Mobile Handset Touches on Capacitive Sensing

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Executive Summary

This article shows how to incorporate capacitive sensing features into a mobile handset, and addresses the important issues that lead to successful design. Topics addressed are Signal-to-Noise requirements for capacitive sensing, meeting requirements for low power consumption, mechanical considerations for mobile handsets, the advantages of a programmable controller in system development, and transparent touchscreens based on capacitance.

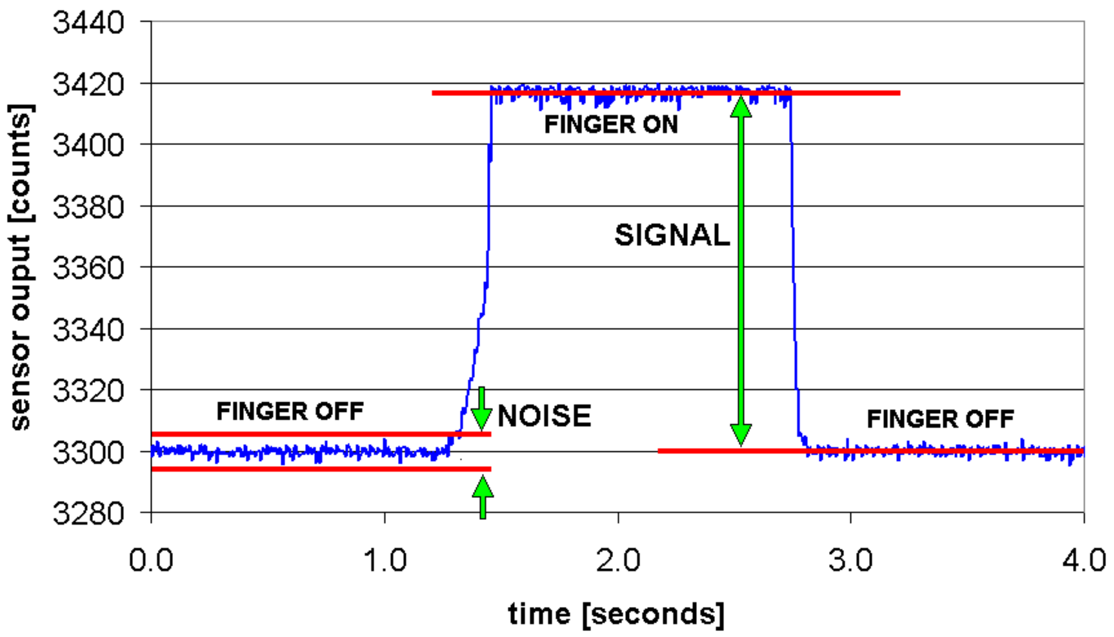
Introduction

The capacitive sensing user interface has established itself in recent years as a practical and innovative upgrade for mechanical buttons in portable media players. That same trend is beginning to emerge in mobile handsets. The capacitive sensor can be viewed as a drop-in replacement for mechanical buttons, but this technology has more to offer than just being a stand-in for dome switches. Enabling a handset with touch sensors leads to exciting new look-and-feel options for handset designers. Using capacitive sensors, the handset buttons, known as the keymat, can be made with no moving parts, resulting in a smooth and sleek touch surface. Alternatively, a designer could opt for capacitive sensing on top of mechanical buttons, where a light touch would trigger the capacitive sensor, and a heavy touch would actuate the mechanical switch. The handset incorporating such technology would sense both the location of a finger, and how hard it is being pressed. A light touch could be associated with paging through a menu of phone numbers, and a more forceful key press could initiate a call to the selected number. One of the most interesting trends to emerge in handset design in years results from the combination of capacitive sensors and transparent conductors. The transparent keymat offers many creative options for the handset designer.

SNR for Capacitive Sensing

The key to a robust capacitive sensing design in a mobile handset is a high Signal-to-Noise Ratio, SNR. In electronic communications and other engineering fields, SNR is commonly measured in decibels, dB. In finger sensing applications, the dB is not recommended for SNR measurements due to uncertainty in its calculation. The equation for dB based on power is 10*log(P2/P1), and based on voltage magnitude is 20*log(V2/V1)). It is not clear which equation is more appropriate for touch applications. There is also confusion in the interpretation of "dBs of touch". To avoid these problems, Cypress Semiconductor has adopted a simple ratio as the preferred metric for capacitive sensing SNR. The best practice guideline offered by Cypress is to achieve a signal that is at least 5 times larger than the noise [1]. Stating this in engineering terms, this is a minimum SNR of 5:1.

Figure 1. Signal and noise components of a capacitive sensor waveform. In this example, sensor counts increase when a finger is placed on the sensor. The peak-peak noise has 8 counts, the signal has 118 counts, so SNR is 15:1.



