

MSP430™ FRAM microcontrollers with CapTivate™ technology

*The most noise immune capacitive touch MCUs and
first to offer an IEC 61000-4-6 certified solution*



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Introduction

As a technology leader, TI's role is to understand the challenges its customers will face and develop products that will provide solutions that make it easier for them to implement innovative technologies. For example, we've heard from many of our customers who are developing industrial equipment that they need to design simple interfaces that can tolerate harsh operating environments subject to noise, dirt and liquids which can interfere with the reliable operation of mechanical buttons (Figure 1).

We recommend capacitive touch technology to those customers because it offers an exciting and cost-effective alternative to mechanical buttons across industrial and commercial applications. For example, mechanical push buttons on a coffee pot have seams in which liquid and coffee grounds can seep into the enclosure, potentially causing damage. With a touch-based user interface (UI), an appliance can be protected by a seamless metal or plastic enclosure.

	Industrial Design	Cold Temp/ Environment Noise	Sealed/Durability	Reliability	Haptic Feedback
Kitchen	++	+	++	○	+
Home automation	+	○	+	○	+
Industrial	○	++	++	+	+
Consumer electronics	++	○	○	○	++
Medical	○	++	++	○	+
Automotive	++	+	○	+	++
Wearables	○	+	+	○	++

Figure 1. Developers of industrial equipment need to be able to design simple and reliable interfaces to tolerate harsh operating environments.

Capacitive touch enables a better user experience, as well as a wide range of differentiating features, including:

- **Buttons, wheels, and sliders:** Engineers are no longer restricted by the limitations of mechanical buttons. Wheels and sliders enable the design of more efficient and intuitive UIs.
- **Reliability:** Touch-based UIs are not susceptible to breaking like mechanical buttons. They also offer increased protection from environmental factors.
- **Proximity sensing and gestures:** Identify when users are within range of a system enables a whole new level of power management and efficiency. Furthermore gestures allows user to interact more intuitively.
- **Manufacturing:** Simplified design and reduced component count reduces manufacturing complexity and cost.
- **Aesthetics:** Capacitive touch-based UIs have a more sleek appearance that is attractive to users and can be hidden until lit. Devices are also easier to keep clean.

MSP430™ FRAM MCUs with capacitive touch technology

To help its customers take full advantage of the benefits of touch-based UIs, TI has created the new ultra-low-power MSP430FR25x/26x family of MCUs

with CapTIvate™ technology (Figure 2). The MCU has been designed to enable simplicity in small and large home appliances, personal electronics, factory and building automation systems.

With their efficient architecture, MSP430FR25x/26x MCUs are the industry's lowest power capacitive touch technology, making this family ideal for implementing interfaces in devices such as battery-operated electronic locks, portable electronics and appliances with ENERGY STAR® requirements. The technology offers features that provide a robust and reliable performance in noisy and harsh environments as well as the ability to tolerate moisture. The high sensitivity of CapTIvate technology allows the use of thick overlays to protect equipment and can be used with metal panels to implement metal-on-touch capacitive buttons. The technology has also been designed

with ease-of-use in mind, so engineers do not need to become capacitive-sensing experts to take advantage of touch-based UIs.

As previously mentioned, the first devices to use TI's CapTIvate technology are the MSP430FR25x/26x family of FRAM-based MCUs. By integrating capacitive touch as a self-contained analog front end with a full-featured FRAM MCU, TI enables developers to build true single-chip systems (see Figure 3 on the following page). The MSP430 MCU architecture provides sufficient processing capacity to support operations such as driving LCD, LEDs, haptic feedback or any other system management tasks without requiring a second MCU. This has the added benefit of speeding design and lowering overall system cost.

