A Designer's Guide to Rapid Prototyping of Capacitive Sensors on Any Surface

By (Mark Lee, Senior Application Engineer, Cypress Semiconductor Corp.)

Executive Summary

This article will discuss how to replace the mechanical buttons on a product with a smooth and sleek touch-sensitive surface. It will present the concept of prototyping capacitive sensors on any nonconductive surface using silver-ink pens and copper tape. Topics included are capacitive sensor basics, silver-ink and copper tape, and construction technique. Measured results are presented for sensors applied to the back side of a simple acrylic sheet.

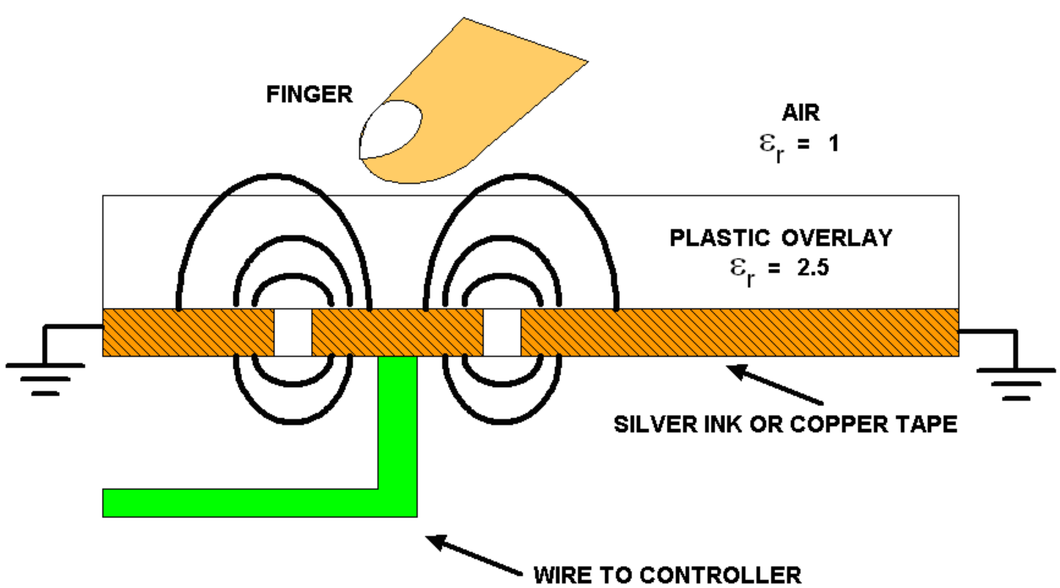
Introduction

Capacitive sensing provides consumers a cool new way to interact with their MP3 players and mobile phones. Touch sensors are hidden below the surface, so the area normally covered with the uneven features of mechanical buttons now look clean and uncluttered. An effortless finger touch accesses product features that are usually controlled by the click of mechanical buttons. To encourage experimentation with this new technology, this article presents a designer's guide to rapid prototyping of capacitive sensors on any nonconductive surface.

Alternatives to PCBs and Flex Circuits

Imagine that you have a great idea for a product that includes a plastic injection-molded case or a glass panel, and you would like to explore the possibility of replacing the mechanical buttons with capacitance sensors buried under the surface. The first step in making a capacitive sensing system is to arrange a set of conductors on a nonconductive surface [1]. The traditional approach to implementing the sensors is to create a printed circuit or a flex circuit, but this can be time consuming, and may not fit within your budget for a prototyping effort. How can you avoid the time and expense associated with traditional prototyping methods, and open the design process to after-the-fact nudging and tweaking?

Figure 1. Cross-sectional view of prototyping technique for capacitive sensors.



Published in Planet Analog (http://www.planetanalog.com) January 2007

Silver ink pens and copper tape provide a prototyping solution for capacitive sensing that is both inexpensive and quick to implement. A cross-sectional view of the concept is shown in Figure 1. Conductive patterns are applied by hand, directly to the nonconductive overlay material. Jumper wires connecting the microcontroller to sensor pads replace PCB traces of the more traditional approach to prototyping.

