability of the system.

Figures assume 3V CR2032 with 200mAh usable capacity at 25°C. Total average current is the sum of standby using watchdog with internal oscillator × 0.999 and active power consumption at 1MIPS × 0.001

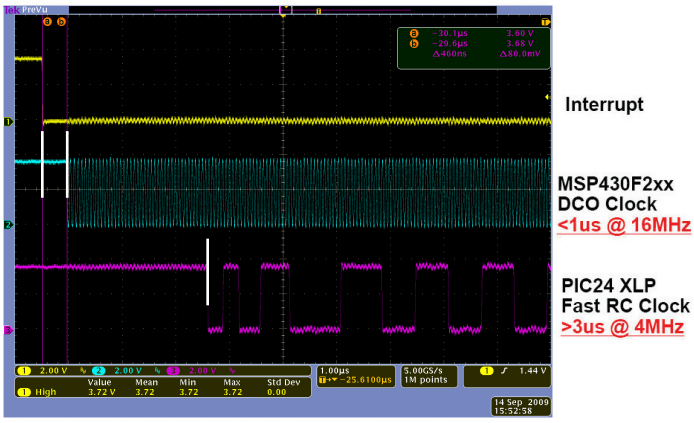
Datasheet specifications are used.

M430F20xx = (0.6µA × 0.999)+(300µA × 0.001), 200mAh/0.009/24/365 = 25 years

M430F26xx = (0.6µA × 0.999)+(515µA × 0.001), 200mAh/0.011/24/365 = 21 years

P24F XLP = (0.8µA × 0.999)+(1110µA × 0.001), 200mAh/0.019/24/365 = 12 years

MSP430 / PIC24 XLP Clock Start



The screen capture shows an interrupt signal on channel 1 (top), the startup of the MSP430F2xx DCO on channel 2 (middle) and PIC24F16KA102 internal fast RC oscillator startup on channel 3 (bottom).

Both the MSP430 and PIC24F are programmed on interrupt to run 10k CPU cycles in a loop then return to a standby state.

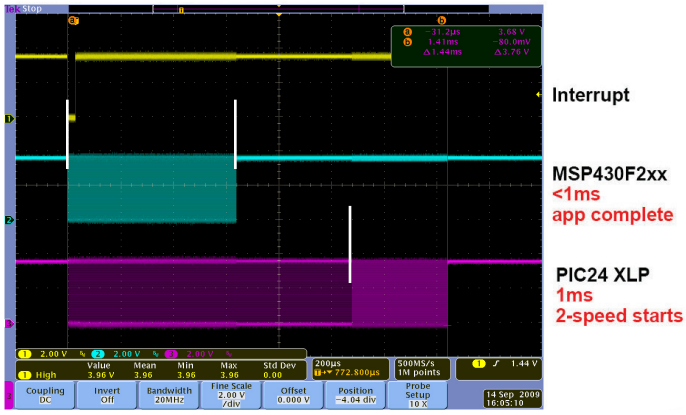
In this example it can be seen that from an interrupt event the MSP430F2xx DCO is active and stable at 16MHz in well under 1us as specified in the device datasheet. In fact, in this example the measured DCO startup time is actually 406ns.

The PIC24F XLP fast RC shown on channel 3 starts slower in the 3µs range and is also limited initially to 4MHz. For higher-speeds, a 1ms delay is required for an internal PLL to lock. This is called a 2-speed start-up.

With the MSP430, clock startup is “instant-on”. It is important that the high-speed DCO not only starts instantly, but also stabilizes instantly. Both instant-on and instant stability are important for features like asynchronous serial communication. A common benefit of an instant-on and stable oscillator is response to serial communication; a high-speed UART for example. As long as the oscillator – as the clock source for the UART – starts instantly and is stable, no characters are lost. If a slow or 2-speed oscillator is used, at a minimum, the first character in the received data stream is lost and will need to be resent. This wastes time and power.

With the MSP430 DCO, no delay or 2-speed clock startup occurs. The user’s application has instant access to the high-speed DCO from any operating mode. Instant-on capability saves power as the system does not have to waste energy waiting for start up. Interrupt activities are serviced immediately.

10k Instructions DCO … 2-Speed



The screen capture shows an interrupt input on channel 1 (top), the startup of the MSP430F2xx DCO on channel 2 (middle) and PIC24F16KA102 internal fast RC oscillator startup on channel 3 (bottom) over an extended time scale.

Both the MSP430 and PIC24F are programmed on interrupt to run 10k CPU cycles in a loop then return to a standby state.

This example uses 16MHz for both the MSP430F2xx and PIC24F XLP CPU clock. It can been seen that the MSP430F2xx starts instantly at 16MHz and completes the 10k cycle burst in 625µs = 10,000/16,000,000.

The PIC24F XLP oscillator is initially limited to 4MHz as can be seen, then after 1ms, when the PLL locks, the clock moves to 16MHz. This means the PIC24F XLP takes much longer to finish the task.

In this 10k burst example the PIC24F takes 1.44ms to complete the task – this is more than 2× as long as the MSP430F2xx. Additionally the instant-on MSP430 DCO can be used to clock other internal and external peripherals.

With the MSP430 DCO the device starts faster and at a higher speed, if required by the given application, to finish the task fast and shut down sooner. The instant-on MSP430F2xx DCO is much more flexible, improves performance and reduces system power consumption.

MSP430 Summary

- **World's lowest-power MCU family by design**
  - 100nA storage mode, <500nA standby, <1µA RTC mode
  - 0–16MIPS <1µs, agile instant-on clock system
  - Intelligent peripherals reduce CPU load, improve performance

  - *MSP430F2xx is lower power compared to the PIC24F XLP in all modes of operation, by the datasheet and on the bench*
  - *At a measured 700nA in a true 3V standby mode with self-wakeup, PIC24F XLP is 75% higher power compared to MSP430F20xx at 400nA*
  - *When evaluating ULP MCUs be cautious of incredibly low marketing numbers such as "20nA deep sleep". These are often under unrealistic conditions such as 1.8V, no BOR, no RAM retention and no self wakeup – this is not a very useful state for a 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 a true standby mode under 500nA, the highly agile instant-on clock architecture that enables high-performance 16-bit MIPS on-demand, to the smart integrated peripherals, to our easy-to-use tool chain.

The MSP430F2xx general-purpose family of devices is lower power than the PIC24F XLP in all modes of operation, compared per the device datasheets and proven on the bench.

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