Projected-Capacitive Touch Systems from the Controller Point of View

Projected-capacitive touch has grown more than 100-fold in revenue since the iPhone was introduced in 2007, and it shows no signs of slowing down. This article describes many of the design and application challenges that must be faced when integrating projected-capacitive touch into a device, with a particular focus on the importance of the controller's signal-to-noise ratio.

by Tim Wang and Tim Blankenship

EVER SINCE the iPhone was introduced in 2007, projected-capacitive (pro-cap) touch-screen technology has been adopted in a growing range of applications. However, integrating a pro-cap touch sensor into a touch-screen device is still a challenging problem, especially with respect to the noise generated by the liquid-crystal display (LCD), peripherals, and environment. One of the most promising solutions is to make use of a high-signal-to-noise-ratio (SNR) touch-screen controller to combat the noise problem. A high-SNR controller also has a number of other benefits that will be explored here.

SNR is defined as the power ratio between a signal (meaningful information) and the background noise (unwanted signal). If the signal and noise are measured across the same impedance, the SNR can be obtained by calculating the square of the root-mean-square (RMS) amplitude values. The numeric ratio of the power values (PS/PN) is often so large that it is best described using the logarithmic decibel (dB) scale. SNR can therefore be expressed as

$$\begin{aligned} \mathrm{SNR_{dB}} &= 10\log_{10}(P_S/P_N) \\ &= 10\log_{10}(\mathrm{RMS_S}/\mathrm{RMS_N})^2 \\ &= 20\log_{10}(\mathrm{RMS_S}/\mathrm{RMS_N})\ . \end{aligned}$$

Higher SNR values represent higher signal strength measured relative to the background noise.

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Overall Touch Performance

From a high-level view, there are two main components that determine overall touch performance: the touch-sensor design and the touch-controller design. Various projected-capacitive touch-sensor pattern designs exist, often referred to by names that are indicative of the shape or construction of the pattern, such as triangles, diamonds, snowflakes, streets and alleys, and telephone poles. For example, "diamond" is a grid of diamond-shaped (rhombus) structures, while "streets and alleys" is a grid of intersecting rows and columns that resembles a city layout. Some patterns use a single layer of ITO, while others require two or three layers, depending on the system performance desired and the architecture of the touch-controller integrated circuit.

Often, the touch-sensor pattern and layer structure ("stack-up") are tailored to the touch-controller architecture to maximize SNR. For example, in a single-layer mutual-capacitance diamond pattern with crossovers (shorting bridges), the distance from the touch surface to both the X and Y layers of ITO is the same. This reduces gain error and makes the SNR levels similar for rows and columns. However, this design may also require a shielding layer to prevent the sensor from picking up LCD noise. Using a touch-controller capable of high SNR can reduce the touch-sensor cost by relaxing the constraints on the design, enabling the use of a wider range of patterns and layer structures. As will be discussed later in this article, a high-SNR touch controller can also provide additional benefits such as making it easier to find a touch event's center of mass, reducing the touch screen's susceptibility to environmental noise and allowing the use of gloves and a small-tipped conductive stylus.

Controller Architecture

The two main competing pro-cap touch technologies are self-capacitance and mutual capacitance.[1] Self-capacitance is based on measuring the capacitance of a single electrode with respect to ground. When a finger is near the electrode, the human-body capacitance changes the self-capacitance of the electrode. Spatially separated electrodes

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are usually arranged in a single layer; each electrode is measured individually.

Mutual capacitance is based on measuring the capacitance between two electrodes. When a finger is near the electrode pair, the human-body capacitance changes the capacitance between the electrodes by "stealing" some of the charge. Electrodes are typically arranged in two spatially separated layers, usually in rows and columns; every intersection of every electrode is measured. A brief summary of the characteristics of self- and mutual capacitance follows.

Self Capacitance

- Early-generation pro-cap method still used today.
- Generally limited to one touch or two touches with ghosting (false touches positionally related to the intended touches).
- Diamond pattern is most common.
- Lower LCD noise immunity.
- Simpler, lower-cost controller.

Mutual Capacitance

- New-generation design gaining market share.
- True multi-touch with two or more unambiguous touches.
- Better touch accuracy.
- Allows more flexibility in the sensor pattern design, which can help maximize SNR.
- Better immunity to noise.
- More-complex higher-cost controller.

