Take your HMI design to the next level with transparent capacitive-touch technology

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Introduction

Capacitive touch has become a popular technology for human-machine interface (HMI) design. In order to have a more sleek appearance, reduce manufacturing complexity and increase reliability, engineers have employed capacitive-touch technology to replace mechanical buttons in embedded designs such as building security panels, smart thermostats, home appliances and electronic door locks. These capacitive-touch button, slider, wheel and proximity designs are implemented on a printed circuit board (PCB) mounted behind a silkscreened cover lens. Many engineers also incorporate capacitive-touch technology in their HMI designs as touch sensors over liquid crystal displays (LCDs). Those applications require an optically transparent sensor.

While display touch sensors give engineers new ways to create innovative user interfaces, they also raise some challenges, including manufacturing cost, development time, environmental durability, system reliability and power consumption. This is especially true for those who want to transition from traditional mechanical buttons or resistive-touch sensors but are concerned about the price and difficulty of implementing a capacitive-touch sensor. If you're unfamiliar with capacitive button, slider, wheel, proximity or capacitive-touch sensor design, these challenges can be difficult to understand and implement. In this paper, we will show one way to address these challenges, by combining a Texas Instruments (TI) MSP430™ microcontroller (MCU) with CapTIvate™ touch technology and a transparent touch sensor.

MSP430 capacitive-touch sensing MCUs with CapTIvate technology

TI MSP430 MCUs featuring CapTIvate technology enable touch controller designs with a feature-rich capacitive-sensing peripheral. This peripheral is configurable for ultra-low-energy battery-powered applications that require high reliability without compromising touch performance. The peripheral also supports self- and mutual-capacitance measurement topologies to enable designers to create unique interfaces that leverage the benefits of each topology in the same design, using the same MCU. High-level noise tolerance, an ultra-low-power architecture, a full-featured and programmable MCU and a comprehensive ecosystem differentiate MSP430 MCUs with CapTIvate technology from other capacitive-touch controllers.

Transparent touch sensors

Most transparent capacitive-touch sensors are built using indium tin oxide (ITO), a transparent conductor sputtered onto a substrate such as glass or plastic. Once the substrate has been coated with ITO, a pattern can be etched into the ITO using a variety of processes. Photolithography and laser ablation are the most popular patterning technologies. Etching electrode shapes into the ITO forms a capacitive touch sensor—either single- or multi-layered. The electrodes are routed out to the edge of the substrate, where a flexible printed circuit (FPC) tail is bonded to the electrodes. The tail connects to a circuit board with a touch controller that drives and measures the electrodes. **Figure 1** shows the components and structure of a typical touch sensor. For more information on ITO manufacturing, see the [ITO Manufacturing and Patterning section](#).

Optical transparency and clarity are key design factors for a transparent touch sensor. The optical transparency in an ITO touch sensor is directly related to the resistance of ITO on the substrate, which varies based on the sputtering process and amount of ITO deposited. Typical resistances for touch sensor applications range from 30 ohms per square (Ω/□) to 200 Ω/□. Higher-resistance ITO is more transparent, but lower-resistance ITO is better from an electrical performance standpoint. As more ITO is deposited to lower the resistance, the material begins to take on a yellow tint which may not be desirable for certain display applications. Ideally, the resistance should remain above 100 Ω/□ for the best optical clarity and to minimize the visibility of the electrode pattern. (For more information on measuring ITO resistance in ohms per square, see the [ITO Resistance Measurements section](#).)

While ITO sensors are typically used for full touch-screen sensors, they can also be used to implement button, slider, wheel and proximity sensors. When combined with an MSP430 MCU with CapTIvate technology, a transparent button, slider, wheel and proximity sensor enables a variety of innovative HMI designs.

Transparent capacitive-touch sensor advantages

Replacing high-end full-featured touch-screen controllers

The most common type of transparent touch sensor is a full-featured touch screen over an LCD that returns a specific X, Y coordinate for a touch. However, the user interfaces in many cost-sensitive applications such as thermostats and printers with segmented LCDs do not require a full-featured touch screen. For those applications, a one-layer ITO-based button, slider, wheel and proximity sensor controlled by an MSP430 MCU with