TI's CapTIvate technology is extremely sensitive; it has the ability to measure changes in capacitance

as small as 10 Femto Farad (fF) and sense a wide dynamic range of capacitance, up to 300 Pico Farad (pF), allowing systems to provide:

- Reliable operation with thicker overlays, up to 60-mm glass
- Greater proximity sensing range, up to 30 cm
- Enhanced resolution, up to 10-bit usable resolution for sliders and wheels
- Reduce false detects in presence of large parasitic capacitance loading
- Smaller form factor through the ability to use smaller electrodes

MSP430FR25x/26x MCUs with CapTIvate technology can also scan four electrodes in parallel in

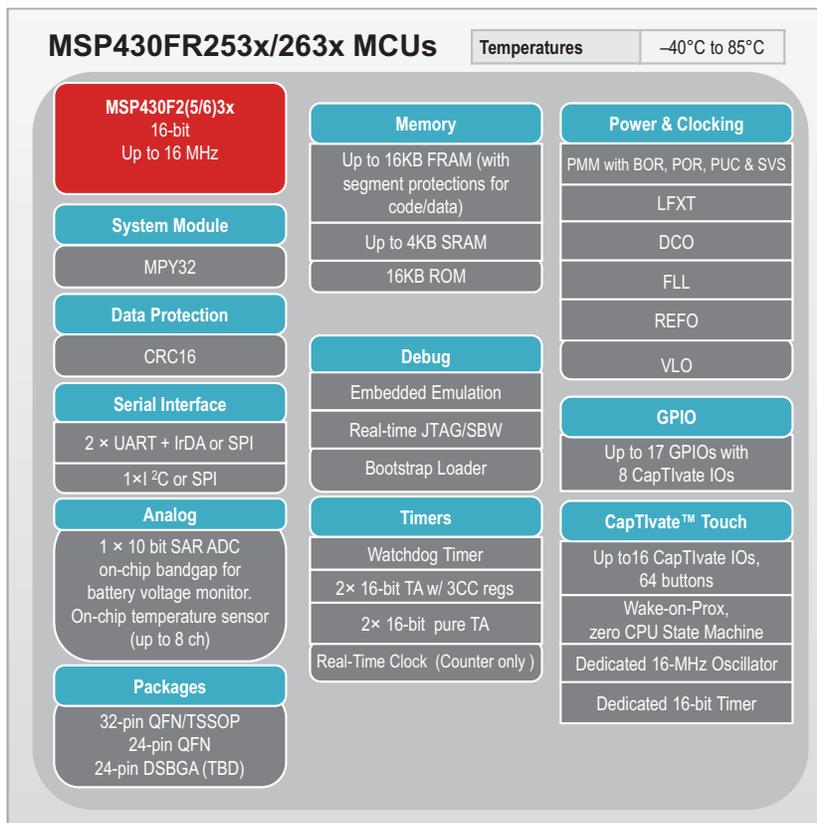


Figure 2: TI's first devices to utilize CapTIvate technology are the MSP430FR25x/26x family of FRAM-based MCUs.

