MSP430 Ultra-Low-Power Microcontrollers

Third Quarter 2000
MSP430 Microcontrollers—The Solution for Battery-Powered Measurement

The increasing demand to integrate features and processing capabilities into battery powered products has created a need for microcontrollers that are both powerful and highly integrated, while only requiring minute amounts of energy to operate. Using its leadership in both mixed-signal and digital technologies, Texas Instruments (TI) has met this challenge. The result is the MSP430 line of ultra-low-power microcontrollers, which enables system designers to simultaneously interface to analog signals, sensors, and digital components while maintaining unmatched ultra-low-power performance.

The MSP430 achieves its high performance through a revolutionary architecture that integrates a powerful 16-bit RISC CPU for fast execution of code and a design that makes extensive use of standby modes to minimize current consumption when the CPU is not active. The MSP430 architecture includes an array of powerful and highly flexible peripherals that are also optimized for ultra-low-power operation.

A key to the MSP430 performance is its unique ultra-low-power modes. The MSP430 is able to switch from ultra-low-power standby mode, where it only draws 0.8 µA of current, to full active mode in a maximum of 6 µs. This ultra-fast start up allows the MSP430 to stay in standby mode longer, eliminating the unnecessary current other microcontrollers use in ramping to active mode. In addition, while in active mode, the MSP430 only requires 250 µA in a typical 3 V system. The time the MSP430 stays in active mode is minimized by its powerful 16-bit CPU, which ensures high speed and efficient code execution.

All MSP430's peripherals are able to run independently of the CPU. This allows them to remain active even while in ultra-low-power standby mode. For example, an external 32 kHz crystal can increment a counter for a real-time clock function, while the part is drawing just 0.8 µA. The MSP430 can also maintain an LCD display and await external key switch interrupts while in standby mode. This allows the user interface to be fully active while simultaneously maximizing the battery life. The MSP430 is even capable of accepting external interrupts while it is in RAM retention/off mode. While in off mode, the MSP430 requires a mere 0.1 µA of current.

When battery life, processing power and hardware flexibility are major design concerns, TI's MSP430 offers an unbeatable combination of features. For applications such as, security systems, utility metering, portable medical devices and handheld instrumentation, the MSP430 line of ultra-low-power microcontrollers offer solutions that enable product ideas to become reality.

MSP430 16-Bit RISC CPU

The MSP430's powerful 16-bit RISC core offers many advantages over competing 4- and 8-bit microcontrollers. The MSP430 CPU features the ease of use of a RISC instruction set and the flexibility of numerous 16-bit CPU registers. These and other features result in a revolutionary architecture that is highly orthogonal by design.

The MSP430 has a RISC instruction set that consists of a mere 27 core instructions, and to facilitate more intuitive programming, 24 additional emulated instructions are included to further simplify the code generation process. For example, a common instruction such as enable interrupts (EINT) is included in the instruction set. The assembler automatically substitutes the emulated instruction with the correct RISC instruction (BIS #8, SR). This combination of RISC and emulated instructions minimizes code space while also simplifying programming.
All instructions can be used with all seven addressing modes across the entire MSP430 architecture. There are no special instructions or modes required to work with RAM, peripherals, the CPU, registers or any other part of the MSP430. This feature greatly increases the efficiency of the 16-bit RISC instruction set and forms the basis for the orthogonal design of the MSP430.

There are 16 registers in the CPU core of the MSP430. Four of the registers have the dedicated functions of Program Counter (PC), Status Register (SR), Stack Pointer (SP) and Constant Generator (CG). The remaining 12, 16-bit registers, are completely user definable. These general-purpose registers in the CPU allow often-used variables, pointers and other data to be directly accessed by the CPU without performing memory fetches. The number and flexibility of the CPU registers further contributes to the high code efficiency of the MSP430.

