Aggressively combat noise in capacitive touch applications

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A touchscreen device can be subject to many different noise sources, both internal and external, in a given day. Charger and display noise are two of the most common and problematic noise sources today. As devices get thinner and noisier chargers enter the market, these challenges will only become tougher to manage. Additionally, many other everyday items can generate noise that causes interference, including radio signals, AC mains, and even fluorescent light ballasts. In the presence of noise, the positions reported by low-performance capacitive touch systems will be distorted impacting accuracy and reliability.

Today’s touchscreen controllers employ a wide variety of techniques both to increase SNR and to filter out bad data from noise: high-voltage Tx generated on-chip, specialized hardware acceleration, high-frequency Tx, adaptive frequency hopping, and saturation prevention techniques. However, touch technology continues to advance in how the touch controller utilizes these features, dynamically adapts to the noise present in the system, and accurately track touches despite changing environmental conditions.

Effects of injected noise include large amounts of jitter (high variability in the touch coordinates reported for a non-moving finger), false touches reported where there is no finger on the screen, not reporting a finger that actually is touching the screen, and even completely locking up the device. In a touchscreen phone, for example, this could mean not being able to unlock your phone (due to your finger not being reported) or dialing the wrong number due to jitter and false touches (a late night call intended for a friend may not be as well-received if your boss is dialed instead). Figure 1 shows the results when testing finger tracking (i.e., single finger drawing a circle) on a best-selling smartphone that is in the market today. As noise increases, the reported location of the finger on the panel (shown in blue) is corrupted and additional false touches are detected on the panel (shown in various other colors).
The quality of the touch interface a user experiences can be greatly affected by how a touchscreen controller combats noise. Poor touch performance in the presence of noise can lead to unhappy customers and an increase in returns. Because not all noise is the same, it is important for touchscreen controllers to be able to detect, differentiate, and manage noise, particularly the two most problematic noise sources: chargers and displays.

**Chargers and Common-Mode Noise**

A major problem for capacitive touchscreen devices is degraded touch performance due to chargers that emit noise that is high amplitude, high frequency, or both. Some mobile devices have addressed the noisy charger problem by providing only limited touch functionality when plugged into a charger or by displaying messages stating that the connected charger is not supported when it is not the device’s approved charger. These solutions are incomplete at best. A quick look through some related online forums and message boards quickly reveals that problems in touchscreen devices due to charger noise are quite prevalent and have created some very frustrated consumers.

The proliferation of USB as a standard charger interface to mobile devices has led to a flood of low-cost aftermarket chargers. Many of these chargers prioritize cost over performance, using cheap components or lacking certain components that would otherwise assist in reducing common-mode noise.

Common-mode noise occurs when both the power and ground supplies of a device fluctuate in voltage, relative to earth ground, but retain the same voltage differential between them. This fluctuation only affects touchscreen performance when an earth ground-coupled finger touches the screen. As the finger’s voltage potential is roughly that of earth ground and the phone’s power and ground are fluctuating relative to it, this causes noise to be injected into the touchscreen through the finger.

The amount of charge injected is primarily determined by the peak-to-peak voltage of the noise. The amount of charge that is transferred is also greatly affected by two other factors: the area of contact between the finger and the touchscreen, and the thickness of the touchscreen’s cover lens. The effect of both of these factors can be understood through the equation for the capacitance of a parallel-plate capacitor:

![Figure 1. Effects of Charger Noise on Finger Tracking](image)
More capacitance means more noise injected into the touchscreen. In this case, the parallel plates of the capacitor are formed on one side by the finger’s contact area and on the other side by the touchscreen sensor’s Rx (receive) electrode. At a first order, as the area of the finger’s contact with the touchscreen increases, the capacitance increases proportionally. However, since Rx electrodes are laid out in very narrow rows or columns, it is really the finger diameter that matters (see Figure 2). Aggressively combat noise--Page 2.

\[ C = \varepsilon_r \cdot \varepsilon_0 \cdot \frac{A}{d} \]  

Some OEMs use smaller fingers (e.g., 7 mm) to test their device’s immunity to charger noise. However, this does not cover the range of use cases. A typical finger is 9 mm in diameter and a typical thumb is in the 18 - 22 mm range. A common scenario of using a thumb to unlock a phone or scroll through a list is not ensured if only testing with 7 mm fingers. In fact, looking at the difference in diameter, a 22 mm thumb injects more than three times the charge of a 7 mm finger!