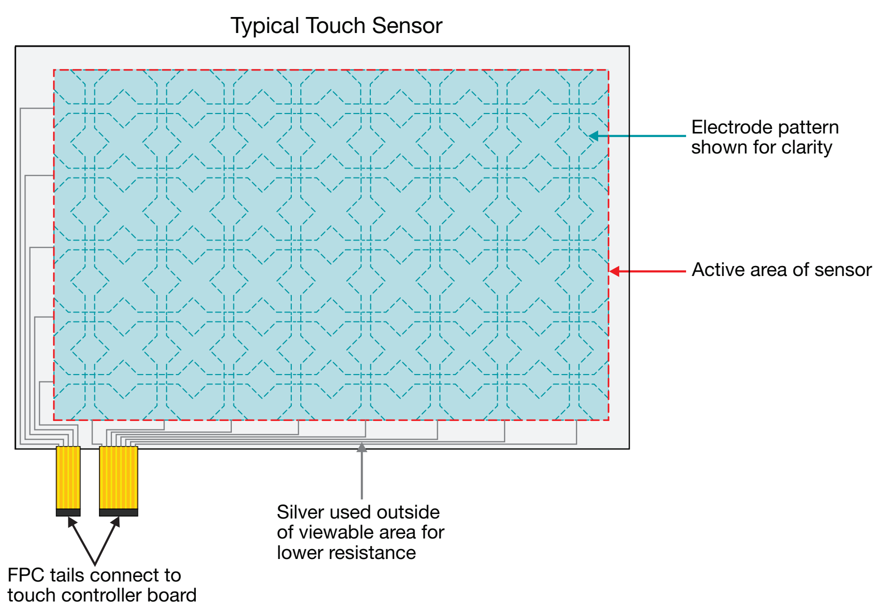

***Figure 1**. Typical touch sensor structure.*

CapTIvate technology is a better choice because of the lower cost and easier implementation.

The lack of a specific X, Y coordinate does not mean that you lose the ability to reconfigure HMI functionality; a grid of mutual capacitance sensors can support reconfigurable discrete buttons and sliders over the LCD. The cost of a button, slider, wheel and proximity touch controller is also significantly lower compared to the cost of a high-end full-featured touch-screen controller. Plus, you can use the programmability of the MSP430 MCU to add features currently handled by the host processor (e.g., backlighting control, discrete touch buttons and proximity sensors) while controlling other user-output subsystems such as haptic motors for tactile feedback and buzzers for audible feedback.

Replacing mechanical buttons

As consumers become more comfortable with capacitive-touch buttons on their products, embedded designers are beginning to appreciate the benefits of replacing mechanical buttons with capacitive touch buttons. This is another great application for an MSP430 CapTIvate controller. In most embedded applications, mechanical buttons are simple digital input/outputs (I/Os) going into a host processor. But most button, slider, wheel and proximity controllers use a communications interface such as I^2C, making it difficult to replace mechanical buttons with capacitive buttons. You can easily set up the MSP430 CapTIvate controller to provide the exact same digital I/O interface as for existing mechanical buttons, eliminating the need to change the host software.

Capacitive buttons are often located on a separate PCB mounted to the back side of the cover lens. In some cases, you can eliminate this extra PCB by incorporating the button electrodes into the capacitive touch sensor used for the touch screen, simply extending the touch sensor out to the button area. The button electrodes are included on the same touch sensor substrate layers as the touch sensor electrodes. Routing the button traces back to the touch sensor controller board (which includes the MSP430 CapTIvate controller) eliminates the need to mount a separate PCB just for the buttons. **Figure 2** shows a sensor design with the touch screen and capacitive buttons integrated on the same layer.

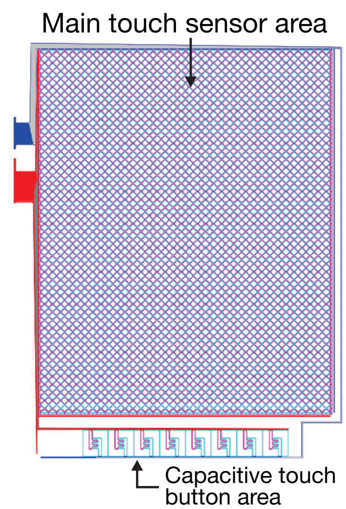

***Figure 2**. Touch screen with capacitive buttons.*

Since the button electrodes are transparent, you are free to implement a variety of backlighting schemes, including multicolor LEDs, light guides for precise lighting control and other innovative lighting techniques that can differentiate your product. You can even use the MSP430 MCU to control these lighting effects, removing that burden from the host processor. The MSP430 CapTIvate controller with ferroelectric random access memory (FRAM) technology can provide real-time [electrically erasable programmable read-only memory (EEPROM) emulation]() for remembering the state of the buttons or for data logging. Also, on-field reprogrammability with [bootstrap loader]() (BSL) can speed up production time and reduce manufacturing costs.