Sensors applied to acrylic sheet

As a demonstration of the technique, two capacitive sensors were applied to a 3mm-thick sample of acrylic sheet. One sensor is copper tape, and the other is silver ink as shown in Figures 2 and 3. It only took a few minutes to apply these conductive patterns by hand to the backside of the acrylic sheet.

Figure 2. Two capacitive sensors applied directly to a 3mm-thick acrylic sheet. The sensor on the left is made of silver ink, and on the right is copper tape.

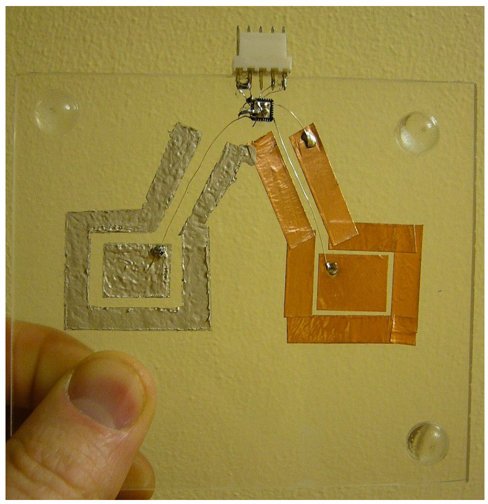
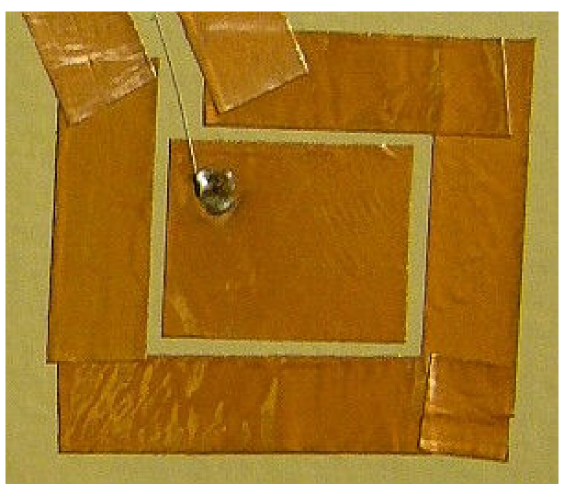


Figure 3. Close-up view of the copper tape construction. The outer ring is ground, and the inner square is the sensor pad. The wire is a jumper back to the PSoC.



Total project time was about one hour. Most of the time was spent soldering connections to the controller IC that was glued dead-bug style to the sheet. A connector was glued to the edge of the sheet to provide access to the PSoC both for programming and for a data-logging serial connection to a host PC.

Silver Ink Pen

The silver "ink" pen is most frequently used to do electrical repairs, such as fixing broken heating elements in a window defogger. High conductivity silver particles are suspended in acrylic epoxy system that cures into a flexible electrical connection. It forms a good bond with many surfaces, including glass and acrylic. There are a few versions of this kind of pen from different manufacturers. For this demonstration, a CircuitWorks Micro Tip pen from Chemtronics was used.

With the silver ink pen, the conductive sensor pattern is defined by drawing directly onto the surface. It takes an hour or two to cure to the point were it can be used as a sensor. For this demonstration, the ink cured overnight at room temperature. The product description says the cured ink can be soldered to with a low temperature soldering iron. Based on earlier experience with this product, it was decided to attach the jumper wire to the sensor pad using an extra dab of ink. The jumper wire became glued to the sensor pad after this ink cured. Although the conductive pattern can be completely done by drawing freehand, the pattern shown in Figure 2 received crisply defined edges by masking-off the pattern with tape before the ink was applied. The mask was removed after curing.