How to Measure SNR

As an example of how to measure SNR in a touch sensor application, consider the waveform in Figure 1. A finger not on the sensor results in peak-peak noise of 8 counts. Placing a finger on the sensor results in a signal of 118 counts. SNR is 118:8, which reduces to a ratio of 15:1.

SNR should be measured with best-case and worst-case fingers. A best-case finger would be a large finger centered on the sensor pad. A worst-case finger would be a small finger placed off-center. Using an actual finger is an acceptable method for early development of a handset system. A metal disk or rod can be substituted for a real finger if it is desired to make the testing more operator-independent and repeatable.

The overlay thickness has an attenuating effect on signal strength, so a conservative approach is to develop the system using an overlay that is slightly thicker than planned. To avoid masking effects of higher-level firmware, measure SNR using raw, unprocessed sensor counts. Turn off any self-compensating or auto-calibration features that force the sensor output to zero when a finger is not present. The raw counts should appear similar to the waveform shown in Figure 1.

Create a Noise Budget

Creating a noise budget is one way to manage the performance of the capacitive sensors, and involves making a list of noise sources that can decrease the SNR of the system. For mobile handsets, these noise sources include internal IC noise, RF noise, and AC line noise. Estimate the effect on the sensor counts for each noise source. The sum of all these count values plus some extra counts thrown in for design margin should result in SNR greater than 5:1.

A mobile handset by nature creates an environment that is high in RF energy, and this may have a bigger effect on the system than adding a few counts of noise to the system. The problem with operating capacitive sensors next to an RF transmitter is that a sensor trace can act as efficient antenna. Coupling large amounts of RF energy into a controller IC can cause unexpected results in the sensor system that can make touch sensing impractical. A simple solution to this potential problem is to damp the resonance using series resistors. A few hundred ohms in series with the sensor inputs, placed as close as possible to the pins of the control IC, are enough to prevent this problem from occurring.

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Mobile Implies Low Power Consumption

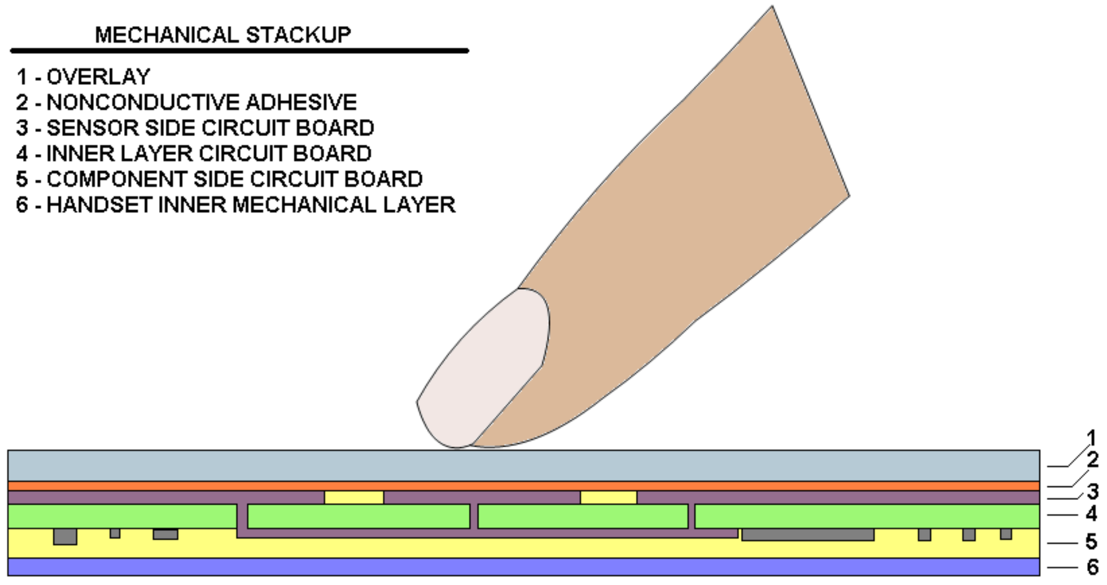
A capacitive sensing solution for mobile handsets needs to have low power consumption. As with any battery powered mobile device, the low power goal dictates that the controller should report to the host no faster than required, should scan the sensors no longer than required, and should sleep if no other events are pending.

The key to long battery life is to minimize the levels of average current that flows when the sensor is actively scanning and processing data. Average current is computed using a simple time-weighted average of the active current and sleep current, so the longer the controller is sleeping between scans, the longer the battery life. A practical limitation to long sleep intervals is the latency of the system, which is the time delay between the touch event and the response of the system to the touch. A non-technical user would describe a high latency as slow or sluggish buttons. In the extreme case, very long sleep intervals would result in missing some of the user interaction. **The challenge in handset design is to find a good balance between fast sensor response and low power consumption.** Latency of 30 to 50 milliseconds is a good goal for mobile handset design. To lower the power consumption even further, it is common for the sensor to enter a longer latency mode if there has been no user input for an extended period. This slower scanning mode, called standby mode, has a latency of 100ms or more. As soon as user input resumes, the system enters the active scanning mode that has more responsive buttons.