Increased reliability

System reliability is an essential requirement for HMI applications. Transparent capacitive touch-sensing interfaces are inherently susceptible to many types of noise coming from different sources, which creates serious challenges for those looking to design capacitive touch into products requiring high reliability. The MSP430 MCU with CapTIvate technology ensures excellent noise immunity through a combination of low-noise hardware design, signal-processing algorithms and noise-avoidance techniques. CapTIvate technology uses an integrator-based charge-transfer engine with a frequency-hopping oscillator, as well as a parasitic capacitance offset subtraction stage and spread-spectrum clock modulation. **Figure 3** demonstrates the use of frequency hopping to avoid noisy bands.

To further improve noise immunity, the CapTIvate software library provides signal-processing algorithms including multi-frequency algorithms, infinite impulse response (IIR) filtering stages, de-bounce mechanisms and dynamic threshold adjustment. The real-time recalibration algorithm and dynamic long-term average (LTA) tracking help compensate environmental changes to ensure a robust system.

Reduced development time

Another benefit of using MSP430 capacitive touch-sensing MCUs is access to extensive design tools and touch software libraries available from TI. Many hardware designers do not have a strong background in firmware development but want to replace mechanical buttons with capacitive-touch buttons. For these designers, using a touch screen with full functionality requires extra software development to communicate with the touch controller, obtain the coordinates and decode them to specific touchable areas on the screen. By using a button, slider, wheel and proximity sensor with an MSP430 MCU, you can—regardless of your firmware development skill levels—quickly create capacitive-touch solutions with minimal effort, significantly shortening product development time.

The CapTIvate Design Center resource includes graphical user interface (GUI)-based sensor design software that provides real-time debugging and tuning capability. The CapTIvate software library makes it easy for you to write custom firmware for the MSP430 MCU that emulates the previous interface so that no firmware changes are required on the host. Additionally, the CapTIvate Technology Guide provides extensive resources for capacitive-touch sensing design and implementation.

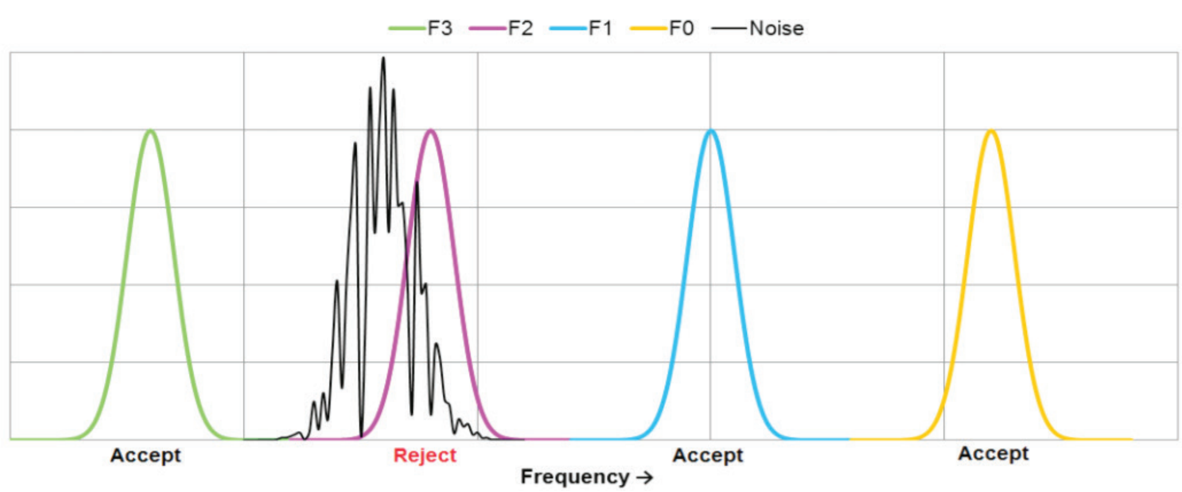

Figure 3. *Frequency hopping to avoid noisy bands.*

Lower power consumption

Engineers are facing increasing pressure to optimize system power consumption when designing battery-operated applications. For products powered by a standard CR2032 coin-type manganese lithium battery with 220-mAh capacity, the system cannot consume more than 2.5 µA in order to achieve a 10-year shelf life. From an HMI sensor design perspective, the touch controller needs to achieve the lowest power consumption possible. And from a system design perspective, the touch controller needs to provide a wake-up mechanism to reduce the overall system power by keeping other components in sleep mode until triggered by a touch or proximity event.