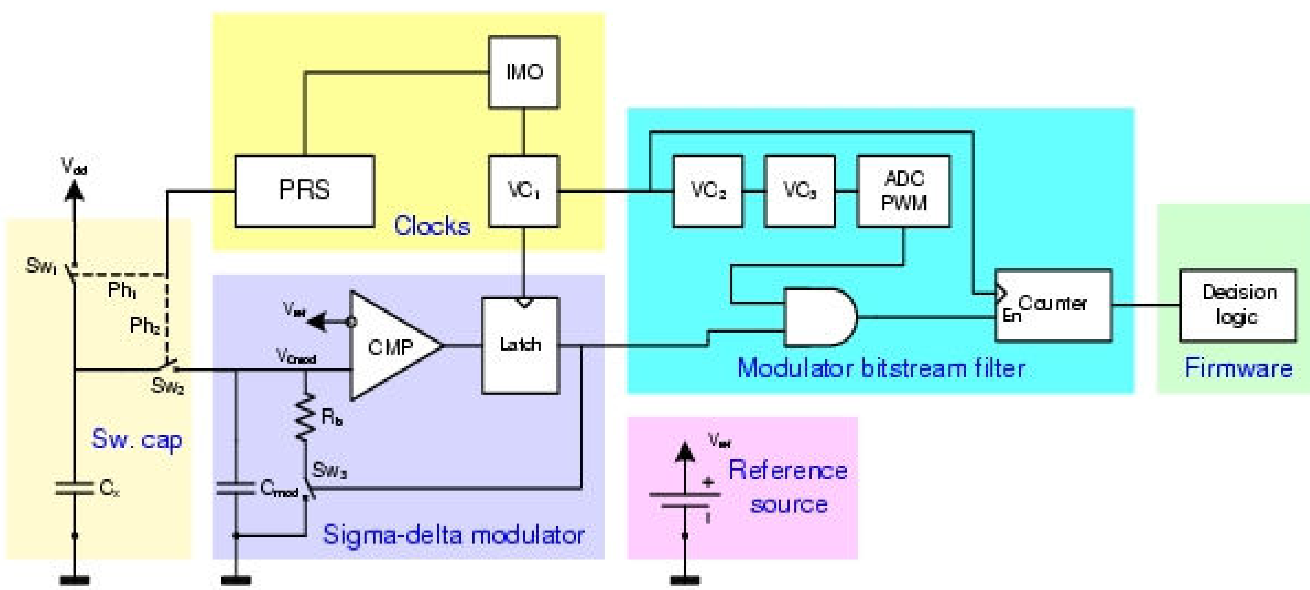
Copper Tape

The copper tape is made of thin copper foil, and is most frequently used for shielding. The conductive tape used for this demonstration, product number 1181 by 3M, has a special conductive adhesive that makes it easier to electrically connect overlapping tape sections. Unlike the silver ink, the copper tape can be used immediately for sensing after the tape is applied. Soldering the jumper wire to the sensor works well with this conductive tape. Copper was selected for the demonstration, but the tape is available in other metal types, like aluminum, that work equally well.

Circuit details

Applying the conductive traces by hand leads to less than ideal sensors performance compared to PCBs and flex circuits. To compensate for this, a sensing method with high Signal-to-Noise Ratio (SNR) is required. The CSD configuration of PSoC from Cypress Semiconductor was selected for this demonstration [2]. The designation "SD" in the name "CSD" stands for Sigma-Delta. This new sensing method that can be implemented in both the CY8C21x34 and CY8C24x94 versions of PSoC. The CSD functional blocks are shown in Figure 4.

