Improved Capacitive-Sensing Technology Expands the Realm of Potential Applications

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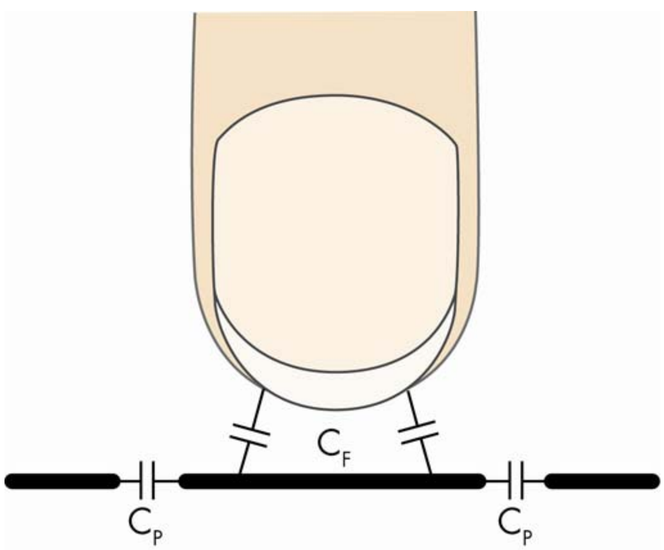
Executive Summary

With all the excitement about capacitive sensing in the portable media player, laptop PC and mobile handset markets, it is easy to forget that such interface technologies have been actively designed into White Goods applications for years. Significant improvements in sensing algorithms and control circuitry have expanded the suite of applications in which the technology can be implemented. Designers are seeing the value of capacitive sensing as a mechanical button and membrane switch replacement as well as discovering new, exciting applications such as touchscreens and proximity sensors.

Sensing Capacitance

A capacitive sensor is constructed of a conductive pad, the surrounding ground, and its connection to a controller. In most applications, the conductive pad is a large copper footprint and the surrounding ground is a poured fill. A native (parasitic) capacitance, C_P, exists between these two objects. When a third conductive object, such as a human finger, is brought into proximity with the sensor, the capacitance of the system is increased by the capacitance of that object, C_F.

Figure 1. Illustration of capacitive sensing system.



There are several methods for detecting the increase in capacitance caused by the addition of C_F. *Field Effect* measurement uses a AC voltage divider between a sensor capacitor and a local reference capacitor. Finger detection is achieved by monitoring the change in voltage on this divider). *Charge transfer* uses a switched capacitor circuit and a reference bus capacitance with repeated charge transfer steps from the smaller sensor capacitor to the larger bus capacitor. The voltage on the bus capacitor is proportional to the sensor capacitance. The capacitance can be determined by measuring the voltage after a fixed number of steps or by counting the number of steps necessary to reach a threshold voltage. A *relaxation oscillator* is a charge time measurement where the charging ramp is determined by the current source (usually fixed) and the sensor capacitance value. Larger sensor capacitors yield longer ramp times, usually measured with a PWM and a timer.

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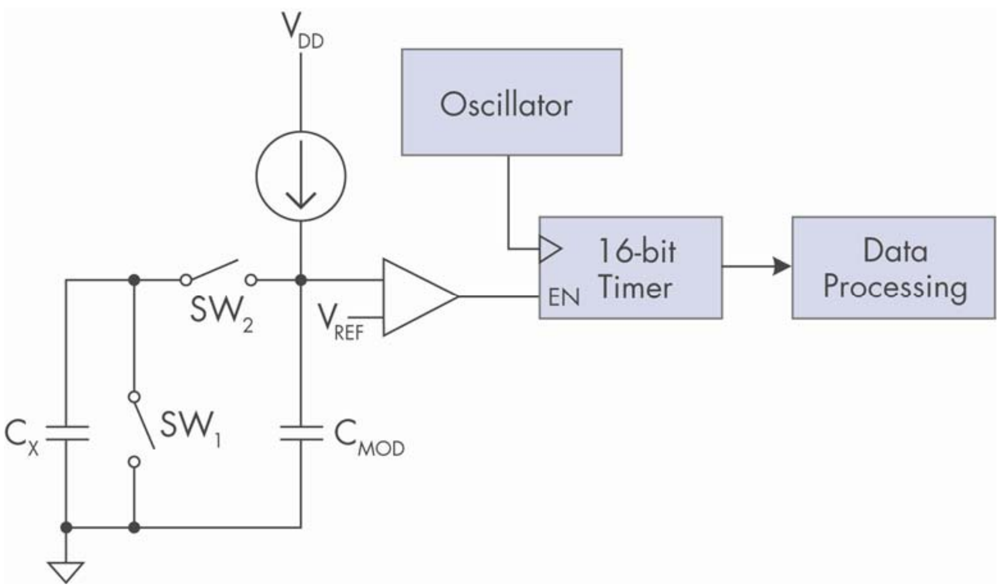
Successive Approximation is a capacitance charging time measurement where start voltage is determined by successive approximation.

