The Truth about Power Consumption in PIC® MCUs with XLP Technology vs. TI's MSP430

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INTRODUCTION

This white paper will clarify the facts behind Texas Instrument's arguments that presented TI's MSP430 as a better low power device than Microchip's XLP technology.

In a white paper published online, Texas Instruments compared Microchip's PIC24F with extremely low power nanoWatt XLP technology with their own MSP430 with Ultra Low Power.

TI's white paper makes reference to eight individual parameters, important in extremely low power applications, where they argue that its own technology outperforms Microchip's XLP technology.

This white paper discusses each of TI's eight claims, identifies the flaws in TI's arguments and presents the facts.

CLAIM 1: ALL MSP430 MCUs ARE CONSISTENTLY LOW POWER

The facts here do not support the argument. There are several MSP430 MCUs, such as the MSP430F2252, that consume 100 nA while in Sleep. There are also devices such as the MSP430F553X family that consume 1700% more current in sleep at 1690 nA. These numbers are an order of magnitude different from each other, and are therefore not consistent.

Table 1 illustrates the extreme differences within the MSP430 line.

TABLE 1: DIFFERENCE BETWEEN THE DEVICES

TI Device (3V Data)	Flash Memory & Pins	LPM5 - Off (nA)	LPM4 - Storage (nA)	LPM3 + WDT (nA)	LPM3 + RTC (Simple Timer)	Run Mode 8 MHz with DCO (mA)
MSP430F2001	2 KB 14 pins	—	100	500	900	2.0
MSP430F2252	8-32 KB 40 pins	—	100	600	900	2.8
MSP430F2619	92-120 KB 64-80 pins	—	200	600	1100	4.3
MSP430F553X	192-256 KB 80-100 pins	100	1690	1800	2600	1.1

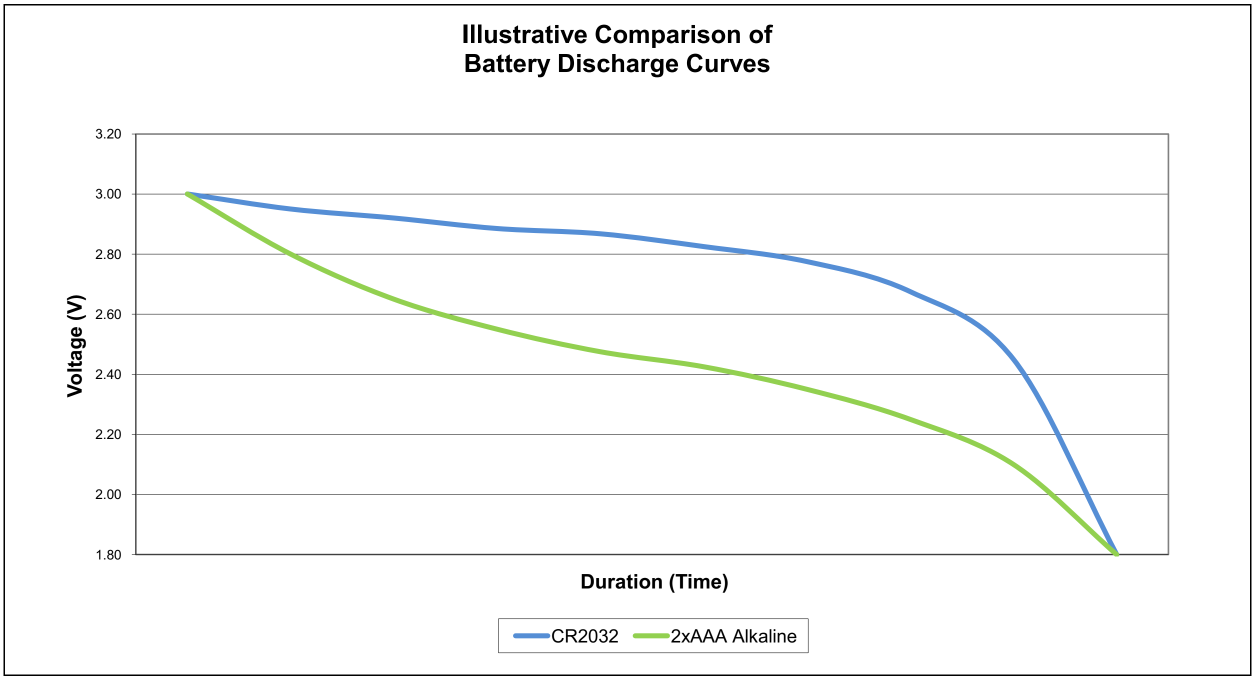
CLAIM 2: OPERATION FROM A 1.8V POWER SOURCE IS NOT RELEVANT IN EXTREMELY LOW POWER APPLICATIONS

This is an erroneous claim since it simply dismisses a serious design consideration: the operation of the MCU as the supply voltage is reduced due to battery voltage degradation.