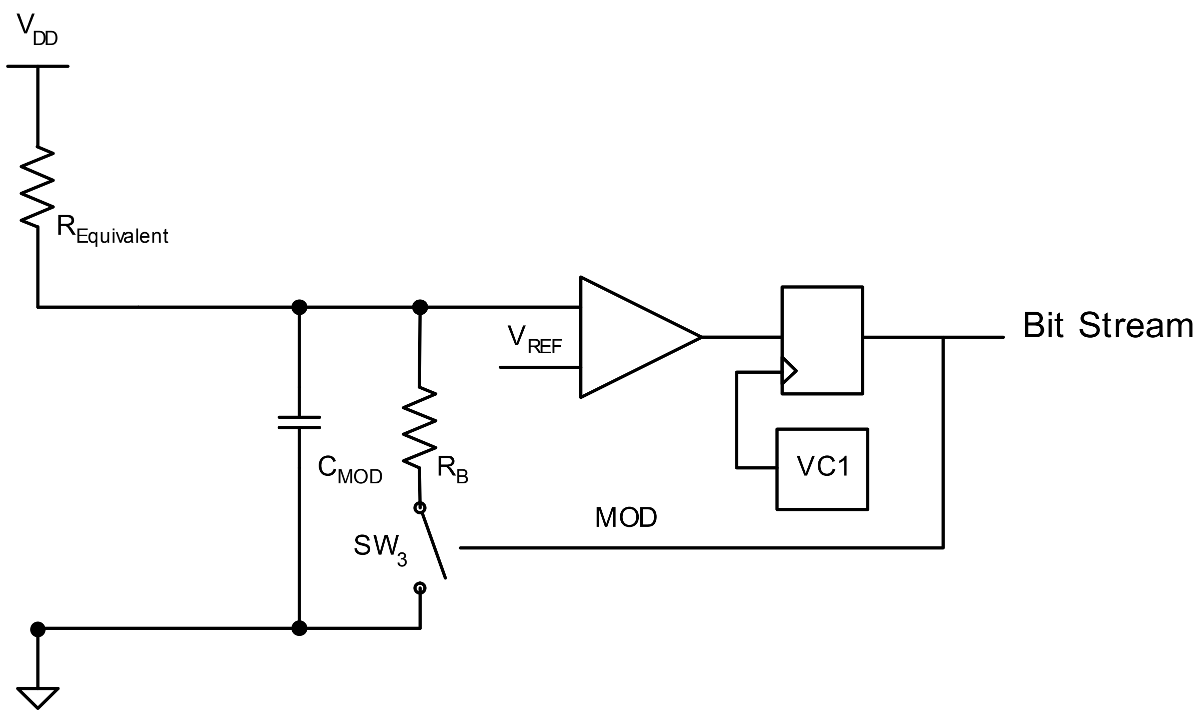
Figure 4. CSD configuration of PSoC CapSense for CY8C21x34 devices.



[+] Feedback

An equivalent circuit of CSD is shown in Figure 5. The switches on the front end of the circuit have turned the sensor capacitance into an equivalent resistance that is modulated by the presence of a finger. The change in the resistance results in variation in the bit stream at the output of the sigma-delta modulator.

Figure 5. CSD block diagram with equivalent resistance of the switched sensing capacitor.



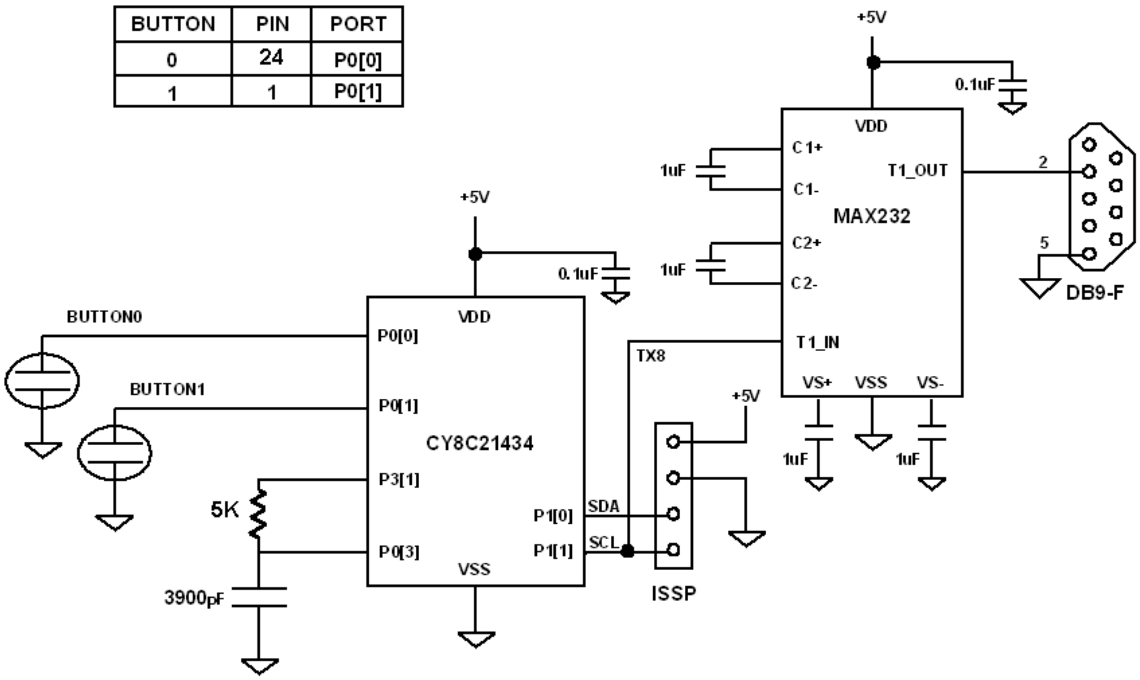
The CSD User Module is a standard functional block included in the PSoC Designer library. It contains API routines that perform all the low level and high level functions required to make a practical capacitive sensing system. The PSoC is selected by dragging-and-dropping the CSD User Module from the library. The system level operation of the sensors is defined in C.