The successive approximation method (patents applied for by Cypress Semiconductor) implemented with the PSoC device uses a capacitance to voltage converter and single slope ADC. The capacitance measurement is achieved by converting the capacitance to a voltage, storing this voltage on a capacitor, and then by measuring the stored voltage using an adjustable current source.

Figure 2. Schematic of capacitance sensing system.



The capacitance to voltage converter is implemented with switched capacitor technology. The circuitry brings the sensor capacitor to a voltage relative to the capacitance of the sensor. The switched capacitor is clocked by the PSoC's internal main oscillator.

The sensor capacitor is connected to the analog mux bus and is charged via a programmable current output digital-to-analog converter (iDAC) also connected to the bus. The charge on each bus is given by q=CV. SW2 is opened and SW_1 closed to bring the potential across C_X to zero and reducing the charge on the bus by a value proportional to capacitance of the sensor capacitor. This (charge-discharge) is repeated so that the sensor capacitor is a current load on the bus.

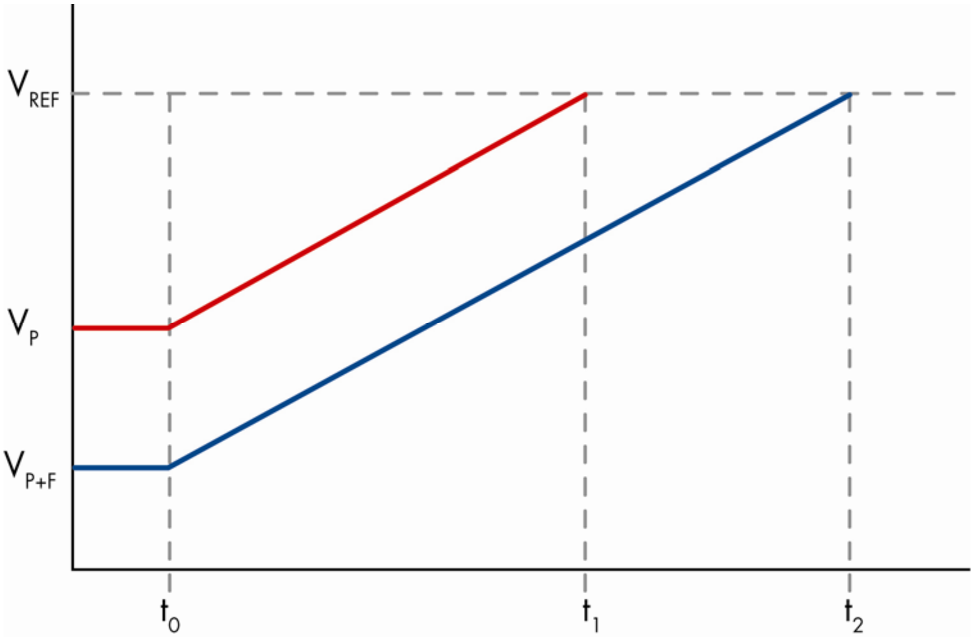
With the switched capacitor circuit running, the iDAC uses a binary search to determine the value at which the voltage on the bus remains constant. This voltage is a factor of the switching frequency, the sensor capacitance and the iDAC value (current). The bus also functions as a bypass capacitor, stabilizing the resulting voltage. Additional capacitors can be added to the bus and affect performance and timing of the circuit.

$$V_X = \frac{1}{f_{OSC} C_X} I_{DAC}$$

$$V_{BUS} = V_{REF} - V_X$$

The calculated iDAC value is then used to charge the bus again and the time required to take the bus from an initial voltage to the comparator threshold is measured. The initial voltage with no finger present and therefore the charge time is known. A finger on the sensor increases the value of C_X, decreasing the initial voltage and increasing the charge time measurement.

Figure 3. A finger on the sensor increases charge time measurement.