**Simplified MSP430 CPU**

<table>
<thead>
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<th>Register</th>
<th>Function</th>
<th>Addressing Modes</th>
<th>Data Types</th>
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<tbody>
<tr>
<td>R0/PC</td>
<td>Program Counter</td>
<td></td>
<td></td>
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<tr>
<td>R1/SP</td>
<td>Stack Pointer</td>
<td></td>
<td></td>
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<tr>
<td>R2/SR</td>
<td>Status Reg</td>
<td></td>
<td></td>
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<tr>
<td>R3/CG</td>
<td>Constant Generator</td>
<td></td>
<td></td>
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<tr>
<td>R4</td>
<td></td>
<td></td>
<td></td>
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<td>R5</td>
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<td>R6</td>
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<td>R13</td>
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<td>R14</td>
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<tr>
<td>R15</td>
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</tr>
</tbody>
</table>

**MSP430 Orthogonal Architecture**

**Non-Orthogonal Architecture**
MSP430 Low-Power Modes (LPM)

Active Mode
CPU Active
Various Modules Active
250 µA

Lower Power Mode 0
CPU Off
System Clocks On
30 µA

Lower Power Mode 3
Ultra-Low-Power / Real-Time Clock Mode
CPU Off / ACLK On
0.8 µA

Lower Power Mode 4
Memory Storage Mode
CPU & Clocks Off
0.1 µA

MSP430 Clock Modules
The clock modules of the MSP430 are fully programmable and offer system designers an array of clocking options. The Digital Controller Oscillator (DCO) can be programmed to supply a system frequency of 1 to 8 MHz. Typically the MSP430 only needs a single external 32 kHz crystal to generate an accurate high-speed system frequency. Additional advantages of the 32 kHz crystal include low cost, direct division to real-time using a single counter and the elimination of high-frequency PCB layout. The 32 kHz signal is available both internally and externally when low frequency is a requirement. The MSP430 parts that include the Frequency Locked Loop (FLL) circuit, automatically regulate the system frequency to a multiple of the crystal.

The DCO in all MSP430 products starts operation in a maximum of 6 µs when an interrupt or reset occurs. This allows the processor to stay in a low-power mode much longer and greatly reduces the time required to bring the part to an active state, saving battery power.

The MSP430 has a failsafe feature that allows the processor to start operation using the DCO even if the crystal fails. So even if the crystal fails or is missing, the processor will still begin executing code. This feature makes it possible to design MSP430 circuits that do not include a crystal.

MSP430 Product Roadmap
## MSP430 Selection Guide

<table>
<thead>
<tr>
<th>Device</th>
<th>OTP</th>
<th>Flash</th>
<th>ROM</th>
<th>RAM</th>
<th>Peripherals</th>
<th>Pins/Package</th>
</tr>
</thead>
<tbody>
<tr>
<td>MSP430P112*</td>
<td>4KB</td>
<td>2KB</td>
<td>128</td>
<td>256</td>
<td>15-bit Watchdog/Timer</td>
<td>20 SOP</td>
</tr>
<tr>
<td>MSP430C111</td>
<td>2KB</td>
<td></td>
<td>128</td>
<td>256</td>
<td>16-bit Timer_A, 3 CC registers</td>
<td>20 SOP</td>
</tr>
<tr>
<td>MSP430C112</td>
<td>4KB</td>
<td></td>
<td>128</td>
<td>256</td>
<td>I/O Ports P1 &amp; P2</td>
<td>20 SOP</td>
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<tr>
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<td>2KB</td>
<td>128</td>
<td>256</td>
<td>15-bit Watchdog/Timer</td>
<td>20 SOP, TSSOP</td>
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<td>MSP430F1121</td>
<td>4KB</td>
<td>2KB</td>
<td>128</td>
<td>256</td>
<td>16-bit Timer_A, 3 CC registers</td>
<td>20 SOP, TSSOP</td>
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<tr>
<td>MSP430C1111</td>
<td>2KB</td>
<td></td>
<td>128</td>
<td>256</td>
<td>Analog Comparator_A, references</td>
<td>20 SOP, TSSOP</td>
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<tr>
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<td>128</td>
<td>256</td>
<td>I/O Ports P1 &amp; P2</td>
<td>20 SOP, TSSOP</td>
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<tr>
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<td>256</td>
<td>16-bit Watchdog/Timer</td>
<td>64 QFP</td>
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<tr>
<td>MSP430F135</td>
<td>16KB</td>
<td>512</td>
<td>16-bit Timer_A, 3 CC registers</td>
<td>64 QFP</td>
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<tr>
<td>MSP430F147</td>
<td>32KB</td>
<td>1 KB</td>
<td>15-bit Watchdog/Timer</td>
<td>64 QFP</td>
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<tr>
<td>MSP430F148</td>
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<td>2 KB</td>
<td>16-bit Timer_A, 3 CC registers</td>
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<tr>
<td>MSP430F149</td>
<td>60KB</td>
<td>2 KB</td>
<td>16-bit Timer_B, 7 CC/shadow registers</td>
<td>64 QFP</td>
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<tr>
<td>MSP430P315*</td>
<td>16KB</td>
<td>512</td>
<td>15-bit Watchdog/Timer</td>
<td>56 SSOP</td>
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<tr>
<td>MSP430P315S*</td>
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<td>512</td>
<td>8-/16-bit Timer_Port</td>
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<tr>
<td>MSP430C311S</td>
<td>2KB</td>
<td>128</td>
<td>64 or 92-segment LCD driver</td>
<td>48 SSOP</td>
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<tr>
<td>MSP430C312</td>
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<td>256</td>
<td>Low-Power UART HW</td>
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<td>MSP430C313</td>
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<td>I/O Port P0</td>
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<td>MSP430C314</td>
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<tr>
<td>MSP430C315</td>
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<td>56 SSOP</td>
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<tr>
<td>MSP430P325A*</td>
<td>16KB</td>
<td>512</td>
<td>15-bit Watchdog/Timer</td>
<td>64 QFP, PLCC</td>
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<tr>
<td>MSP430C323</td>
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<td>256</td>
<td>8-/16-bit Timer_Port</td>
<td>64 QFP, PLCC</td>
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<tr>
<td>MSP430C325</td>
<td>16KB</td>
<td>512</td>
<td>84-segment LCD driver</td>
<td>64 QFP, PLCC</td>
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<td></td>
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<tr>
<td>MSP430P337A*</td>
<td>32KB</td>
<td>1 KB</td>
<td>15-bit Watchdog/Timer</td>
<td>100 QFP</td>
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<tr>
<td>MSP430C336</td>
<td>24KB</td>
<td>1 KB</td>
<td>8-/16-bit Timer Port</td>
<td>100 QFP</td>
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<tr>
<td>MSP430C337</td>
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<td>1 KB</td>
<td>120-segment LCD driver</td>
<td>100 QFP</td>
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</tr>
</tbody>
</table>