Many applications require only one or two touches and therefore a self-capacitance solution can be attractive, especially if the touch locations in the user interface can be controlled to eliminate ghosting. While a typical SNR of over 30 dB can be achieved with self-capacitance systems, this generally requires a shield layer between the LCD and the bottom touch layer of the sensor, which adds cost and reduces display brightness.

Other techniques can be applied to self-capacitance solutions to further increase SNR. These include (a) increasing the number of samples per channel; (b) increasing the sensor drive voltage, which increases signal amplitude in the presence of fixed background noise such as that from an LCD; and (c) sampling at various frequencies in order to avoid fixed-frequency interference such as at 60 Hz (this is known as "frequency dithering"). However, these techniques also typically reduce frame rate and increase power consumption, both of which are usually undesirable.

In order to maximize SNR and support two or more unambiguous touches, it is clear from the above that the most desirable touch-system architecture relies on mutual capacitance. The system block diagram in Fig. 1 illustrates a generalized mutual-capacitance implementation that applies an excitation signal to one of the touch-sensor capacitor plates. The other touch-sensor capacitor plate is connected to the analog front-end (AFE) of the touch controller. The AFE output is converted to digital form and further processed in a digital signal processor (DSP).

Design Challenges

There are many technical challenges when integrating a pro-cap touch sensor into a touch-screen-equipped device. The following paragraphs describe some of the most common situations that can benefit from a high-SNR touch controller.

Sensor stack-up: A wide range of touch-sensor layer structures exists in the touch industry today, driven by materials considerations, device-thickness goals, performance requirements, and cost targets. One example appears in Fig. 2. Single and multiple substrates, "face-up" and "face-down" structures, variations in the thickness of the X and Y sensor layers, variations in the thickness of optically clear adhesives (OCA), and other factors all affect the signal level produced by the sensor. A high-SNR touch controller can reduce the significance of these structural differences because it is able to handle a wider dynamic range of touch-sensor signals. This gives the designer more freedom in the design of the stack-up.

Thick cover lens: Some applications such as a bank ATM may require a thick cover lens to protect the display from vandalism. However, a thick cover lens reduces the signal strength of the finger touch detection and reduces the accuracy of the touch position because the finger is further away from the touch sensor.

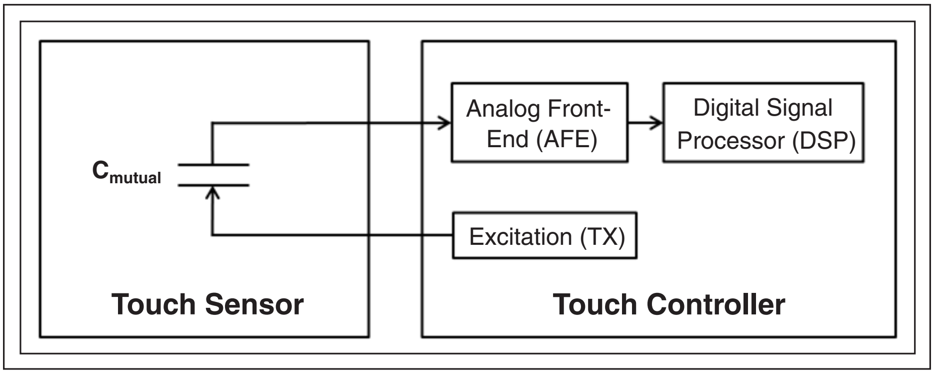

Fig. 1: *The relationship between touch sensor and controller is shown in a system block diagram of a generalized mutual-capacitance system. Source: Maxim.*

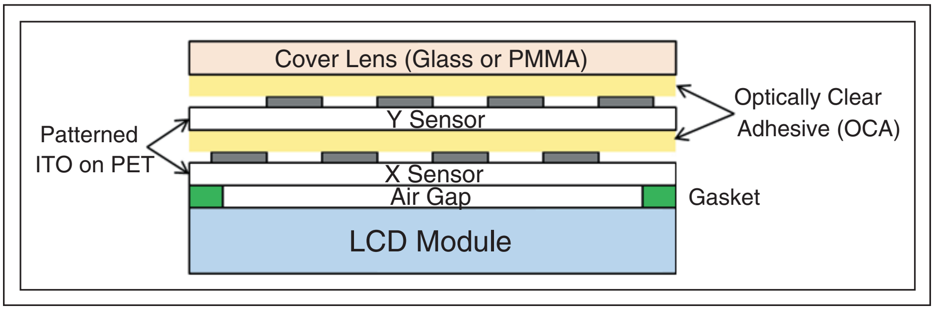

Fig. 2: *Shown is but one of many different mutual-capacitive touch-sensor stack-ups (not to scale). Source: Maxim.*