The distance (d) between the finger and the Rx electrode is primarily determined by the thickness of the touchscreen’s cover lens (See Figure 3). A typical cover lens thickness ranges from 0.5 mm to 1.0 mm. This means that a device with a 0.5 mm cover lens has roughly half the “d” and twice the capacitance as a device with a 1.0 mm cover lens. In other words, a 0.5 mm cover lens will inject twice as much noise as a 1.0 mm cover lens. With device form factors trending towards becoming thinner, cover lens thickness and thus a touch controller’s ability to support noise on these thinner lenses becomes important.
Though there are several product certifications for chargers, there are no requirements associated with common-mode noise. In 2010, a group of mobile phone OEMs agreed upon a common specification, EN62684, regulating the maximum allowable peak-to-peak voltages emitted by a charger across the frequency spectrum. This specification establishes that a charger should emit noise no more than 1 Vpp (from 1 kHz to 100 kHz), and even lower amplitude voltages at frequencies above 100 kHz. The typical aftermarket charger does not follow this guideline.

While quieter chargers produce noise on the order of 1 – 5 Vpp, noisy chargers can fluctuate in the 20 – 40 Vpp range, causing huge amounts of charge transfer. The amount of charge injected depends on the voltage amplitude of the noise \( Q = C \times V \). Despite this massive amount of noise, the touchscreen controller must still be able to detect a finger which causes a change in charge that is several orders of magnitude smaller.

A newly emerging source of common-mode noise in capacitive touchscreen phones is MHL (Mobile High-Definition Link), a standard interface used to transmit audio and video from mobile phones to HDTVs. A phone is connected to the HDTV via an MHL adapter which converts the phone’s USB interface to the TV’s HDMI interface. The common-mode noise is sourced from the TV’s power supply and driven through the HDMI and USB cables to the phone.

**The Challenges of Thinner Devices**

Today, thin is in. The push to make aggressively thin form factors for touchscreen devices, especially mobile phones, creates a two-fold problem: more noise coupled into the sensor from the display and a higher parasitic capacitance of the sensor.

Displays generate noise that is much lower amplitude when compared with charger noise, but they can have a huge impact on touch performance due to their close proximity to the touch sensor. While AMOLED displays are very quiet (but more expensive than LCDs), the majority of the market today is still the noisier ACVCOM and DCVCOM-type LCD displays. It is the VCOM layer, the common electrode, of these displays that is the source of their noise. Equation (1) will be revisited, but this time to determine the capacitance of the parallel plate capacitor created between a given Rx electrode in the touch sensor and the VCOM layer of the display. In this case, the area “A” is the entire area of the Rx electrode, as the display covers the whole screen, and the distance “d” is between the Rx electrode and VCOM layer.

Previously, touchscreen devices used an air gap or shield layer to protect the touch sensor from display noise coupling into the Rx electrodes. However these solutions add both thickness and cost (as much as $1.00 for a shield layer on a 4” display). Now, as devices are
getting thinner, air gaps and shields are removed and the touch sensor is laminated directly to the display with optically clear adhesive (OCA). This puts the sensor’s Rx electrodes closer to the noisy VCOM layer, thus reducing “d”, increasing capacitance, and coupling in more noise. Capacitance is increased even more due to replacing the air gap (dielectric constant, $E_r$, of 1) with OCA (dielectric constant, $E_r$, of 3). The next trend in thin devices is for some or the entire touch sensor to be integrated into the display, known as on-cell and in-cell respectively. Display-integrated stackups like these push the Rx electrodes of the sensor even closer to the VCOM layer of the display, thus coupling in even more noise.