$$I_{AVE} = \frac{t_1 I_{ACTIVE} + t_2 I_{SLEEP}}{t_1 + t_2} \quad (1)$$

The following example calculation shows how to reach an average current in standby mode of just 33uA in a 12-sensor handset design. The equation for average current, I_{AVE}, is shown in Equation 1. Scan time is set to 0.5 milliseconds per sensor (t_1 = 12*0.5 = 6 milliseconds). The report rate in standby mode is 100 milliseconds, so the sleep interval is set to 94 milliseconds (t_2 = 100 - 6 milliseconds). Sleep current and active current are read from the controller IC datasheet (I_{SLEEP} = 3uA, I_{ACTIVE} = 1500uA). Evaluating Equation 1 with these parameters yields an average current of 93uA. If only a subset of sensors are scanned in standby mode, then the average current can be reduced even further. Arranging the 12 sensors in groups of three reduces the scan time (t1 = 12/3*0.5 = 2 milliseconds). The average current in this case drops to 33 microamps.

Figure 2. Cross-sectional view of the mechanical stack-up of a mobile handset capacitive sensor.


MECHANICAL STACKUP
1 - OVERLAY
2 - NONCONDUCTIVE ADHESIVE
3 - SENSOR SIDE CIRCUIT BOARD
4 - INNER LAYER CIRCUIT BOARD
5 - COMPONENT SIDE CIRCUIT BOARD
6 - HANDSET INNER MECHANICAL LAYER
1
2
3
4
5
6

Mechanical Considerations for Mobile Handsets

The packaging trend in mobile handsets is towards thinner packages, so the mechanical stackup, as shown in Figure 2, is an important consideration of the system design. In fact, **poor layout of the sensor traces and excessive overlay material thickness are the leading causes for low SNR in mobile handsets.**

The circuit board is typically a flex circuit, or in some cases a thin rigid board. The circuit board is mounted on the overlay using a thin layer of nonconductive adhesive film, which improves the coupling of the electric field from the sensors to the overlay. The adhesive layer also creates a stable mechanical system that has consistent response for both light and heavy finger pressure. A target overlay thickness of 1-3 millimeters provides mechanical strength to the handset package without excessively attenuating the capacitive sensing signal. More layout guidelines are found in Cypress Semiconductor application note AN2292 [2].

Programmable Solution Makes Development More Flexible

There are a number of options for the system controller. At the application specific end of the spectrum are the fixed function devices that do nothing but scan sensors and output data. At the highly integrated and flexible end of the spectrum are programmable sensing devices that allow for both last-minute design changes and for support of non-capacitive sensing functions. The PSoC family of devices from Cypress Semiconductor, which stands for Programmable System on Chip, provides a programmable solution that fits well with mobile handsets. The capacitive sensing functions supported by CapSense include buttons, sliders, touchpads and proximity sensors. Through a value-added concept called CapSense*PLUS*, the PSoC chip performs capacitive sensing plus a number of other functions that are typically done by one or more other devices. For example, a handset may require capacitive sensing of the keymat, ambient light sensing through a photodiode, tilt sensing via an accelerometer, and motor driving of a small motor that runs when the handset is set in vibrate mode. A single PSoC chip can support the integration of all these functions, with flexible software development done in C.

As another example of the value added by a programmable solution, consider the following scenario. Since all sensing and control functions are under software control, it is possible to configure the capacitive sensors for proximity detection during low power standby mode, and to reconfigure the same sensors as touch sensors in normal operation mode. In standby, the proximity sensors are scanning for the presence of a finger in a zone of one or two centimeters above any of the capacitive sensors. When an approaching finger is sensed, the PSoC is reconfigured in software so that the proximity sensing function is replaced by the touch sensing function. The handset will continue in this mode of operation until the user stops interacting with the capacitive sensor, in which case the handset set back to standby mode with proximity sensors

Transparent Touchscreens Based on Capacitance

The latest trend in touch sensing in mobile handsets is the use of ITO on glass or plastic film. ITO stands for Indium Tin Oxide. It is a conductive material that is transparent when applied as a thin film. It has been used for years in resistive touch screens. Recent advances in microcontrollers have made capacitive versions of the same touch screens practical. Since resistive touch screens rely upon mechanical deflection of the touch surface, they eventually wear out and need replacement. Capacitive versions of the ITO touch screen do not require mechanical deflection. Elimination of this mechanical failure mode is one of the advantages of capacitive-based ITO touch screens over the standard resistive ones.

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Conclusion

This article has demonstrated how to incorporate capacitive sensing features into a mobile handset. It will be interesting to see what cool features emerge in the coming year using this technology.

References

[1] Application Note AN2394, " CapSense Best Practices", Cypress Semiconductor
[2] Application Note AN2292, " Layout Guidelines for PSoC CapSense", Cypress Semiconductor

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