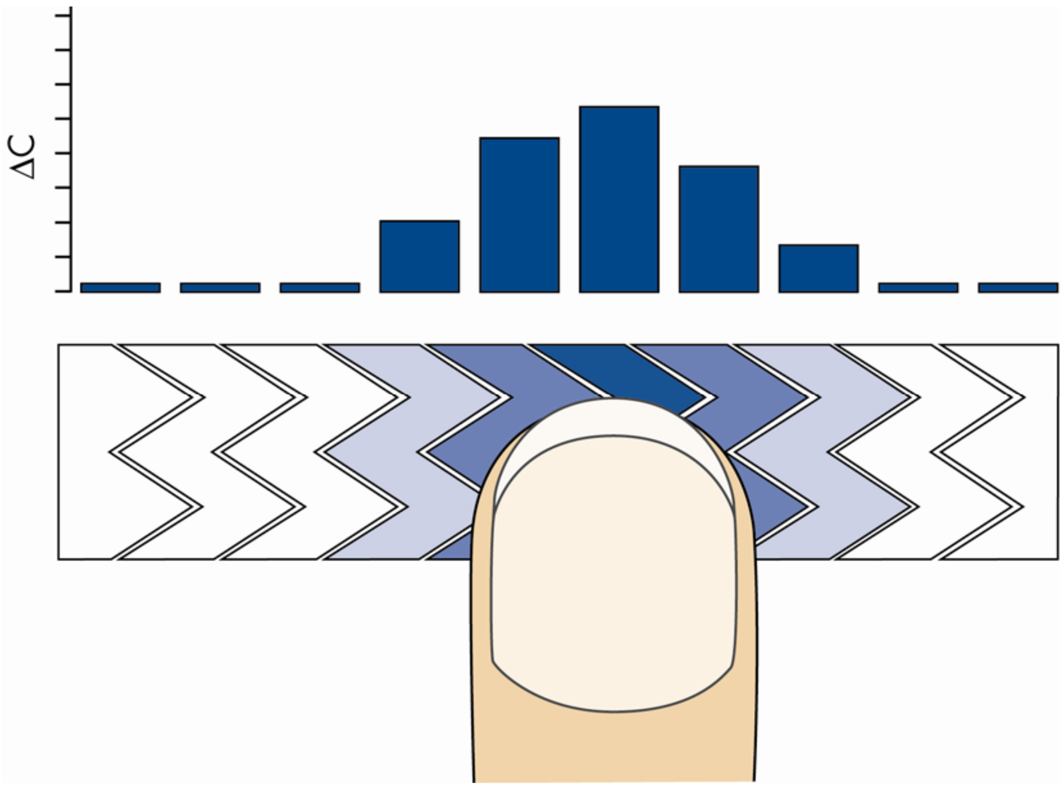


Building a Sensor

Capacitive sensors have diverse form and function. They can use a variety of media. Their implementation ranges from simple to complex. Application requirements determine sensor construction and implementation details.

Buttons and sliders are most common. Buttons are large conductive pads connected to the controller. Capacitance is measured and compared against a series of thresholds. Decisions can be made as digital outputs or with more analog characteristics for activation pressure or finger size. Sliders are linear or radial arrays of conductive pads. Center of mass algorithms determine the position of activation to a resolution far greater than the number of pins used to sense. Most often simple capacitive sensors like buttons and sliders deposited onto a printed circuit board using copper. Other substrates and deposition media such as silver ink can be used, however.

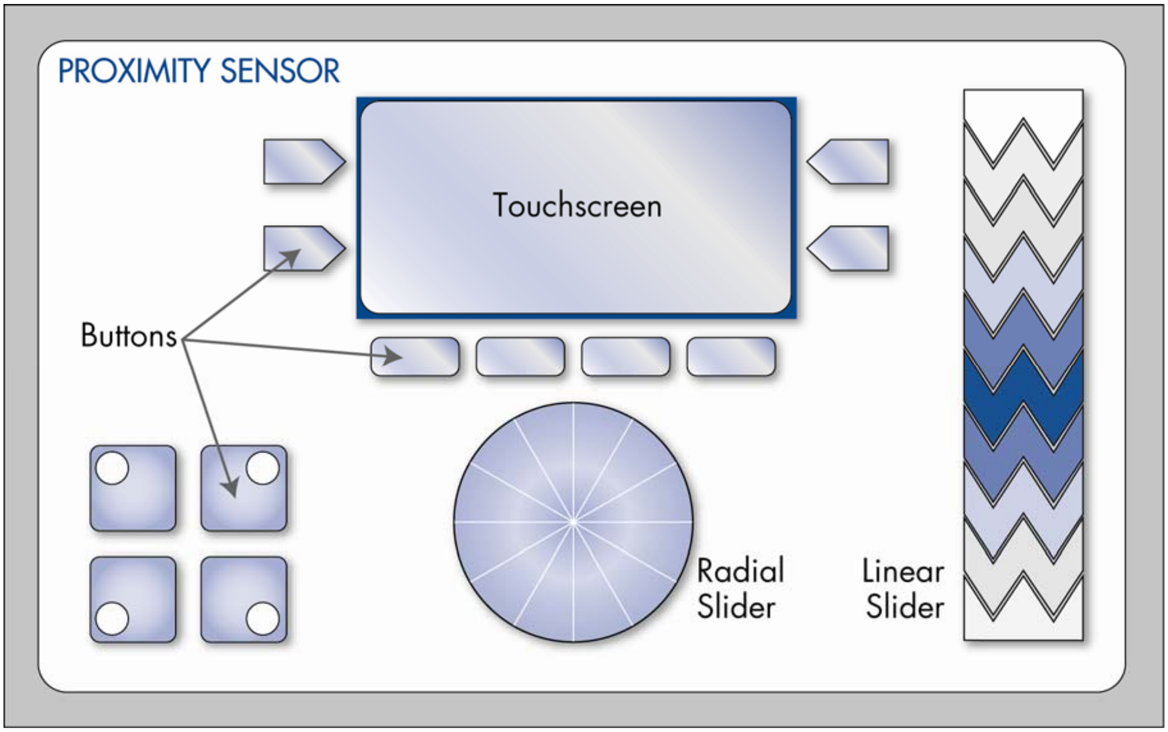
Figure 4. Center of mass algorithms determine the position of activation.