An additional functional block is added to the project to provide a communication link to a host computer. The TX8 user module implements a transmit-only block that sends serial data at 115,200 baud. This turns the system into a programmable data logger for capacitive sensing.

The schematic for this project is shown in figure 6. The circuit contains only the PSoC chip for capacitive sensing and serial communication, another chip for RS232 level shifting. The pin assignments for the two CapSense buttons are shown in the table in figure 6. The PSoC is programmed through the ISSP header that contains power, ground, and the programming pins SCL and SDA. The host PC connects to the capacitive sense board through a DB9 connector.

Figure 6. Schematic for the capacitive sensing circuit configure with the CSD User Module.

BUTTON	PIN	PORT
0	24	P0[0]
1	1	P0[1]



Measured Performance

The measured performance of the capacitive sensing system is shown in Figure 7 and 8. The sensor counts were captured on the host PC via a terminal emulation program, and processed with a spreadsheet.

Performance is measured by touching a finger to the acrylic sheet. The touch surface is separated from the conductive sensor patterns by 3mm of nonconductive acrylic. The finger is placed first over the silver ink pattern, then lifted and placed over the copper tape pattern. The test sequence is repeated a second time. The unprocessed sensor data is shown in Figure 7. The ON/OFF states of the sensors are shown in Figure 8. The system response transitions cleanly between states with no debounce required.

Figure 7. Unprocessed sensor data for the two sensors with a 3mm acrylic overlay. Upper trace is for silver ink. Lower trace is for copper tape.