The MSP430 MCU has a well-deserved reputation as one of the lowest-power embedded MCUs available. By adding CapTIvate technology to the MSP430 MCU, TI can now deliver the lowest power in the industry for capacitive-touch sensing solutions.

Preserving durability

For years, resistive-touch sensors have been used for touch screens over LCDs due to their low cost. However, there are several drawbacks to resistive touch sensors:

- It is difficult to:
  - Clean them effectively.
  - Create a seamless top surface.
  - Add coatings and films to the top surface.
  - Seal the unit against outside contaminants.
- Spacer dots in between conductive layers decrease optical quality.
- The top layer is susceptible to damage, including dents, scratches and pen marks.

Because a capacitive-touch sensor uses an electric field for sensing instead of a contact point, placing the sensor behind a cover lens allows the product to have a seamless surface and be completely sealed. The top surface layer can be standard or strengthened glass or plastic. The surface can also have a number of coatings and/or films, including anti-reflective, anti-glare, oleophobic, hydrophobic or privacy film. For these reasons, capacitive sensors are very quickly replacing resistive-touch screens in a number of applications. **Figure 4** shows the stack-up of a typical ITO resistive-touch sensor and ITO capacitive-touch sensor.

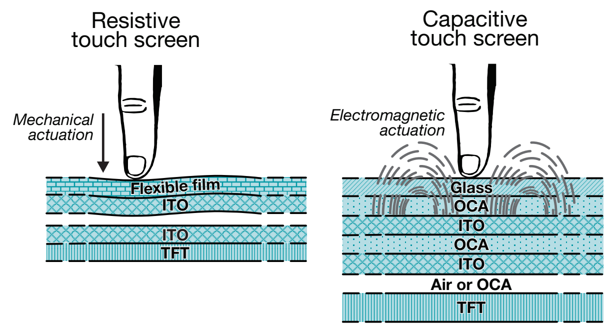

Figure 4. *An ITO resistive-touch sensor vs. an ITO capacitive-touch sensor.*

Conclusion

TI MSP430 MCUs with CapTIvate technology feature the most noise-immune capacitive-touch technology available. The MCUs' configurable combination of button-, slider-, wheel- and proximity-sensing interfaces at the world's lowest power enable you to create eye-catching HMI designs. When combined with transparent touch-sensor technology, CapTIvate technology provides an easy path for upgrading resistive-touch sensors and mechanical buttons, providing all of the benefits of capacitive-touch technology without the complications or cost of a full touch-screen solution.

Appendices

ITO manufacturing and patterning

While there are many ways to coat a substrate with ITO, including evaporation, chemical vapor deposition, spray pyrolysis and sol-gel, the most cost-effective way to deposit ITO with high optical clarity is with sputtering. ITO can be sputtered onto a variety of substrates, including glass and plastics like polyethylene terephthalate (PET) and polycarbonate (PC). The ITO coating is typically very thin, measuring from 100 Angstrom (Å) to 2000 Å. Thicker coatings are often used on plastic substrates to help prevent breaks in the conductor as the substrate bends.

An electrode pattern is created in the ITO using a removal process like photolithography (chemical etching) or laser ablation. Photolithography is a complicated process involving the deposition of a resistive material, exposure of the resistive material using a mask in the shape of the electrodes, and chemical etching to remove the ITO between the electrodes. Removing the resistive material on top of the electrodes leaves the desired electrode pattern in ITO.

Photolithography allows for very small gaps between conductive areas, typically around 50 μm. The small distance between conductive areas helps reduce the pattern visibility. Another benefit of photolithography is that the complexity of the pattern has no impact on the production time, since the entire substrate is being processed all at once. The drawbacks of photolithography include the management of a variety of dangerous chemical processes, a long production line and the need for masks and other setup fixtures.

Another common technique for removing ITO is laser ablation. The coated substrate is placed inside of a laser chamber. The laser then ablates the ITO based on a programmed pattern. Laser ablation produces even smaller gaps between conductors, 30 μm to 40 μm. The benefits of laser ablation include a small production line; the absence of dangerous chemicals; and the absence of masks and fixturing, which allows for quicker turnaround. Another benefit to using laser ablation is that the laser can also ablate the silver typically used around the edges of the touch sensor at the same time as the ITO, reducing the number of process steps. The downside to laser ablation is that more complicated electrode patterns require more processing time.