For the majority of the embedded electronics industry, the trend towards extremely low power technology is based on the use of batteries as the prime power source. Extremely low power technology, therefore, is synonymous with battery power and, in today's applications, this typically translates to single or dual cell supplies comprising of either a coin cell battery such as the CR2032, or a pair of Alkaline AA/AAA batteries. In both cases, the usable voltage range falls below 3.0V. In the case of a 1.5V alkaline-based battery, the voltage remains usable down to 0.9V, or 1.8V for a system using two batteries. For the popular CR2032, its usable voltage range drops to 2.5V before the voltage begins to reduce significantly, as shown in Figure 1.

TI claims that the MSP430 is designed specifically for battery powered applications. Their choice to not acknowledge that those applications must realistically continue to operate once the battery level has dropped below nominal, infers that the applications the MSP430 are best suited to are not battery powered applications.

FIGURE 1: BATTERY DISCHARGE CURVES



CLAIM 3: MSP IS THE WORLD'S LOWEST POWER MICROCONTROLLER

TI's white paper claims that the MSP430 demonstrates lower power consumption in all modes of operation. However, TI can only support this claim by asserting that the Deep Sleep mode of the PIC24F with XLP technology is both 'dangerous' and 'inconvenient', and thereby discounts it.

In truth, the MSP430s do not include a Deep Sleep mode, and it isn't possible to remove power to the RAM and recover (see Claim 5: Deep Sleep Mode is Dangerous). RAM leakage is a major drain on the battery during extended periods of inactivity; because of this, TI attempts to discredit Deep Sleep by stating it is dangerous or inconvenient. Neither view is defensible. In real-world scenarios, where an application is expected to operate reliably for many years on a single battery, there can be no such operating mode as 'inconvenient'.

Furthermore, the TI white paper claims that Deep Sleep mode is more like an 'off' mode because it can only be instantiated by turning off most other active elements of the PIC24F. However, as Table 2 illustrates, Deep Sleep mode can be instantiated with almost any combination of Brown-out Reset (BOR), Watchdog Timer (WDT) and Real Time Clock/Calendar (RTCC) active, while still achieving lower current consumption than the MSP430 in any of its power saving modes.

Promoting any device as the world's lowest power microcontroller must always carry exclusions, but excluding a competitor's most efficient power saving mode simply because your device cannot support it seems disingenuous.

CLAIM 4: ALL SLEEP MODES ARE THE SAME

The exclusion of Deep Sleep mode is present throughout TI's white paper, presumably because the MSP430 isn't able to offer a comparative extreme energy saving mode. In our opinion, not supporting a feature doesn't make it acceptable to ignore it, yet TI repeatedly refuses to acknowledge the PIC24F with XLP technology's most advantageous features.

Instead, TI chooses to obscure the differences between the PIC24F's Sleep mode and Deep Sleep mode, preferring to label Deep Sleep mode as a 'storage mode' and refusing to recognize its flexibility.

This is most obviously demonstrated in the comparison of the MSP430's LPM4 (Low Power Mode 4) – described by TI as an 'equivalent storage mode' – with power consumption figures obtained for the PIC24F in Sleep mode. Ironically, the PIC® microcontroller's performance in Sleep mode is almost equivalent to the MSP430 in 'storage mode', and if the PIC24F's Deep Sleep mode figures are used – as they should have been by TI – the results are even more favorable for Microchip.

The end result is that the PIC24F demonstrates lower power in Deep Sleep mode than any mode the MSP430 can offer, without sacrificing BOR, WDT or RTCC.

TABLE 2: CURRENT CONSUMPTION FOR DIFFERENT SLEEP MODES

MCU Family (3V Data)	Flash Memory and Pins	Lowest Sleep Current	Lowest Sleep with BOR	Lowest Sleep with WDT	Lowest Sleep with RTCC
MSP430F2001	2 KB 14 Pins	100	100	500	900
MSP430F2252	8-32 KB 40 Pins	100	100	600	900
PIC24F16KA102	4-16 KB 14-28 Pins	28	36	476	676

CLAIM 5: DEEP SLEEP MODE IS DANGEROUS

Deep Sleep mode is characterized in TI's white paper as 'dangerous', and asserts that it is a storage mode because a sleep mode requires the ability to wake up, which is something that, according to the engineers at Texas Instruments, the PIC24F's Deep Sleep mode does not offer.

This is simply wrong. The PIC24F has six methods of waking from Deep Sleep. In fact, it has two dedicated, autonomous, wake-up options:

- Deep Sleep WDT
- Real-Time Clock/Calendar.

