White Paper

Capacitive Sensing Technology, Products, and Applications

ABSTRACT

Texas Instruments offers the industry's lowest power, most automated, and easiest to use capacitive touch microcontrollers for human-machine interface (HMI) and generic capacitive sensing applications. This guide provides an overview of technology, products, applications, and resources which are available now for you to begin solving your capacitive sensing design challenges today.

Table of Contents

Trademarks

CapTIvate™, TI E2E™, and MSP430™ are trademarks of Texas Instruments Incorporated.
All other trademarks are the property of their respective owners.

1 Introduction

1.1 Our Goal

The first impression that a customer forms of a product is often based on two things: aesthetics (what a product looks like) and user experience (how the user interacts with the product). Making a strong first impression is important. We believe that the products of tomorrow will have more innovative user interfaces *and* more advanced sensing capabilities than the products of today. High performance capacitive touch and proximity sensing technology enables product designers to make bold statements to their customers- not only by streamlining how their products look, but also by improving how they are used.

Unfortunately, the process of implementing a capacitive touch design has been notoriously challenging for engineers which are new to the process. There’s a lot to consider- mechanical integration, software development, noise tolerance, and moisture tolerance are all design challenges which are often seen as barriers to entry. This is where CapTIvate capacitive sensing technology from TI comes in.

TI CapTIvate™ MCUs and their associated development ecosystem are designed to enable high performance capacitive sensing applications while also simplifying or eliminating the aforementioned challenges associated with adding capacitive sensing to a product. There’s never been a better time to re-evaluate what capacitive sensing can do for your product.

This document introduces the capacitive touch front-end variants and capabilities, available products, and capacitive sensing applications.

1.2 Additional Resources

For additional information on capacitive sensing technology, visit TI.com/captivate.

To get started on a design today, begin with the capacitive sensing design flow guide.

To ask a question about how to implement capacitive sensing into your product, create a thread on the TI E2E™ support forum and work directly with an experienced engineer on getting your design implemented right the first time.

2 Technology

2.1 Overview

CapTIvate MCUs join together a mainstream or high performance capacitive sensing front-end with TI’s proven MSP430™ ultra-low-power microcontroller architecture, enabling the industry’s lowest power capacitive sensing solution.

2.2 Key Technologies

- **A flexible IO system** that allows any CapTIvate IO to be configured as a self/mutual mode receiver (RX) or a mutual mode transmitter (TX), with run-time reconfiguration possibilities for hybrid self/mutual applications (for example, reconfiguring buttons into a single proximity sensor to reduce power consumption while waiting for a user interaction)
- **One, two, or four sensing blocks** that can run capacitance measurements in parallel to reduce detection latency and increase slider and wheel resolution and linearity
- **A dedicated oscillator** that allows for frequency hopping and spread-spectrum EMC improvement techniques to be applied to capacitive measurements without affecting the system clock frequency used by the CPU and other peripherals
- **Digital blocks** that control the periodic measurement interval, perform noise filtering and environmental drift tracking, and detect proximity or touch- all without the involvement of the CPU, completely freeing up the MCU to run other tasks while the device waits for a user interaction (a first in the industry)
- **On-chip read-only memory (ROM)** that contains capacitive touch libraries and other peripheral drivers to keep the main memory free for the application

Figure 2-1 shows the key functional blocks that are available in all MSP430 CapTIvate MCUs.