While it is possible to create a capacitive-touch sensor using a single layer of ITO, the more common construction (especially in the industrial and embedded markets) is to use two electrode layers. These two electrode layers are typically on separate substrate layers. The two substrates are bonded together using a sheet of optically clear adhesive (OCA). These two conductive layers are then bonded to a cover lens using another sheet of OCA. **Figure 5** on the following page shows the ITO capacitive-touch sensor stack-up. OCA is a thin layer of double-sided adhesive ranging in thickness from 50 μm to 250 μm or thicker. Some OCAs include a substrate (think of double-sided sticky tape). Other OCAs are baseless, meaning that they are just adhesive. OCA bonding involves heat and pressure to ensure the removal of all air bubbles. Even the smallest air bubbles in the bond layer are visible.

It is also possible to create a single substrate with ITO on both sides. This is sometimes called a double-sided ITO, or DITO. The two electrode layers are patterned as before, one on each side of the substrate. A DITO sensor must be bonded to a cover lens using OCA. Otherwise, the top conductive layer would be exposed to the environment.

Once the sensor/cover lens assembly is completed, it is bonded to an LCD using a gasket material (also known as “air-gap” bonding), or with OCA. OCA is the preferred choice for the bond layer, as it provides much better optical clarity than an air gap. A dry OCA layer or a liquid OCA can bond the sensor/cover lens assembly to the display as we described. The liquid bonding agent is dispensed onto the LCD surface. The sensor/cover lens is then placed on top and the OCA is cured. Curing typically involves exposure to ultraviolet light, although some liquid OCAs are also capable of self-curing. **Figure 5** shows the stack-up of an ITO capacitive-touch sensor with a thin-film transistor (TFT) LCD.

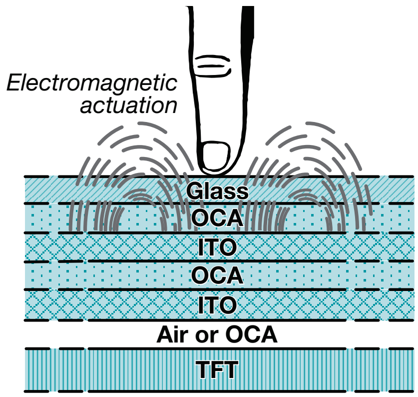

Figure 5*. ITO capacitive-touch sensor with TFT LCD.*

ITO resistance measurements

ITO resistance is measured in Ohms per square (Ω/□). What this means is that, regardless of physical dimensions, as long as a piece of ITO-coated material is a perfect square, it will always have the same resistance. To understand this, start by considering a square piece of ITO-coated material of some arbitrary dimension. Apply copper tape to two opposite edges of the sample and use a multimeter to measure the resistance. For this particular sample, the measured resistance is R. From a circuitry standpoint, you can model this single piece of material as a single resistor of value R. **Figure 6** shows a circuit model of the sheet resistance for one unit square.

Now consider a piece of that same material that is twice as long as it is wide. Think of this piece as two squares connected together. The circuit model for

Sheet Resistance: One Square

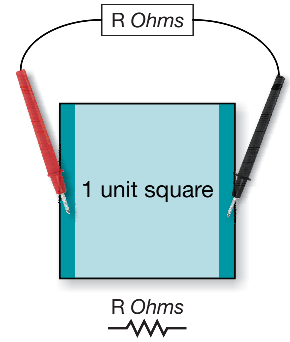

Figure 6*. Sheet resistance for one unit square.*

this is two resistors of value R in series, giving a total resistance of 2R. What if you took two of these rectangles and put them side by side? You would form another square that is exactly twice as large as the original. From a circuit-model standpoint, you can model this configuration as a network of four resistors: two in series and two in parallel. The resistance of this model is 2R/(R + R) = R. Therefore, the resistance of a square of ITO-coated material is always R—regardless of the physical size of the square. So when an ITO-coated piece of glass or plastic is specified as having a resistance of 100 Ω/□, the resistance of any square of that material, no matter how large or how small, will be 100 Ω. **Figure 7** shows the circuit model for the sheet resistance for four squares.

Sheet Resistance: Four Squares

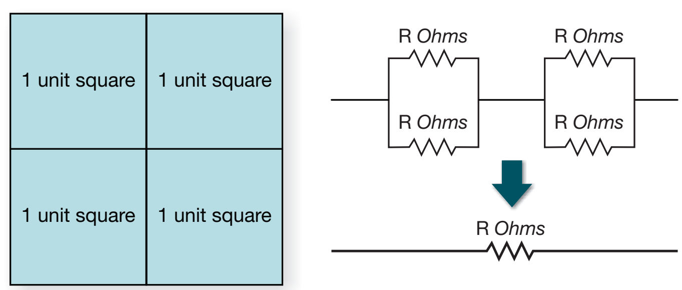

Figure 7*. Sheet resistance for four squares.*

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