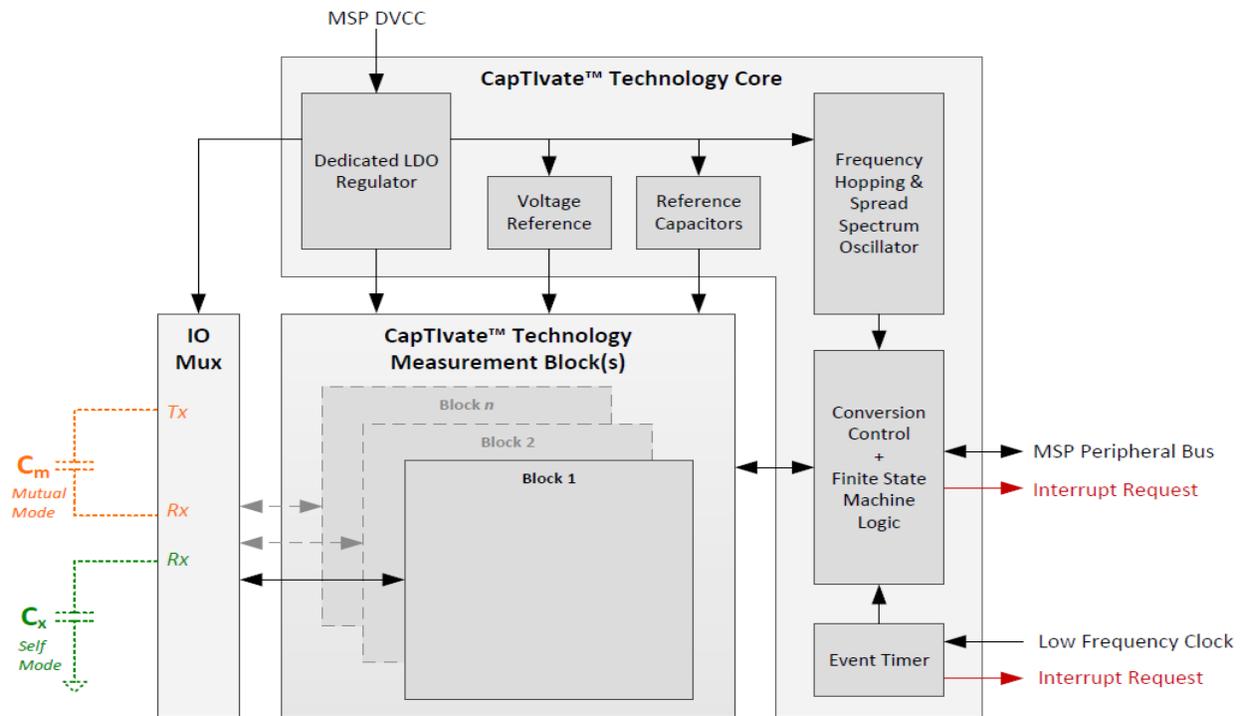


Figure 3: By integrating TI's CapTivate™ technology as a self-contained peripheral with a full-featured MCU, TI enables developers to build true single-chip systems that can accurately detect touches even when the CPU is asleep.

500 μ sec. This allows for improved common-mode noise rejection and lower power consumption. Furthermore, with fast scans and high sensitivity, MSP430 FRAM MCUs with CapTivate technology can enable 3-D gesturing applications.

Reducing the effects of noise

Noise is a primary challenge facing designers of capacitive touch-based systems because noise can come from internal or external sources. It can trigger false detects that can be dangerous—imagine an induction cooker turning itself on inadvertently due to powerline noise. MSP430FR25x/26x MCUs have incorporated several features in-silicon to meet the rigorous requirements of applications that must operate in noisy environments and meet electromagnetic compatibility (EMC) standards,

including IEC61000-4-4 for electrical fast transients (EFT), IEC61000-4-6 for common-mode noise (CMN) and IEC61000-4-2 for electrostatic discharge (ESD).

The high performance of CapTivate technology is important for achieving better noise immunity. Greater sensitivity translates to the ability to have small electrodes or sensors. The CapTivate technology analog front end is also able to maintain good performance even when the system requires long traces in the PCB. CapTivate technology minimizes the effects of noise using various hardware-based control mechanisms:

- **Integrator-based charge transfer:** The method of operation enables CapTivate technology to make robust capacitive measurements.
- **Oscillator:** The oscillator allows oversampling and frequency hopping functionality independent of the MCU's DCO (digitally

controlled oscillator), thus increasing reliability in noisy environments.

- **Zero-crossing synchronization input pin:** The pin allows touch detection to take place during AC power supply zero crossing events. The result is higher conducted noise performance.
- **Spread spectrum clocking:** This clocking method lowers electromagnetic radiation emissions that can interfere with system circuitry.
- **1.5 V voltage regulator:** Ability to drive sensors at 1.5 Volts reduces emissions compared to driving them at higher voltages.

CapTIvate technology further improves reliability through software-based signal processing. Among the signal processing algorithms in use are multi-frequency, oversampling, dynamic threshold adjustment, AC noise filtering and debounce. Together, this combination of high performance with hardware and software features provides high noise immunity designed to help developers achieve compliance with EMC standards. For example, the CapTIvate technology EMC reference design offers conducted noise immunity up to $10 V_{\text{rms}}$ and ESD and EFT up to 4 KV peak voltage. A full test report from a third-party laboratory can be found at <http://www.ti.com/lit/pdf/slay045>.