* UV-EPROM (E) versions available for prototyping - PM S430E112, PM S430E315, PM S430E325A and PM S430E337A
MSP430x11x(1) Application Examples

The MSP430x11x(1) series has expanded the reach of low-cost system design. A real-time clock (RTC) or battery monitor/charger, with as much as 10 years of battery life, are just two applications where a MSP430 device minimizes system cost while dramatically simplifying design and reducing development time.

These applications operate primarily in low-power mode 3 (LPM3), with the device interrupt timing coming from an external 32 kHz crystal oscillator. The 11x(1) device periodically wakes up to update the time or to measure and adjust the charging conditions. The pulse-width modulation (PWM) for the charger is automatically generated even while the device is in LPM3. The extensive use of low-power modes allows system design engineers to design applications that only require an average current of 1.52 µA.
The new MSP430F13x family expands the number of applications that can take advantage of the MSP430’s ultra-low-power performance. The family adds new modules and features to enable more applications to become true system-on-a-chip designs. The 12-channel, 12-bit high-speed ADC incorporates buffer memory, autoscans, internal voltage references, a temperature sensor and battery monitor. The Timer_B module includes three capture/compare registers with shadow capability. These work with the integrated 8-, 10-, 12- or 16-bit Timer_B counter, which can operate independently of the CPU. The 13x family also retains the powerful Timer_A in addition to Timer_B. The Basic Clock module has been expanded to allow a high-speed crystal to be used in addition to, or substituted for, the standard 32 kHz crystal. The dedicated hardware USART module with UART/SPI capability is also included. Flash memory options have been extended to 16K bytes in the 13x family.

**MSP430F13x Application Example**

The new Timer_B with shadow capability allows three PWM signals to be changed simultaneously, making the 13x devices ideal for many motor control applications. The high-speed ADC allows up to eight channels to monitor sensors for closed-loop control.

