Clear Capacitive Technology from Discrete Sensors to In-Cell and TDDI

Executive Summary

This white paper will assist the reader to better understand capacitive sensing and various implementations through the evolution of discrete ClearPad sensors to In-Cell and single-chip Touch Display Driver Integration (TDDI). Capacitive sensing has been used in Synaptics TouchPad™ interface solutions in laptops since 1995 to enhance the user experience and enable users to more easily interact with content on the display. The introduction of LGE’s Prada phone with Synaptics ClearPad™ in 2007 and then the popular iPhone, clear capacitive touchscreens enabling direct touch interaction (versus indirect touch with TouchPad devices) are the expected input method for electronic devices and part of mainstream culture.
The first clear capacitive touch implementations used discrete sensors to drive technology adoption and maturity. For example, polyethylene terephthalate (PET) sensors were based on existing materials technology used for resistive sensing. Synaptics and industry partners have continuously improved capacitive technology leading to today's leading edge offerings with touch sensing integrated into the display.

**Capacitive Sensing**

A brief overview of capacitive sensing is provided here as a basis for understanding various implementations of capacitive touch sensing. The baseline technology of self-capacitance (or profile sensing) was introduced by Synaptics into laptops almost 20 years ago and has continued to be a go-to technology for this segment. Self-capacitance enables multi-finger gestures such as Pinch and two-finger swipes but does not support true independent multi-finger tracking, which is frequently used, for example, in handheld gaming applications.

Transcapacitive (or mutual) sensing is required for true multi-finger tracking and continues to gain traction as the technology for mainstream and high-end smartphones. It is also the primary technology for the purposes of this paper to simplify the variables. Transcapacitive technology requires receivers (Rx) and transmitters (Tx) and they are usually both made from indium tin oxide (ITO) on glass or PET substrates. The following are some other conductive materials which are also possible substitutes for Rx and Tx:

- Carbon nanotubes (CNT)
- Wire/metal mesh
- Conductive inks

In general, the Rx and Tx run orthogonal to each other in a grid orientation but emerging technologies are enabling true multi-finger tracking on single layer sensors, that is, no Rx/Tx crossings, jumpers, or shields are required.
Discrete Sensors

Capacitive touch technology for mobile devices was initially developed for discrete sensor implementations, as shown in Figure 1.

In this manner, discrete sensors can be integrated into a phone or other handheld devices in a fairly straightforward manner. The capacitive sensor is between the cover lens and the display, and typically, the discrete sensor is laminated to the cover lens and can be laminated to the display as well. Although discrete sensors continue to be used extensively, there are challenges with multiple suppliers and the potential for yield fallout across the manufacturing and integration process which have to be optimized and closely monitored during mass production.

Lamination to the display, if used, can be costly as it is an additional process step with yield considerations and if there is a defect such as air bubbles or dust, it can be difficult to rework. However, UV hardened resins more easily enable re-work for fully laminated designs if the defect is discovered before curing the resin. A number of handsets use display lamination to have high optical qualities, in particular, low reflectance.

There are two primary materials used for discrete sensors, glass and PET. For glass sensors, the Rx and Tx are either both on top of the glass, as shown in Figure 2, or Rx on top and Tx on the bottom.

Figure 1. Discrete sensor implementation

Figure 2. Glass sensor example with Rx and Tx.
Rx and Tx on the top of the glass are commonly referred to as SITO (single-sided ITO) or as DITO (double-sided ITO) when Rx and Tx are on the opposite sides of the glass. SITO sensors need to electrically isolate the Rx from the Tx which is not needed for DITO sensors, as the glass substrate is the insulator. On SITO a dielectric insulator is placed on top of the Tx followed by an additional ITO jumper for Tx continuity across the sensor, as shown in Figure 3.

For PET sensors, the Rx's are on the first PET layer which is laminated to a second PET layer with the Tx's. The Rx and Tx are also generally made from ITO and sputtered onto the PET film. Some PET sensor suppliers are able to sputter and pattern ITO on opposite sides of a single PET substrate and SITO for PET.

Sensor-on-Lens (SoL)

Putting the sensor pattern directly on the lens streamlines the stack-up by eliminating discrete sensors and integrating the sensor directly onto the cover lens. For SoL, Rx and Tx are on the back of the lens like a SITO glass sensor, as shown in Figure 4.

As a result SoL enables handsets to be up to 1 mm thinner than discrete sensors. SoL has some challenges and manufacturing considerations and various suppliers are working to improve this. First, the ITO must be sputtered on top of the decorative ink on the underside of the lens unless the ink is on the top of the cover lens, in which case the ink is not well protected from wear and scratches.
This process is typically limited to black ink. Also, because the ink cannot be overly heated, the ITO cannot be annealed at high temperatures, which can result in the ITO having higher resistivity than discrete sensors. This leads to slower sensing frequencies with a reduction in noise immunity. Finally, a subtle issue is that the coupling between the fingers and the receivers is quite strong in SoL designs, which can lead to further noise immunity reduction and also aggravates the floating-condition impairment (called low-ground mass effect at Synaptics). SoL continues to be a viable touch implementation and Synaptics 3200 Touch Controller has been used on numerous handsets including Sharp’s SH-07D.