The industry's lowest power capacitive touch MCU

Appliance and industrial designers face increasing pressure to minimize power consumption in their next-generation designs. MSP430FR25x/26x MCUs have been designed to provide the lowest power in the industry for capacitive touch button, slider,

wheel interfaces and proximity sensing. TI has developed several innovative technologies to make this possible.

Typically, capacitive-sensing controllers on the market today require the CPU to wake and check electrodes. The high power consumption of the CPU, combined with how long the CPU takes to wake, substantially impacts the power required to scan electrodes. This raises power consumption to more than 20 μA per sensor for current-generation touch controllers.

In contrast, MSP430FR25x/26x MCUs have zero CPU wake on touch. It is implemented as a finite state machine that can actively monitor up to four sensors for touch/proximity while the CPU is asleep. When an event occurs, the finite state machine wakes up the CPU for processing the event. The result is outstanding power efficiency; when scanning four electrodes, power consumption is only 0.9 μA per sensor. This level of productivity helps engineers meet ENERGY STAR compliance requirements and drive years of operating life from a single coin cell battery.

For applications needing more than four electrodes, MSP430FR25x/26x MCU consumes as low as 1.7 μA per button (assuming 16-button self-capacitance or 64-button mutual-capacitance solution at 8-Hz sampling frequency).

Ferroelectric Random Access Memory (FRAM) for greater power efficiency

Industrial applications typically need to store data when the system is powered down or experiences a power failure. TI's FRAM MCU technology combines

the speed of SRAM with the non-volatility of FRAM memory to provide robustness with flexibility and efficiency in a single memory technology.

Comparable to Flash in price, FRAM offers superior write speeds (100 times faster), read access (no wait states at up to 8 MHz), endurance (virtually unlimited at 10^{15} cycles) and energy efficiency (6 times better), making it a universal memory that can be used for both code and data. Developers have the flexibility to partition how much memory is allocated for program code and how much for data storage. This allows developers to make optimal use of memory, even as specification changes arise, without having to change to a new processor with a different memory configuration.

The MSP430FR2633 FRAM MCU allows engineers to quickly create differentiated applications. For example, consider an electronic door lock. With non-volatile FRAM, the lock can log information such as which individuals have used the door, when they used it and whether their code was entered correctly. This value-added functionality can be implemented without adversely impacting battery life or increasing system cost.

Self or mutual capacitance and proximity: No-compromise design

MSP430FR25x/26x MCUs give engineers a high degree of flexibility when designing capacitive touch-based systems as they support both self- and mutual-capacitance sensing and proximity sensing in the same design. This allows developers to select the right sensing method for the task at hand.

In simple terms, self-capacitive is the capacitance between a single sensing electrode and ground, where the user's finger acts as ground. It provides performance for applications that require long-range sensing (proximity), high sensitivity, greater noise immunity or ultra-high resolution sliders and wheels. In contrast, mutual capacitance measures the capacitance between a transmit and receive electrode. As a user's finger approaches and touches the panel, the capacitance measured between each electrode changes. Mutual capacitance is ideal for applications that require a large number of buttons, have sensors that are tightly spaced, or require moisture rejection.

This means developers do not have to compromise the performance of one part of the touch-based UI to accommodate another.

Moisture rejection

To provide a robust experience for users, a touch-based UI must be water tolerant. Water and other liquids have a different dielectric than air and are conductive, creating the potential for a variety of issues engineers must address. This can generate false detects across a number of sensors, especially if the liquid has pooled on the panel.

To enable water rejection, CapTivate technology can use a dedicated guard channel for detecting anomalies such as changing environmental conditions so it can accommodate them. The CapTivate Touch Library provides software to handle guard channel management, making it straightforward for developers to build robust systems for applications where the presence of water is commonplace.

Support for plastic, glass and metal overlays

CapTIvate technology works reliably with plastic and glass overlays. The high sensitivity of CapTIvate technology allows for 60-mm thick glass overlays as well as 25-mm thick plastic overlays, while metal overlays provide another method to create innovative touch solutions. In case of metal overlays, a button press involves an actuation force that bends the metal sheet making a small change in capacitance detected by sensors mounted below the panel. Metal overlays allow for designs that are completely agnostic to dirt and moisture in the environment. As metal touch involves an actuation force, it also registers a gloved touch. Furthermore, CapTIvate technology also differentiates force of touch, allowing for differentiated human-machine interface designs.