The hardware USART module allows straightforward interfacing via UART or Serial Peripheral Interface (SPI) to a host or other system components.
MSP430F14x Configuration

The new MSP430F14x family further expands on the capabilities of the 13x family and is currently the high-end solution of the non-LCD devices. Additional capabilities of the 14x family include: four capture/compare/shadow registers added to Timer_B for a total of seven, a second hardware USART module, with UART/SPI capabilities, the single-cycle, 16-bit hardware multiplier module is included, Flash memory options of up to 60K bytes and static RAM memory of up to 2K bytes are available.

MSP430F14x Application Example

The large selection of peripherals on the 14x devices make it well suited for many high-end control and monitoring applications. The second hardware USART module allows for simultaneous communications with a host and other system components, as shown in the example. The high frequency crystal option on the Basic Clock enables the 14x to generate stable clock signals for applications such as RF communications. The high-frequency crystal can be turned off to save power when not in use. The MSP430 is still able to operate from its fast-start, high-frequency, internal DCO.

The large number of high-speed ADC, analog comparator and I/O pins allow a wide array of sensors, switches and other signals to be interfaced directly to the 14x.
**MSP430x31x Configuration**

The MSP430x31x family is the most cost-optimized version with a LCD driver in the MSP430 product line.

It can be used for sensor applications by measuring resistive values. The Timer/Port module can perform this resistive-to-digital conversion by measuring the charge/discharge time of an external capacitor. Where this function is not required, the module can be used as a 16-bit timer or as two 8-bit timers.

The Watchdog/Timer module can be configured as a 15-bit watchdog or as a 15-bit general-purpose timer. The Basic Timer includes two 8-bit timers for general-purpose use. It generates the basic LCD frequency and supports the real-time clock function.

**Digital Thermometer-Thermostat**

The LCD driver module can drive up to 92 segments in 1-to-4 MUX mode. Each pin of the I/O port can be individually configured and each has interrupt capability. The 8-bit Timer/Counter supports serial communication protocols like UART or I2C bus on the I/O port. The necessary software routines for this and many other modules are listed in the MSP430 Application Report book.

**MSP430x31x Application Example**

The MSP430 requires very few external components to form a complete system. The low component count of the digital thermometer shown here ensures fast design cycle, maximum flexibility and very competitive system cost. For resistive sensors, such as thermistors, the 16-bit single-slope A/D converter, implemented using the Timer/Port module is ideal. Three additional external components, a crystal (optional), the battery and the LCD display, are all that are needed for a complete system with the MSP430.
MSP430x32x Configuration

The MSP430x32x series offers a high-resolution A/D converter in addition to the peripherals of the MSP430x31x configuration. This 14-bit A/D converter has six inputs to convert analog signals to 14-bit digital values over the full supply voltage range or to provide 12-bit resolution in each of four separate ranges. The integrated current source can be programmed with an external resistor to connect current-driven sensors.

MSP430x32x Application Example

One of many application areas where the MSP430 proves very effective is single-phase electricity meters. The cost-competitive single-chip solution shown here uses the 14-bit on-chip A/D converter to convert the current (via a current transformer on A0) and voltage (via a voltage divider on A1) into digital values. The symmetrical supply voltage enables signed measurement, while the LMx85 creates a reference voltage. The amount of energy consumed is calculated by the CPU and the value displayed on the LCD or transmitted via the optional UART connection. Nonvolatile data storage is possible with an optional external EEPROM. A detailed application note is available for this as well as many other applications.

Single-Phase Electricity Meter

The single-phase electricity meter uses the 14-bit on-chip A/D converter to convert the current and voltage into digital values. The symmetrical supply voltage enables signed measurement, while the LMx85 creates a reference voltage. The amount of energy consumed is calculated by the CPU and the value displayed on the LCD or transmitted via the optional UART connection. Nonvolatile data storage is possible with an optional external EEPROM. A detailed application note is available for this as well as many other applications.
MSP430x33x Configuration

The MSP430x33x series focuses on high-end applications. It includes several additional, powerful modules.

The hardware (HW) multiplier module performs 16x16, 16x8, 8x16 and 8x8 multiplication and accumulations (signed, unsigned). After loading both operands into the multiplier, the result is available after a single cycle.

The Timer_A module includes a 16-bit timer/counter and five capture/compare registers, which can be fully configured by software. The capture mode is primarily used to measure external or internal events from any combination of positive and/or negative edges. The compare mode is primarily used to generate timing for software or application hardware or to generate PWM output signals for various purposes. Examples are D/A conversion functions and motor control applications. Timer_A can run independently of the CPU, allowing it to still be active in LPM3.