This "spreads out" the capacitance profile and reduces the peak, which makes it more difficult to determine the precise location of the intended touch. Gloved hands have a similar effect.

LCD V_{com} type: LCD V_{com} refers to "common voltage," the reference backplane voltage of a typical LCD. The technique of driving the backplane varies depending on the system requirements. Two common methods are AC V_{com} and DC V_{com}. AC V_{com} modulates the backplane between multiple voltage levels, while DC V_{com} maintains a constant voltage on the backplane. The former method produces more noise.

Air gap between touch sensor and cover lens: One of the most common problems reported by touch-screen-device end-users is a broken cover lens. To make a product thinner, a pro-cap touch sensor can be laminated to the back side of the cover lens. However, when replacing a broken cover lens, the touch sensor must also be replaced, which increases the cost of the repair. To avoid this cost – as well as the cost and lower yield of lamination – device manufacturers often separate the touch sensor and the cover lens with a thin gasket.

However, when an air gap is introduced between the touch sensor and the cover lens, it becomes more difficult for the touch sensor to detect a finger touch since the low dielectric constant of air reduces the signal strength from a finger touch. One way to solve this problem is to boost the touch system's sensitivity threshold, but this is a dangerous game since the sensor can then pick up unintentional signals such as LCD noise or other ambient noise from the environment, which makes it more difficult for the touch sensor to differentiate a touch from the noise.

Industrial design requirement: Some device manufacturers laminate the touch sensor directly onto the display in order to achieve an overall thinner design. But this also poses significant risk since the touch sensor is then located directly on top of a significant noise source. One solution is to add a shield layer between the touch sensor and the display. However, adding an extra ITO layer increases the overall material cost and has a negative effect on optical clarity.

On-cell touch sensor: In order to reduce the overall manufacturing cost, one approach increasingly being taken by LCD manufacturers is to locate the touch sensor directly on top of the color-filter glass under the polarizer. While this eliminates the need for an external sensor and lamination, the touch sensor is located even closer to the heart of the display, which increases the noise level seen by the sensor even further.

Touch-controller location: Pro-cap touch controllers are most commonly located on the touch-sensor cable (chip-on-flex or chip-on-PCB), or sometimes directly on the touch sensor (chip-on-glass). However, to make testing the touch sensor easier, some designs require the touch controller to be mounted on the system board. This approach may require a long flexible printed circuit (FPC) connecting the touch sensor to the touch controller. A long FPC can act as an antenna that readily picks up additional noise, making it more difficult for the touch controller to process the analog information from the touch sensor.

Other noise sources: The major sources of noise on a mobile device are from the LCD (or EPD), LCD inverter, WiFi antenna, GSM antenna, and various high-speed circuits within the device. Ambient noise can also have a significant impact on the touch system. Some AC power sources produce a high level of noise that is readily conducted through the device's AC adapter. Also, when a device is placed close to a strong source of noise such as a desktop fluorescent lamp, the touch system can misinterpret the noise as an intentional touch.

For a normal-sized finger (>7 mm) under normal conditions, a high-SNR controller may not have a significant advantage over a low-SNR controller. The advantage appears when a weak input signal, such as that created by a stylus or a small or gloved finger, is combined with a noisy environment. A low-SNR controller will not be able to differentiate the signal from the baseline noise in this situation. If the sensing threshold is lowered to increase the touch-detection sensitivity, the touch system can easily be triggered by noise, causing unintended activation. In real-world applications, unintended activation is absolutely not permitted.

Application Challenge

Touch accuracy: Touch accuracy is an important specification in touch-sensor design. For example, in a virtual keyboard application, the characters are tightly packed into a relatively small area. Precision response to a touch is critical to avoid mis-typed characters. One way to achieve high accuracy is to add more sensor channels in the controller to support a higher touch-sensor grid density. But this also comes with a cost penalty because more pins are needed on both the touch sensor and the touch controller. In addition, more sensor channels require more traces running along the border of the touch screen, which may increase the bezel width.