Compensating for manufacturing tolerances

During manufacturing, variations in the thickness and size of such materials can negatively impact sensitivity. As a result, the responsiveness of systems can differ from panel to panel. Rather than require manual tuning to compensate for manufacturing variations, CapTIvate technology can be configured to automatically adjust its gain and analog front settings. Developers specify the expected capacitance count to detect a touch and the system adjusts itself to hold to this baseline. Automatic sensitivity adjustment can be enabled in the field as well, allowing systems to continuously

adjust themselves to maintain responsiveness and sensitivity.

Enhancing touch interfaces with haptics

Haptics refers to a mechanism that provides tactile (vibrational) feedback to users when a button is pressed. Employing haptics can enhance user safety by increasing user confidence when operating devices by confirming UI inputs through feedback increases. This results in faster input, fewer errors and improved productivity. For example, an 18 percent reduction in extra/secondary glances at the UI can be achieved by adding haptic feedback^[1].

TI has the largest portfolio of haptics drivers in the semiconductor industry and supports eccentric rotating mass (ERM), solenoid-based, piezoelectric, and linear resonant actuators (LRA). Integrating haptics driver with an MSP430FR25x/26x MCU is easy. When a touch is detected by the capacitive sensors, the MCU sends a haptic code over I²C to the haptic driver. This in turn causes the actuator to move in a specific pattern, creating a vibration.

CapTIvate Design Center: Flexibility and ease of use

In addition to being the lowest power capacitive touch technology, MSP430FR25x/26x MCUs are also the easiest to design with. Developers of all programming skill levels can create capacitive touch solutions with minimal effort; allowing them to focus on designing the application instead of the nitty-gritty details. With CapTIvate Design Center, designers can start tuning their sensors in

five minutes or less. The program is available for Windows®, Apple® OS X® and Linux®. The five-step guide below shows the streamlined design process.

1. Drag and drop sensors into the GUI

- Example: 5 buttons, 3-element slider, 1 proximity sensor

2. Configure each sensor

- Self capacitance or mutual capacitance
- MSP430FR25x/26x MCU device selection
- Tweak auto-generated I/O configuration

3. Real-time tuning

- Display sensor data – Bar chart/Oscilloscope
- Tune performance – Touch threshold, debounce, filter settings
- Optimize for noise immunity, power, sensitivity, range using menus
- Guidelines are available to show engineers how to easily set thresholds and test them.

4. Auto-generate configuration file and fully compile in Code Composer Studio™ IDE or IAR project.

- No projects tweaks are necessary unless application code needs to be added.

5. Compile firmware, Flash firmware and Run.

CapTlvate technology Touch Library

TI provides a comprehensive CapTlvate Touch Library for implementing enhanced features beyond legacy capacitive touch capabilities. The library is imaged in ROM, freeing up memory on the MCU for use by the application.

The library offers access to different application layers, including:

- **Hardware Abstraction Layer (HAL):** IP-specific, “bare metal” access to the CapTlvate peripheral
- **Basic touch layer:** Access to basic proximity and touch detection functionality as well as filtering capabilities
- **Advanced feature layer:** Provides button, slider, and wheel processing
- **Communications layer:** Includes communication protocols
- **Low-level serial drivers:** Basic interface capabilities

These layers simplify implementing functionality and provide developers access to the advanced capabilities needed. The application is notified of sensor updates through a user callback mechanism. Sensor configuration is automated with CapTlvate Design Center and factory sensor tuning and programming can be done at one time.