An external interrupt or a Master Reset, POR, or BOR can also be used as wake-up options.

It is possible that TI is equating the PIC24F's Deep Sleep mode to the MSP430's LPM5; which, by its own admission, is a virtual off mode. When entering LPM5, power is removed from the processor's core, removing all data from the registers, SRAM, and, most significantly, the I/O pin state. Exiting from LPM5 is only possible from an external event and causes a system-wide reset. It is clear that using such restrictive measures like LPM5 to conserve power must be used wisely and only in situations where a total system reset is possible from external sources; otherwise, it might be considered dangerous.

CLAIM 6: MSP430 WINS BATTERY-LIFE CASE STUDIES

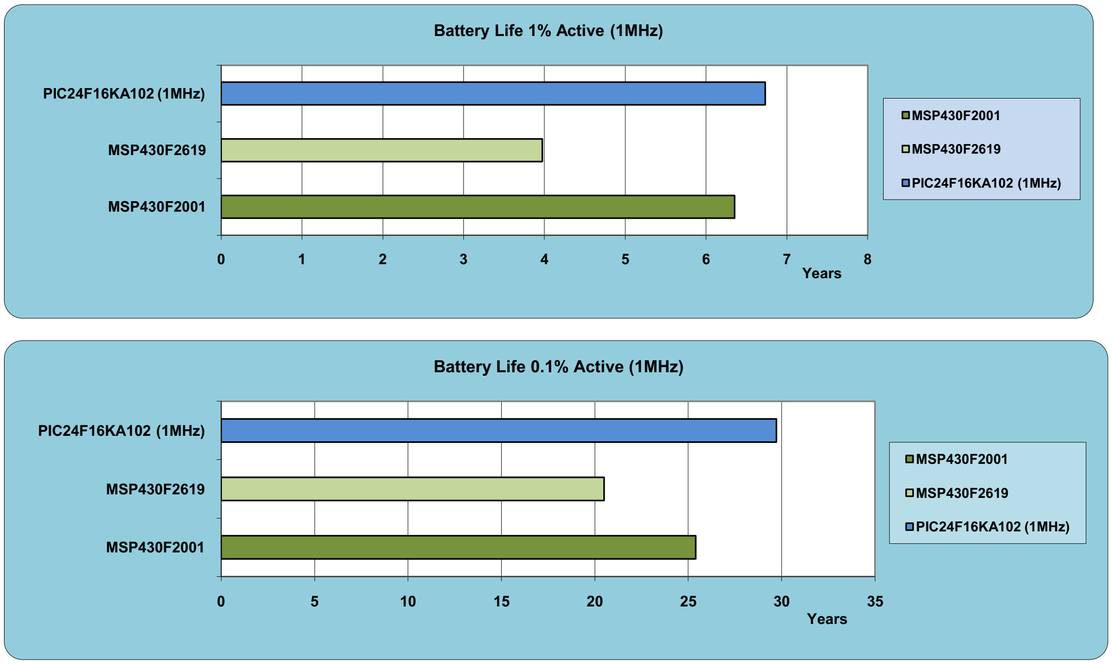
In this claim, a use case is presented to illustrate run time from a battery. For the examples cited in the white paper, TI uses 'typical' data sheet figures for its own device, but maximum (data sheet) figures for the PIC microcontroller. There is no explanation given in the paper as to why this was done, or why it would be a proper comparison.

The examples given in TI's white paper cover two scenarios: an application with a 1% duty cycle, and an application with a 0.1% duty cycle. In each example, TI uses absolute maximum data sheet figures when calculating battery lifetime for the PIC24F, but typical data sheet figures when calculating the battery lifetime for the MSP430.

In addition to the mis-use of specification data, the comparison is made without using the PIC MCU's lowest power mode, Deep Sleep. Clearly for a use-case to be described as typical, it must use 'typical' figures throughout the comparison. Furthermore, it should include all possible features of the microcontroller.

When Microchip's engineers reconstructed this experiment using TI's own data for its part, but the correct data for the PIC24F – including the use of Deep Sleep Mode – the results were significantly different (refer to Figure 2). First, for the application example with a 1% duty cycle, instead of achieving a lifetime of less than 2 years, the PIC24F remains operable for 6.7 years, which is 4 months longer than the best figures returned by the MSP430 parts. Second, for the application example with a duty cycle of 0.1%, the PIC24F achieves almost 30 years of operational time, which is nearly 5 years longer than the best reported MSP430 figure. It should be noted that a 30 year lifetime is theoretical as it would be much longer than the shelf life of typical CR2032 coin cells.