A high-SNR touch controller increases touch accuracy because it enables stronger signal readings from a touch and collects sample data from a larger surrounding area. The larger area provides more reference points from which the precise location of a touch can be calculated. Figure 3 illustrates the effect of the touch-controller SNR on line drawings made by a robot arm holding a 4-mm metal slug. The line drawn with a high-SNR controller is noticeably smoother than that drawn with a low-SNR controller. Note that these measurements were recorded with the same touch sensor and the same post-processing software to ensure the fairness of the comparison.

Stylus: Resistive touch-screen users have long been accustomed to using a fine-tipped stylus. A typical resistive touch-screen stylus has a tip diameter of less than 1 mm and is usually made of non-conductive plastic. It has been an extremely difficult challenge for pro-cap touch systems to detect such a small, non-conductive device, since its influence on the signal generated by the touch controller is so weak. Many of the existing touch systems on the market require a large-diameter stylus (3–9 mm), which is difficult to use for drawing and writing because the large tip obscures the digital ink being created.

A high-SNR touch controller can detect a stylus with a 1-mm-diameter tip, as long as the stylus is coated with a conductive material (a relatively small sacrifice). Figure 4 illustrates the effect of touch-controller SNR on the detection of a conductive stylus with a 2-mm tip. It is very difficult for a low-SNR controller to recognize the small stylus with a noisy background, particularly in the noisiest portion of the screen. Reducing the stylus to a 1-mm tip in the low-SNR case would result in the desired signal being buried in the background noise, rendering the stylus useless.

Hover detection: Proximity detection is gradually being adopted in touch-screen applications. For example, by increasing the touch-system sensitivity while using an eReader application, the user can flip a page with a hand-gesture without physically touching the screen. However, a touch system with increased sensitivity can also be triggered by surrounding noise. It is a constant struggle for designers to find the optimum balance that maximizes proximity distance without causing accidental activation. Mitsubishi has done some interest-

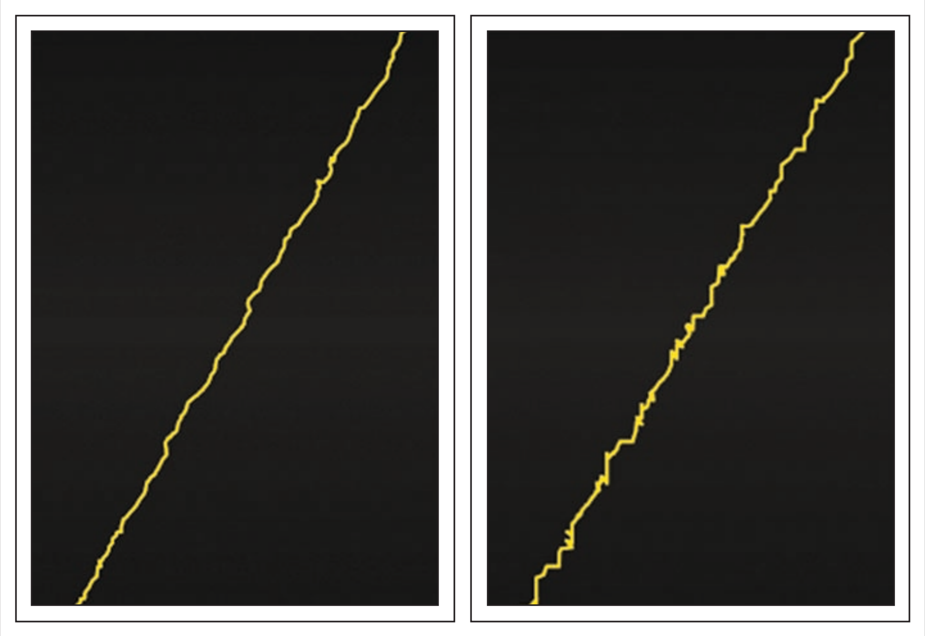

Fig. 3: These line drawings were made by a robot arm holding a 4-mm metal slug. The drawing on the left reflects the use of a high-SNR touch controller; the one on the right, a low-SNR touch controller. Source: Maxim.