CapTlvate MCU development kit

To further accelerate evaluation and design, TI offers a range of development boards and kits. As an example, the CapTlvate MCU development kit (MSP-CAPT-FR2633) enables developers to evaluate and design with all the capacitive touch capabilities of the MSP430FR25x/26x touch-based MCUs (Figure 4 on the following page). This bundled kit contains the eZFET programmer/debugger with TI's EnergyTrace™ technology, MSP430FR2633 MCU processor PCB, isolation PCB for battery operation and EMC/EMI testing, and sensor PCBs for demonstrating mutual-, self- and proximity-sensing capabilities. For accelerating haptics development, the kit includes a DRV2605L haptic driver included in the CAPTIVATE-PHONE

Start tuning sensors in 5 minutes or less with CapTIvate™ Design Center

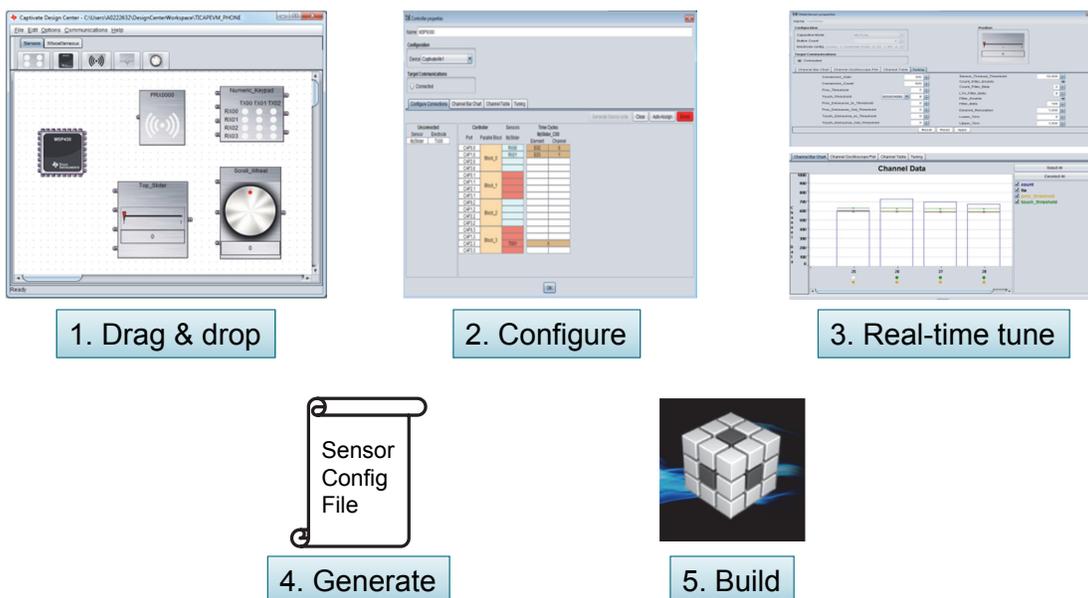


Figure 4: The MSP430FR2633 CapTIvate™ MCU development kit allows user to evaluate self and mutual capacitance, proximity sensing, gestures as well as metal overlays.

electrode panel. TI also offers the DRV2605 Haptics evaluation kit and DRV2667 evaluation board that can be used with external actuators.

CapTIvate-Metal Sensor PCB will be available as an add-on kit to demonstrate metal touch capabilities.

Documentation and reference designs for CapTIvate technology

The **CapTIvate technology guide** is a one-stop shop for all documentation for this new technology. It can also be accessed within the CapTIvate Design Center. The tool contains in-depth information on getting started with CapTIvate technology and advanced design topics for designing sensors, optimizing for low power, moisture and noise immunity. Code examples are also available for designers to quickly evaluate the capabilities of

the MSP430FR25x/26x MCU architecture with CapTIvate technology and speed their time-to-market.

With MSP430FR25x/26x MCUs, engineers have the ability to introduce capacitive touch to a wide range of applications quickly and cost effectively. Not only does capacitive touch address the reliability issues of mechanical buttons, it enables innovative interfaces with differentiating functionality. TI has the lowest power capacitive touch sensing technology available in the industry today and offers developers an ecosystem of tools to help them achieve the performance and reliability required for even the most demanding industrial applications. These tools accelerate design through their flexibility and ease of use, enabling engineers to build robust touch-based systems without having to write software drivers or become capacitive-sensing experts.

Learn more about CapTIvate technology today:

www.ti.com/CapTIvate

Sources:

[1] Pitts, 2011: Page 8 from Mark Toth's "TI Haptic Drivers for HMI"

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