Dynamic user interfaces use buttons or activation regions that reconfigure in response to the display itself. These displays are moving the user experience forward by promoting more seamless and intuitive interaction. The construction of these systems is somewhat more complex that simple buttons or sliders. Projected capacitance touchscreens use transparent conductive materials over a display. The conductive surface is deposited onto a substrate such as glass or PET film and connected to the control circuitry. The substrate is then adhered to the overlay between the overlay and the display. The position of the activation is determined in the same way as a slider. Two sliders, one for each axis are intertwined to provide complete coverage of the display area. Activation is detected on both axes and the position exported as x- and y-data except on two axes. Because a projected capacitance touchscreen is behind an overlay, it is protected from impact, flexion, and environmental factors that plague traditional resistive touchscreens.

Proximity Sensors are essentially large buttons. The object of a proximity sensor is not to detect the exact position of a conductive object, rather the presence. Since the device does not need to know exact position, the response time may be slower (3-4ms vs. 250us). The sensitivity of a proximity sensor is much greater; 30cm can be achieved in a well constructed design. Since proximity sensors do not need to be associated with any display graphic, their placement on the device is more flexible. A copper ring around the outside of the control circuit board or a wire behind the overlay allows very basic, cost-effective construction of a proximity sensor.

Figure 5. Illustration of proximity sensor arrangements.



Using a Capacitive Sensor

Usage of capacitive sensors is expanding. The described sensors have created new opportunities for designers to work with such flexible, durable and elegant design elements. Buttons are still used for basic menu navigation and activation. However, analog characteristics of buttons that are not expensive potentiometers are allowing easier and less expensive implementation of increased functionality and safety features.

The LG LA-N131DR Air Cleaner uses five capacitive sensors for front panel display menu navigation buttons. These buttons have allowed the designers to implement a seamless chassis design while still realizing the user interface. The capacitive buttons detect the presence of a human finger through four millimeters of glass. The control circuitry is located on the non-sensor side of a two-layer printed circuit board. LG uses the PSoC Mixed-Signal Array to control the sensors and output status to the main device processor.

Figure 6. The LG LA-N131DR air cleaner, developed by LG Electronics, uses five capacitive sensors for front panel display menu navigation buttons. *Photo: LG Electronics.*

Proximity sensors allow for reactive backlighting for night-time operation or for safety features requiring a larger activating element such as an adult hand or metal pot to engage the range-top controls. Proximity sensors, buttons, sliders and even touchscreens can be controlled by a single processor using PSoC. Firmware routines allow changes in state based on user inputs or host commands.

Create Your Capacitive Sensing Application

The PSoC Mixed Signal Array is a configurable array of digital and analog resources, flash memory and RAM, an 8-bit microcontroller, and several other features. These features allow PSoC to implement innovative capacitive sensing techniques in its CapSense portfolio. Use PSoC's intuitive development environment to configure and reconfigure the device to meet design specifications and specification changes. New sensing technologies exhibit improved sensitivity and noise immunity, reduced power consumption, and increased update rate. For more information on PSoC, go to www.cypress.com. For more information on PSoC CapSense, visit www.cypress.com/capsense.

References

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