The USART module features two serial communication modes, a standard asynchronous communication protocol (UART, up to 115.2 kBaud) and a SPI function. The mode is selectable by software via a control register. The 33x series’ LCD module offers 30 segment lines to drive up to 120 segments in 4MUX mode.

MSP430x33x Application Example

The array of modules and number of I/Os on the MSP430x33x make it well suited for high-end applications that require demanding user and hardware interfaces. The example circuit shown here can maintain the LCD display and await keypad interrupts while operating in LPM3. When interrupted, the circuit switches to active mode, with the high-speed MCLK running, in less than 6 µs. While in LPM3 the circuit is fully operational from a user’s perspective, but the MSP430 is drawing less than 2 µA of current.
Kickstart User Interface

MSP430 Design Support
Kickstart Environment
Kickstart is a fully integrated Windows-based development environment. It is derived from the popular IAR Workbench user interface. This one interface allows the user to develop code, simulate operation, download software and debug applications for all MSP430 derivatives. Kickstart allows the setting of breakpoints and the monitoring of special function registers, memory, the stack, as well as other useful information.

Kickstart includes the IAR assembler, a software simulator, a limited version of the IAR C compiler and the C-SPY debugger. Upgrading to the full version of IAR C is simple and does not require the user to learn a new interface. MSP430 devices with Flash, OTP or UV-EPROM memory can be programmed directly from Kickstart using either a Flash Evaluation Tool (FET) or the serial programming adapter.

MSP430 Flash Evaluation Tools
MSP-FET430x110, MSP-FET430P140
The new Flash evaluation tools, combined with the IAR Kickstart environment, enable system designers to quickly update, download, run and debug their code without ever disconnecting the MSP430 from the PC. This greatly speeds the development and debug portions of the application development cycle.
The FET tools allow designers the flexibility of operating the device under JTAG control, running to internal breakpoints or free-running the MSP430. Each FET comes with an evaluation board, two Flash devices, PC parallel connection, development software and the MSP430 CD-ROM. The MSP-FET430x110 is a complete low-cost application development for MSP430F11x1 products.

The MSP-FET430P140 supports application development for both the MSP430F13x and MSP430F14x product families. It includes a parallel interface that also allows direct in-circuit programming of MSP430 Flash devices.

**MSP430 Evaluation Kits**

**MSP-EVK430S320 and MSP-EVK430S330**

The MSP430 evaluation kits (EVK) are powerful development tools that include much of the hardware and software required to complete your application development. Each EVK comes with an evaluation board, two UV-EPROM devices, serial programming adapter, development software and CD-ROM. The MSP-EVK430S320 EVK supports the MSP430x32x and MSP430x31x families of devices. The MSP-EVK430S330 EVK supports the MSP430x33x and MSP430x31x families of devices.

**MSP430 Serial Programming Adapter**

**MSP-PRGS430**

The serial programming adapter is a second-generation programming tool that can program any MSP430 Flash, OTP or UV-EPROM device. Devices can be programmed in stand-alone sockets or in-circuit. Software is included to facilitate device programming.

<table>
<thead>
<tr>
<th>MSP430 Development Tools*</th>
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<tbody>
<tr>
<td><strong>Development Environment</strong></td>
</tr>
<tr>
<td>M SP430P112**</td>
</tr>
<tr>
<td>M SP430F11x1</td>
</tr>
<tr>
<td>M SP430F13x</td>
</tr>
<tr>
<td>M SP430F14x</td>
</tr>
<tr>
<td>M SP430P315**</td>
</tr>
<tr>
<td>M SP430P325A**</td>
</tr>
<tr>
<td>M SP430P337A**</td>
</tr>
</tbody>
</table>

*Third party tools are sold and supported by the third party companies offering them  **UV-EPROM (E) versions available for prototyping - PMS430E112, PMS430E315, PMS430E325A AND PMS430E337A
MSP430 Third-Party Support

TI maintains a dedicated MSP430 third-party program for hardware and software tooling as well as for programming support. These third-party developers have the engineering expertise to provide application-specific software tools, helping our customers achieve their design goals. Links from TI’s MSP430 web site will direct you to each company’s home page: www.ti.com/sc/msp430

BP Microsystems Inc.
BP Microsystems Inc. designs and manufactures device programmers for both engineering and production applications. Leading the industry in device support, performance and cost of ownership, BP provides complete device programming solutions to customers worldwide. The company offers a full line of single-site device programmers and Universal Programmers, and multi-site Concurrent Programming Systems.