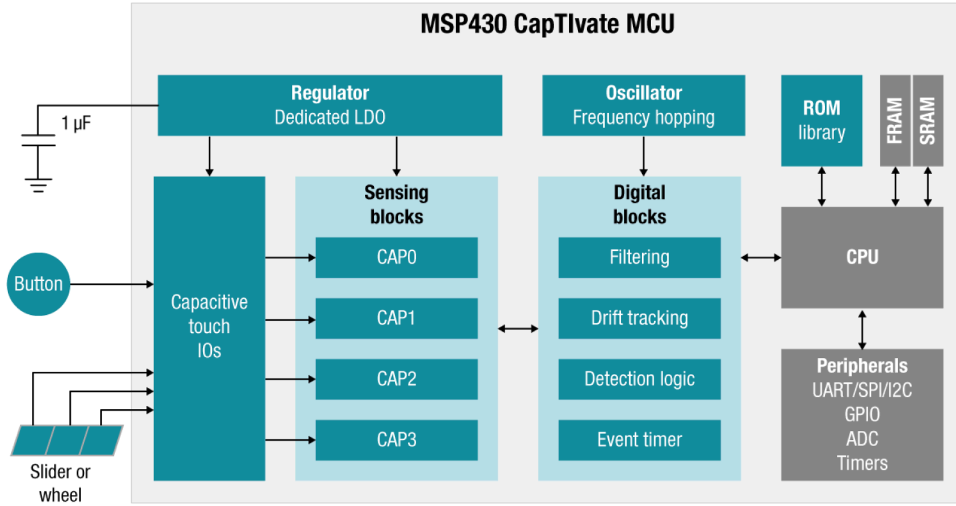


Figure 2-1. MSP430 Capacitive Sensing MCU Block Diagram

Table 2-1 lists key capacitive sensing parameters for CapTIvate MCUs.

Table 2-1. Key Capacitive Sensing Parameters

Sensing method	Tunable charge transfer with parasitic capacitance offset subtraction
Measurement modes	Self-mode (RX to GND) and mutual-mode (RX to TX)
Measurement control	Hardware-managed conversion with timer, sync, or software triggered start
Measurement post-processing	Hardware-managed automatic environmental drift compensation, IIR filtering, threshold detection, oversampling(1), frequency hopping(1), and outlier removal(1)
Parallel measurement	Up to four electrodes (device dependent), enabling fully parallel measurement of slider/wheel sensors for higher sensitivity and improved linearity
Wake-on-touch power consumption	3 µA average (≈30 years on AAAs) (1 button, 8-Hz update rate, MSP430FR2512)(2)
Wake-on-proximity power consumption	5-µA average (≈16 years on AAAs) (1 proximity sensor, 8-Hz update rate, MSP430FR2512)(2)
Active keypad power consumption	72-µA average (≈1 year on AAAs) (12 buttons, 30-Hz update rate, MSP430FR2633)(2)
Noise tolerance (IEC 61000-4)	10-Vrms conducted noise immunity (Class A)(3) 10-V/m radiated noise immunity (Class A)(3) ±4-kV electrical fast-transient (EFT) immunity (Class A)(3) ±8-kV contact electrostatic discharge (ESD) immunity (Class B)(3) ±15-kV air-gap electrostatic discharge (ESD) immunity (Class B)(3)
Moisture tolerance (IPX5)	Accurate detection of touched buttons with no false detections under running water per IPX-5 moisture test environmental conditions(4)
Configuration and tuning	Applications are configured and tuned graphically with the CapTIvate Design Center development tool, which auto-generates the required C source code needed to describe each application
Software support	Complete software stack provided with BSD-3-Clause license, including hardware abstraction layer (HAL), touch detection layer, and advanced layer with out-of-box support for slider/wheel/proximity, touch gestures, and EMC

(1) Hardware oversampling, frequency hopping, and outlier removal is included in high performance technology variants only.
(2) Power consumption is dependent on system parameters such as overlay thickness. Visit ultra-low-power optimization information.
(3) Noise immunity is PCB design and CapTIvate technology variant dependent. See Enabling Noise Tolerant Capacitive Touch HMIs With MSP CapTIvate™ Technology and the CAPTIVATE-EMC evaluation kit.
(4) Moisture tolerance is PCB design dependent. See the Liquid Tolerant Capacitive Touch Keypad Reference Design.

2.3 Performance Variants

TI offers MSP430 microcontrollers with two different versions of CapTIvate capacitive sensing technology: a ***high performance*** variant and ***mainstream*** variant.

- The high performance variant is ideal for designs with challenging application requirements, including: thick overlays, long distance proximity detection, and conducted noise immunity.
- The mainstream variant is a cost-optimized alternative and is recommended when the additional capability offered by the high performance version is not required for a given application. Key capability differences between variants are shown in Table 2-2.