**On-Cell**

In addition to eliminating the discrete sensor like SoL, On-Cell solutions enable display integration. For On-Cell the Rx and Tx are placed on top of the color filter (CF) glass using SITO. On-Cell was made popular by Samsung Mobile Display using AMOLED. In addition to AMOLED support, Synaptics partnered with Sharp Display to bring to market the world's first On-Cell with a 3-D display, the Sharp DC250 phone, in 2011. On-Cell can have similar ITO resistance challenges as mentioned in the SoL case and liquid crystal display module manufacturers (LCMs) continue to invest to improve this as well as to improve SITO yields related to the jumpers on the CF glass.

**In-Cell**

In-Cell solutions require close cooperation with LCMs as the capacitive sensor is embedded inside the display. In-Cell implementations are complex and require optimizing numerous variables including:

- Capacitive loading
- Display timing
- Settling times

There are various In-Cell implementations; most common is with a thin film transistor (TFT)-LCD using in-plane switching (IPS) technology but In-Cell is possible with vertical alignment (VA) and plane line switching (PLS) technologies. For IPS, it is possible to either have both the Rx and Tx on the TFT glass (co-planar) or to have the Tx on the TFT glass and the Rx on the CF glass. The latter gives a better touch performance and higher signal-to-noise ratio (SNR). The reasons for this are:

- Rx is on top of CF glass
- Tx is on the TFT glass
- Rx and Tx are separated (not co-planar), which improves the finger signal by reducing the baseline capacitance of the sensor.
- RX is closer to the finger so for a given finger size or stylus, a larger signal is achieved compared to a co-planar design.
A typical exploded view of an In-Cell design is shown in Figure 5.

Another benefit of In-Cell technology is that the displays can be 10% brighter as there are only narrow Rx's above the image to reduce the backlight transmittance. For other cases (discrete, on-cell, and so on) both Rx and Tx lower light transmittance as does the discrete sensor itself.

Instead of a brighter display, a lower power setting for the backlight can be used to maintain the same brightness but at a reduced power level. In addition, In-Cell is not a SITO design so there are no jumpers which further improves yield for touch display modules. The first Mass Production of In-Cell is the Sony Xperia P, quickly followed by the hTC Evo Design, both of which use Synaptics 3250 In-Cell Touch Controller.

**TDDI**

In 2011, Synaptics introduced TDDI, which further enhances display touch modules. TDDI integrates the touch controller and Display Driver IC (DDI) into a single ASIC. In addition to the In-Cell benefits, the TDDI solution benefits include:

- User experience (UX) enhancements.
- The lowest cost of touch sensing.
- Reduced space requirements on the flexible printed circuit (FPC) as the TDDI is mounted on the TFT glass using chip-on-glass (COG) technology like standards DDIs.

The graph in Figure 6 is an estimate of the relative incremental cost of adding touch from discrete sensors to TDDI for OEMs.
In-Cell air gap enables an air gap between the sensor and cover lens as shown in Figure 7. The primary benefits include:

- Eliminating the lamination step and associated yield which decreases costs.
- Enabling just-in-time cover lens selection and assembly that is done just before the phones are shipped. This allows OEMs to quickly respond to demand fluctuations, carrier-specific logos and trending colors for the cover lens, and capture revenue upside.

The TDDI UX enhancements use the overlay menu in the Synaptics' TDDI solution to provide image and gesture support in a reduced power mode. For instance, the date, time message and call notifications can be continuously displayed even when the phone application processor (AP) is in sleep mode as shown in Figure 8.

The image is maintained by the TDDI overlay memory and updated from the Apps Processor once a minute for the clock example or less frequently for notifications. In addition, touch gestures can be enabled even when the display is off for low power wake-on gestures such as a tap, swipe or further differentiating gestures to bring the phone out of sleep mode.

**Summary**

The evolution of clear capacitive technology from discrete sensors with ITO electrodes to new materials and leading edge implementations such as In-Cell and TDDI has provided ample opportunity for OEMs to differentiate their product offerings with thinner devices and an improved user experience (UX). These advances have resulted in capacitive sensing as a must-have feature for all Smartphones as well increasing the share of Smartphones in mobile devices. Synaptics has working closely with OEMs, LCMs and eco-system partners at every step of the way over the last 20 years and leading the capacitive touch technology development and look forward to continuing the trend with expanding In-Cell and TDDI.
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