The MSP430 can be programmed using any of BP’s universal engineering programmers (BP-1200 and BP-1400), BP’s manual or multi-site Concurrent Programming Systems. For more information, visit the BP web site: www.bpmicro.com

Data I/O Corporation
Universal Programming System - Sprint

Data I/O has invested heavily in the steadily growing market of microcontroller devices by considerably expanding its device library. The universal programming systems of the Sprint family not only standout from most other programming systems through the variety of supported devices, but also by guaranteeing its customers the use of vendor approved algorithms with maximal programming yields and minimal programming times. Data I/O supports TI’s MSP430 devices with the universal programmers Sprint Multisystem as well as with the automatic programming systems PP100. With the latest version of the Sprint software, the following devices are supported: MSP430x31x, MSP430x32x, MSP430x33x and MSP430x11x(1). All these controllers are supported with flexible TOPs or adapters for different packages like PLCC, SSOP or QFP. Special software functions of the devices, such as UserID, Watchdog Timer or Code Protection can be activated via a simple menu. For more information, visit the Data I/O web site: www.dataio.com

Hitex Emulator in an Affordable Quality Concept

With the DProbe430, Hitex offers a modular emulation system which is specifically designed to develop, test and optimize MSP430 applications. Starting with the entry-level system DProbe430, up to the high-end system DBox16, real-time debugging at the highest frequencies and with all the power saving modes is now possible without restrictions. Changing from one derivative to another can be done by an easy and low-cost exchange of the derivative specific part. This also allows an upgrade to future derivatives. For reliable adaptation to the target hardware, adapters for all available microcontroller packages are supported.

With the convenient and easy to learn HiTOP user interface, all the processor internals and application structures are made transparent. Symbolic high-level language debugging, as well as examination down to assembler code, can be done to speed up the development and ensure quality in the application. The high-end features of the DBox16 allow the user to find and eliminate even the most complex bugs. With the features coverage and performance analysis you can optimize your MSP430 product and its competitiveness in today’s difficult markets. For more information visit the Hitex web site at: www.hitex.com

C-Cross-Compiler and C/ASM-Debugger

IAR is a leading provider of C compilers and development tools for programming embedded applications. IAR provides the Kickstart environment that is now the standard interface for MSP430 development.

The EW430 is a fully integrated development environment that includes the full C compiler, linker, librarian and assembler in a seamless interface with easy-to-use project and option handling. The CW430 is an HLL debugger incorporating a complete C expression analyzer and full C-type knowledge. It combines detailed control of code execution required for embedded development debugging with the flexibility and power of the C language. The source window can display C source code and mix it with assembler code.
The CW430 simulator allows an unlimited number of breakpoints on C statements, assembler instructions and on any address with a read, write or opcode fetch access type. An interrupt simulation implements commands to launch specific interrupts, either periodically or at a specified cycle-count. For interrupt simulation with intermittent interrupts, the same algorithm as in the target hardware will be selected for choosing the highest priority interrupt. For more information, please visit the IAR web site: www.iar.com

**Documentation**

TI provides extensive documentation support for the MSP430, including user’s guides, applications books, data sheets and brochures.
- MSP430x3xx Family User’s Guide (SLAU012)
- MSP430x1xx Family User’s Guide (SLAU049)
- MSP430 Application Report book (SLAA024)
- MSP430 CD-ROM (SLAC001B)

The MSP430 Application Report book (SLAA024) includes many hardware and software examples using the MSP430 for low-power metering and high-precision applications. This report contains examples of developing code and circuitry for most of the hardware modules found on the MSP430. It will assist the system designer in developing code for ADC, UART, I²C bus, battery check, digital motor control, as well as arithmetic routines, table processing and much more.

**For More Information**

For pricing and availability, contact your local TI field sales office or authorized TI distributor. For datasheets and the latest information about TI’s ultra-low-power mixed-signal processors, visit: www.ti.com/sc/msp430

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**Notes**
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TI Distributors
www.ti.com/sc/docs/general/distrib.htm

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