Table 2-2. High Performance vs. Mainstream CapTIvate Peripheral Variants

	High Performance Capacitive Sensing MCUs	**Mainstream Capacitive Sensing MCUs**
Typical maximum overlay thickness (Self-mode, plastic overlay)	Button size / overlay thickness 8 × 8 mm / up to 6 mm 10 × mm / up to 7.5 mm 12 × 12 mm / up to 9 mm	Button size / overlay thickness 8 × 8 mm / up to 3 mm 10 × 10 mm / up to 4 mm 12 × 12 mm / up to 5 mm
Typical proximity range (80-mm × 50-mm perimeter ring sensor with 10-mm electrode width)	70 mm (outstretched finger) 110 mm (flat hand)	25 mm (outstretched finger) 75 mm (flat hand)
Typical slider/wheel position resolution (12-mm × 150-mm 4-element slider, 1.5-mm overlay, hatched ground shield)	256 points ±5 points accuracy	64 points ±5 points accuracy
Response time (16 buttons, with EMC, touch ΔC ≈2%)	10 ms	14 ms
Conducted noise immunity (Buttons, IEC 61000-4-6 Class A)	>10 Vrms (no software tuning needed)	3 Vrms to 10 Vrms (software tuning dependent)
Sensitivity (ΔC) (% change in capacitance)	Detect changes in capacitance as low as 0.3%, from –40°C to 105°C	Detect changes in capacitance as low as 1.4% from –40°C to 105°C

3 Products

Table 3-1. Capacitive Sensing MCU Products by Technology Variant

Maximum Buttons	Capacitive I/O (blocks)	GPIO	Packages	FRAM	SRAM	Part Number
High Performance Products						
24	16 (4)	27	32VQFN	8KB	2KB	MSP430FR2672
64	16 (4)	27	32VQFN	16KB	4KB	MSP430FR2673
64	16 (4)	27, 35, 43	32VQFN, 40VQFN, 48LQFP	32KB	6KB	MSP430FR2675
64	16 (4)	27, 35, 43	32VQFN, 40VQFN, 48LQFP	64KB	8KB	MSP430FR2676
Mainstream Products						
4	4 (1)	11, 15	16TSSOP, 20VQFN	8KB	2KB	MSP430FR2512
16	8 (2)	11, 15	16TSSOP, 20VQFN	8KB	2KB	MSP430FR2522
8	8 (4)	15	24VQFN	8KB	1KB	MSP430FR2532
16	8 (4)	15	24VQFN	8KB	2KB	MSP430FR2632
24	16 (4)	19	32VQFN, 32TSSOP	16KB	2KB	MSP430FR2533
64	16 (4)	19	32VQFN, 32TSSOP	16KB	4KB	MSP430FR2633
Mainstream Products in Chip Scale Packaging						
8	8 (4)	17	24DSBGA	8KB	2KB	MSP430FR2632
8	8 (4)	17	24DSBGA	16KB	4KB	MSP430FR2633