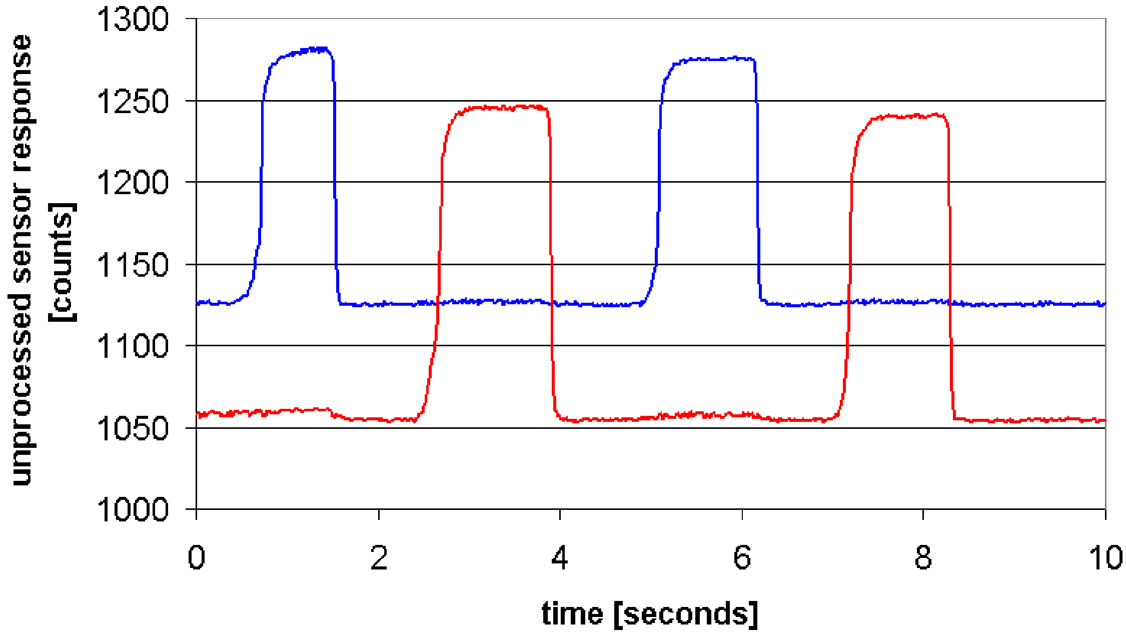
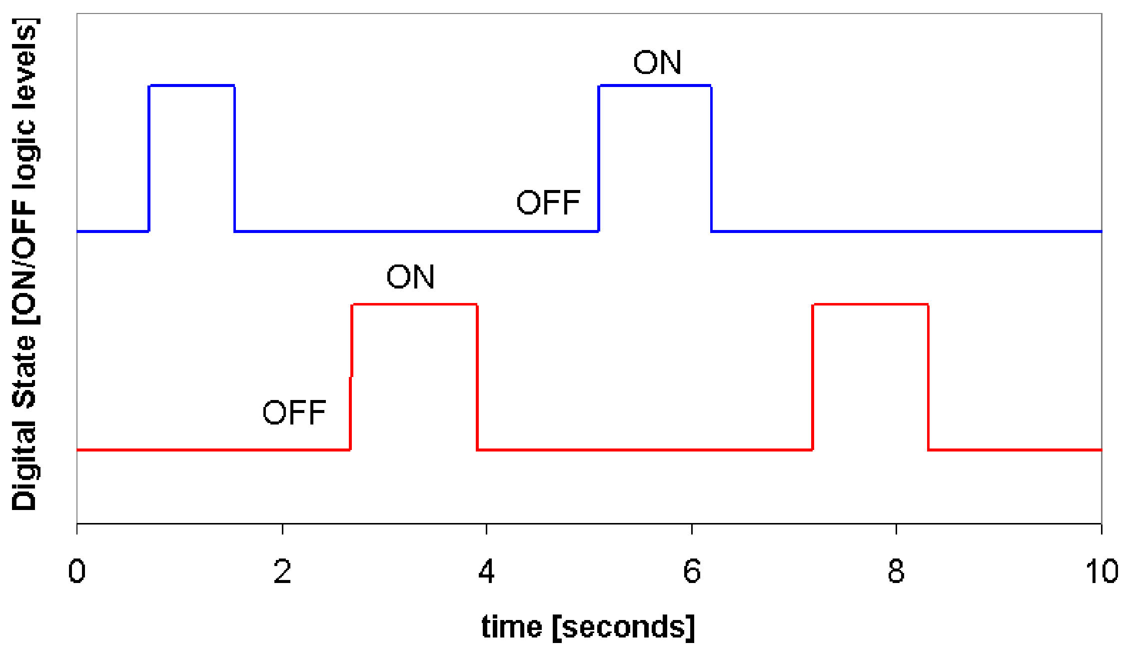


Figure 8. Digital states for the two sensors with a 3mm acrylic overlay. Upper trace is for silver ink. Lower trace is for copper tape.



Both silver ink and copper tape perform well in this prototype. The prototype sensing system has achieved a high SNR due to the excellent performance of the CSD User Module. If you change your mind on the placement or size of the sensors, changes are quick and easy to make. Just remove the tape or ink that you need to change, and reapply the new conductive patterns. This technique of applying sensor to a surface is well suited to the construction of proof-of-concept devices that is often required in the early phases of product development.

Conclusion

To dig deeper into the topic of capacitive sensing, consult the application note titled "CapSense Best Practices" from Cypress Semiconductor.

References

Mark Lee, "The art of capacitive touch sensing", Planet Analog supplement to EE Times, December 28,2006, pages 4-6

Application Note AN2394, "CapSense Best Practices", Cypress Semiconductor

Cypress Semiconductor
198 Champion Court
San Jose, CA 95134-1709
Phone: 408-943-2600
Fax: 408-943-4730
http://www.cypress.com