The second issue with thinner form factors is increased parasitic capacitance ($C_p$) of the touch sensor. In finding ways to make the overall stackup thinner, the ITO substrate layers (made of glass or PET) are getting thinner. This reduces the distance between the transmit (Tx) and receive (Rx) electrodes of sensor, thus increasing capacitance. This increased $C_p$ requires a longer time to charge and discharge when scanning the touch panel and thus reduces the maximum frequency at which the panel can be scanned. The problem with this is that higher scan frequencies are preferred as there is generally less noise present in the higher frequency bands. Additionally, longer scan times mean higher power consumption and lower refresh rates. Aggressively combat noise--Page 3. The second issue with thinner form factors is increased parasitic capacitance ($C_p$) of the touch sensor. In finding ways to make the overall stackup thinner, the ITO substrate layers (made of glass or PET) are getting thinner. This reduces the distance between the transmit (Tx) and receive (Rx) electrodes of sensor, thus increasing capacitance. This increased $C_p$ requires a longer time to charge and discharge when scanning the touch panel and thus reduces the maximum frequency at which the panel can be scanned. The problem with this is that higher scan frequencies are preferred as there is generally less noise present in the higher frequency bands. Additionally, longer scan times mean higher power consumption and lower refresh rates.

### Solving the Noise Problems

With the wide variety of noise sources, touchscreen controllers need to be able to adapt to the level and type of noise present in the system at a given time. The primary metric to focus on to ensure the most robust noise immunity is signal-to-noise ratio, or SNR, in the presence of noise. This is achieved through the use of several different features.

![Progression of Thinner Stackups](image)
One of the key methods to attain a higher SNR is through scanning the touchscreen sensor with a high Tx (transmit) voltage. Raw SNR is directly proportional to Tx voltage and thus, bigger is better. In the past, high voltage Tx has been a challenge for many touchscreen controllers and has been achieved only through the use of an external high voltage analog supply (something that greatly increases power consumption and is not readily available within most consumer handheld devices) or large, expensive external components such as switching regulators. Both of these options add extra cost to the device. New touchscreen controllers generate the high voltage Tx on-chip through an internal charge pump.

Another method to boost SNR is through specialized hardware acceleration. Even though touch performance in the presence of noise is key, spending a lot of CPU time running noise filtering algorithms can come at the expense of reduced refresh rate and increased power consumption. By using proprietary hardware that can run in parallel with the CPU, the target refresh rate and power can be retained will still increasing SNR in the presence of noise. One example of this is Cypress’ Tx-Boost™ technology which triples the existing SNR. The frequency at which the touch sensor is scanned can greatly impact touch performance when noise is present.

Touch data can be corrupted if the frequency of the noise is close to the frequency at which the panel is being scanned. In this case, adaptive frequency hopping can be applied to change the scan frequency to one where noise is low enough amplitude to prevent data corruption. However, the effectiveness of frequency hopping can be limited, depending on the range of Tx frequencies that can be selected and the range of frequencies where noise is present. Some chargers radiate large amounts of noise across a wide range of frequencies, making it difficult to find a quiet area. Fundamental frequencies of charger noise largely exist from 1 kHz to 300 kHz with lower amplitude harmonics at higher frequencies. This can be combed with high frequency scanning in the 300 kHz to 500 kHz range, completely avoiding the highest amplitude noise bands and the first few harmonics. This technique also improves display noise immunity as it moves away from LCD noise frequency ranges.

Even though there are many techniques to increase SNR, the improvements they bring will not prevent touch data corruption if noise levels are so high that they completely saturate a touchscreen controller’s receive channel. Signal processing relies on an analog front-end that will output linear results. If that output is constantly stuck at its maximum value due to noise sources coupling in large amounts of charge, the touchscreen can be rendered useless. Addressing this issue can be done by increasing the range of the receive channel so that it can handle larger amounts of charge. This often comes at the price of additional silicon area, in the form of larger capacitors. Another solution to this problem is to divide down the raw signal prior to the receive channel to reduce the noise, but care must be taken as this also divides down the signal from the finger itself.

Display and charger noise are nothing new, but noisier chargers and thinner displays are triggering a necessary evolution of noise immunity capabilities within touchscreen controllers. To combat the more aggressive levels of noise, controllers today use a combination of features to increase SNR as well as avoid noise when possible. In the end, consumers expect consistent touch performance out of their devices, not varying performance based on a charger being connected or when standing near a noisy fluorescent light. As the challenges of noise change, touchscreen controllers will continue to progress to ensure that consistent performance is delivered.

About the Author

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