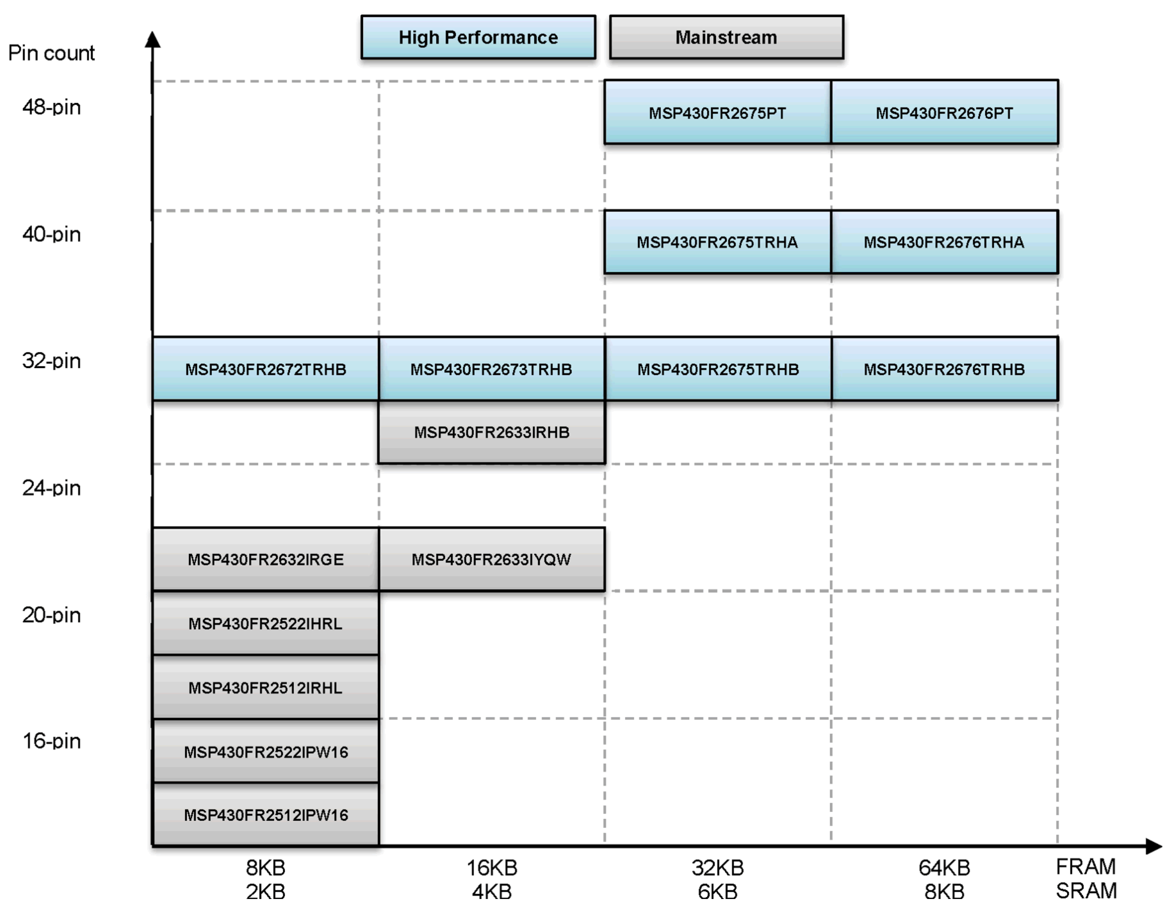


Figure 3-1. Capacitive Sensing MCU Products by Pins and Memory

4 Applications

Electronic Locks and Building Security System HMI Panels

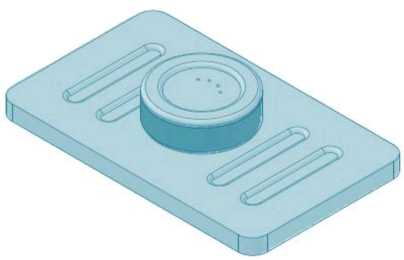
Application requirements

- Ultra-low average power consumption
- Moisture tolerance
- Radiated noise immunity

Recommended tools

- BOOSTXL-CAPKEYPAD evaluation kit
- TIDM-1021 moisture tolerant touch reference design
- TIDM-CAPTIVATE-E-LOCK electronic lock and keypad reference design

Wired and Wireless Lighting Control



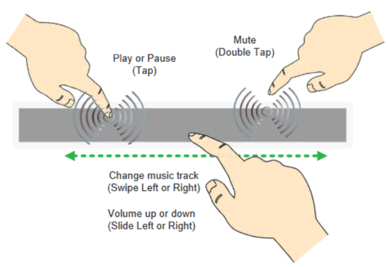
Application requirements

- Small form-factor sensors
- High conducted noise immunity
- State retention though power loss

Recommended tools

- CAPTIVATE-FR2676 evaluation kit bundle
- CAPTIVATE-EMC evaluation kit for testing noise immunity performance

Wired and Wireless Speakers and AV Equipment



Application requirements

- Touch gestures (swipe, tap, drag)
- Metal overlays

Recommended tools

- TIDM-02004 gesture-bases capacitive touch speaker interface reference design
- CAPTIVATE-FR2676 evaluation kit bundle
- CAPTIVATE-METAL evaluation kit