FIGURE 2: BATTERY LIFE IN MICROCONTROLLER APPLICATIONS

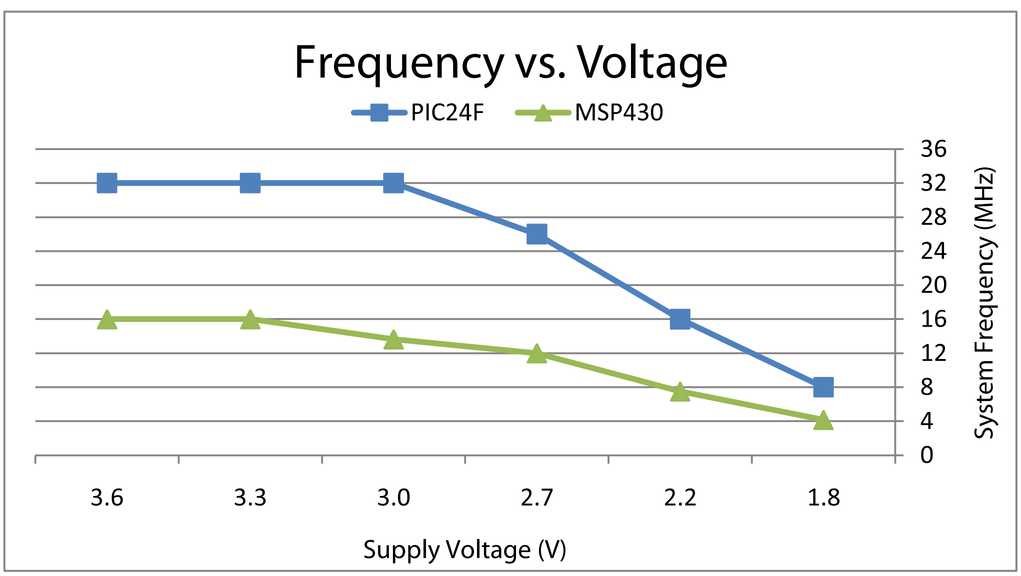


CLAIM 7: MSP430 HAS FASTER WAKE-UP TIMES

This claim is valid, insomuch as the MSP430's digitally controlled oscillator can start up and reach a stable 16 MHz clock signal in 1 µS, while the PIC24F's RC oscillator circuit takes around 2 µS longer to start-up.

However, the MPS430 is only capable of running at 16 MHz with a supply voltage in excess of 3.0V; below this voltage, the part is inhibited from running at 16 MHz (refer to Figure 3). The claim, therefore, is largely academic in battery powered applications, where the nominal voltage would start at 3.0V and degrade from there. Incidentally, the PIC24F is capable of running at 32 MHz at 3.0V.

FIGURE 3: MICROCONTROLLER OPERATION FREQUENCY VS VOLTAGE



CLAIM 8: MSP430 IS 2X FASTER IN EXECUTION

The last claim to refute is related to Claim 7, which proposes that waking faster and executing code quicker results in less energy consumed. Calculating the energy usage shows a different conclusion. The majority of the MSP430's instructions require two or more cycles, while around 90% of the PIC24F's instructions are single cycle. This means that for a given operation, the PIC24F architecture requires fewer instruction cycles than the MSP430. Fewer instruction cycles mean less bus activity and fewer gate transitions, the main cause of active power consumption in a CMOS device.

The example in Table 3 lists the results of a simple but often executed task: copying a 32 byte array from one part of memory to another. It can be seen that, indeed, the MSP430 starts executing code 1 µS after initialization, but it continues to execute code long after the PIC24F has completed the task, expending significantly more energy – almost three times as much – to achieve the same result. This is due to the PIC microcontroller's instruction set offering more single cycle instructions and being more efficient in their application.

TABLE 3: METRIC COMPARISONS

Metric	PIC24F16KA102	MSP430F2619
Clock Startup	3 µS	1 µS
Instruction Cycles	40	316
Execution Time (@ 4 MHz)	32 µS @ 2 MIPS	80 µS @ 4 MIPS
I_{DD}	1.6 mA	1.5 mA
Energy Consumption I_{DD}* Execution Time @ 3V	158 µJ	363 µJ

CONCLUSION

The conclusion put forward by TI in its white paper is that the MSP430 is the world's lowest power microcontroller family, a claim that has proven to be false in the examples analyzed in this paper.

The reality is that the PIC24F has been designed for extremely low power operation in power-constrained applications.

All of the evidence points to the PIC24F family being far superior in every way, from features to function. Not only is it able to make the best use of all the available power from a battery source, it does so in the most flexible and efficient way.

When designing a power-constrained application, the design team doesn't want to compound that challenge by being constrained by the features of the microcontroller. It needs a solution that is simply better at extremely low power operation, whatever the application. The PIC24F family meets that need and does it without imposing restrictions on the power supply, sleep modes or code efficiency.

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