ing research in this area in which it created a touch system that automatically adjusts its sensitivity based on whether a touching finger is hovering or actually touching.[2]

Glove operation: In medical applications, a touch screen should accommodate use with surgical gloves. Similarly, a touch-screen GPS device in a car should accommodate use with gloved hands in winter. Most winter gloves are made of a dielectric material that makes it difficult for the touch sensor to detect a touch. Increasing the touch controller's sensitivity may cause unintentional triggers when the user is not wearing gloves. Currently, the only solution on the market requires the application (or the user) to select different sensitivity levels based on use.

Conclusions

A high-SNR pro-cap touch controller brings many benefits. It can accommodate a wide range of design and application requirements such as a stylus, small fingers, and gloves. It can improve the accuracy of the reported touch position without requiring special ITO sensor patterns or adding more sensor channels. It can accommodate various display types with a variety of backlights while maintaining good touch performance. It offers greater flexibility in sensor design and manufacturing requirements. It can enable touch-system operation in a noisy environment and also has the capability to mitigate noise emitted from the device itself such as that from the LCD, WiFi antenna, GPS antenna, and AC adapter. It offers device OEMs the freedom to select from a broader range of components. Finally, from a performance point of view, it offers precise touch accuracy. In summary, a high-SNR touch controller enables a robust experience for end users.

References

[1] G. Barrett and R. Omote, "Projected-Capacitive Touch Technology," *Information Display* **26**, No. 3 (March 2010).

[2] http://techon.nikkeibp.co.jp/english/NEWS_EN/20090310/166952/?P=1 ■

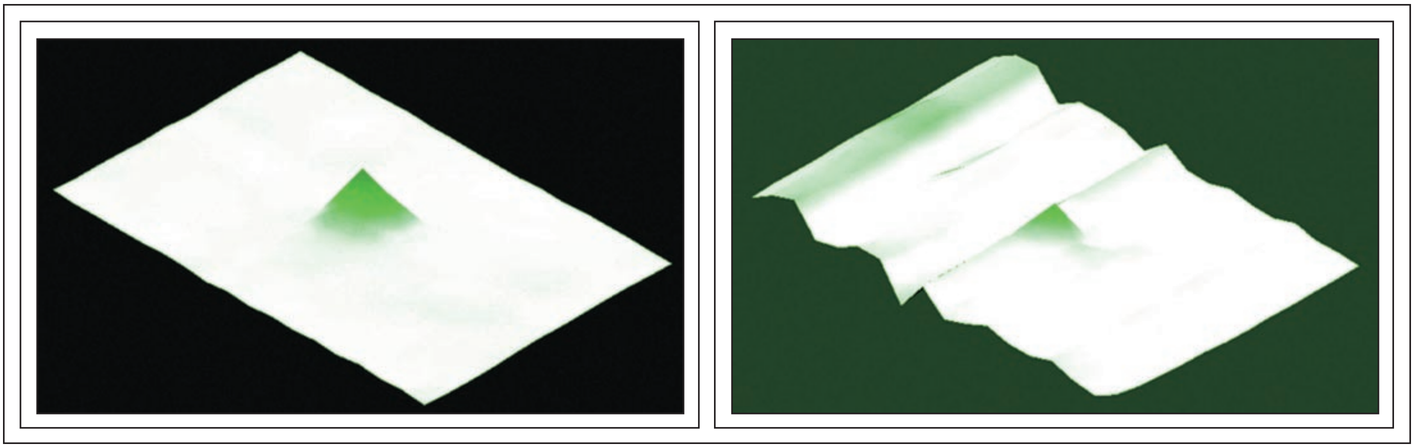

Fig. 4: In these capacitance profiles of a 2-mm conductive stylus on a 4-in. display, the profile on the left reflects the use of a high-SNR touch controller; the one on the right is a low-SNR touch controller. The stylus is positioned at the apex of the green cone; the height of the white surface represents the level of background noise across the display. A large increase in signal-to-noise ratio effectively reduces the peak-to-peak amplitude of the background noise, as shown in the profile on the left. If the stylus in the profile on the right were moved to the left edge of the screen, the signal would disappear into the noise and the stylus would cease to function. Source: Maxim.