A finger-heating effect has been observed on mutual capacitive touch sensors with plastic film overlay. The symptom is exhibited as serious sensitivity degradation when there is a greater than 10°C temperature difference between the finger and a touch sensor. An in-depth experimental and theoretical analysis was performed to understand its fundamentals, followed by a proposed physical model addressing the electric field lines coupling among substrate materials, mutual capacitive electrodes, and the human finger. Recommended sensor stack-up and pattern design solutions based on mutual capacitive sensing chips are presented.

Introduction

Touch sensors with glass overlay prevail on the current smartphone and tablet market. Optical transparency is the major advantage. On the down side, in addition to cost, durability is another concern. Especially for the tablet size, drop tests always have been a challenge for glass overlay. Plastic film overlay, except for a little less transparency, is lighter, lower cost, and has no durability issue as with glass. Hence, there is a growing interest with applying plastic overlay on touch sensor stack-up. A key property difference between plastic overlay and glass, which contributes to the finger-heating effect, is its much higher heat transfer coefficient. To fully understand this subject, we begin with an introduction on stack-ups and sensor patterns under plastic overlay.

Plastic-film (PF) and plastic-film-film (PFF) are illustrated in Figures 1 and 2, respectively. Each has two kinds of structures using a plastic overlay, cross section, and associated sensor patterns for each stack-up. For PF stack-up, ITO film is optically bonded to the plastic overlay. Transceiver (TX) and receiver (RX) electrodes are on the same layer. Fringing or side wall capacitance is the mutual capacitance component. For PFF, plastic overlay is optically bonded to two layers of ITO film. The RX electrode is on the film layer closest to the plastic overlay, while the TX electrode is underneath the RX. Mutual capacitance in PFF stack-up consists of both parallel plate and fringing capacitance.

When a relatively warmer finger comes in contact with a colder sensor with about a 10-15°C temperature difference, this can be large enough to trigger the problem. The signal begins strong, but slowly degrades as the finger remains present. This process may last for several minutes until
the signal falls below threshold, or even becomes negative. Usually a glass overlay doesn’t encounter
this problem as much since glass has a lower heat transfer coefficient than plastic. Substrate
material can play an equally important role as well. In one of our experiments, if the film substrate is
replaced by FR4 in a printed circuit board (PCB), the finger-heating effect disappears – even with a
plastic overlay.

![Figure 1](image1.png)
**Figure 1. PFF stack-up cross section and a dual-layer sensor pattern.**

![Figure 2](image2.png)
**Figure 2. PF stack-up cross section and a single layer pattern.**

**Analysis and physical model**

A simplified equivalent model of a TX/RX sensor is shown in Figure 3, where Cm is the intrinsic
mutual capacitance between the TX and RX electrode, and Cfm is a finger-induced mutual
capacitance. R is the resistance of sensor. Either Cm or Cfm has the following dependency on
dielectric constant $\varepsilon$: length of the TX/RX perimeter $L$, and distance between the TX and RX
electrodes. Also notice that dielectric constant $\varepsilon$ is a function of temperature, $T$:

$$C \propto \varepsilon(T) L/d \quad \text{(Equation 1)}$$
Physical understanding of this equation can be done only by examining the field line coupling in this capacitive system. **Figure 3** illustrates the electric field distribution in both PFF and PF stack-up.

**Figure 3. Electric field distribution in PFF and PF stack-up.**

**temperature controlled experiment**

In an experiment where the temperature is fully controlled, we replaced the human finger with a metal finger, which was kept at the same temperature as the sensor. With this set up, there was no signal variation caused by the temperature. However, once the metal finger itself is heated up, or replaced by a human finger, signal degradation was observed, and the severity got worse as the temperature difference grew. This test showed us that a temperature variance between the finger and sensor is the major root cause for sensitivity degradation.

Next we kept the overlay the same as with the previous test, except that *indium tin oxide* (ITO) film was substituted by FR4 materials in the PCB. Here the finger heating-effect was not identified either. So according to **Equation 1**, it has to be the temperature dependency of dielectric constant of film substrate that contributes to the heating effect.

We also noticed that the dual-layer bar pattern in PFF was worse than the single-layer PF. This observation was attributed to two factors: 1) parallel plate capacitance has much more intensive field line distribution across the substrate than fringing capacitance; and 2) even the finger-TX coupling was through the substrate film.

To summarize the physics understanding, a finger-heating effect is a two-step process. First, a plastic overlay transfers the heat from the finger to the substrate material. Second, if the dielectric constant of the substrate material has a strong temperature dependency, sensitivity degradation will occur. Alternatively, if the substrate is free of temperature variation, then the signal maintains its integrity.
Sensor design solutions

An alternative dual-layer bar pattern was attempted by reducing the intrinsic parasitic parallel plate capacitance between the TX and RX (Figure 4). In this stack-up, the TX sensor was removed under the RX projection area. There was some improvement, but not enough due to finger-TX coupling. Therefore, a dual-layer pattern is not recommended in a plastic cover stack-up, unless the film can be replaced by FR4/PCB materials.

For a single-layer pattern on PF stack-up, according to Equation 1, we can solve the issue by reducing the TX/RX perimeter $L$ and/or increasing TX/RX gap $d$. As a practical matter, since the sensor gap directly relates to the sensor pitch and therefore resolution, increasing the sensor gap is most likely impossible – unless low resistance sensor materials are readily applicable.

![Figure 4. An alternative dual-layer bar pattern.](image)

A pattern with a reduced TX/RX perimeter, such as the diamond pattern illustrated in Figure 6a, was tested with significantly improved performance. For a diamond pattern with pitch size, the perimeter between TX/RX is $a$, whereas it can be close to $6a$ or $8a$ for a three-notch single layer pattern (Figure 2).
Each pattern’s finger-heating tolerance is compared in Figure 5. A dual-bar pattern has the worst sensitivity degradation with time, followed by a single-layer, three-notch pattern. The diamond pattern, however, did not exhibit any adverse effect.

An improvement on the finger-heating effect can be made by reducing the three-notches down to either two or even one (Figure 6b). Still, reducing the TX/RX perimeter is a double-edged sword. While it solves the finger-heating effect, it decreases the finger-induced mutual capacitance, which may lead to homogeneous sensitivity decrease. So a detailed whole system simulation needs to be carried out during sensor design.
Conclusion

The finger-heating effect on mutual capacitive touch sensors, which is mainly attributed to heat transfer coefficient of overlay and temperature dependency of substrate materials’ dielectric constant, was investigated comprehensively. A physical model including overlay, substrate, finger, sensor stack-up and sensor pattern was analyzed and proposed. A dual-layer stack-up and pattern demonstrated a stronger finger-heating effect due to intensive field coupling with the substrate. A single-layer pattern with smaller TX/RX perimeter is recommended. Potential performance tradeoff was discussed.

References

For more information, visit: www.ti.com/captouch-ca.

About the Authors

Tao Peng is an Applications Manager for TI’s touch screen total solution development group. Tao is an industry expert in capacitive touch technology and sensor design. He pioneered whole system designs using a simulation methodology which includes sensors, controllers, radiation environments, power supplies and the human body, from the physical layer, signal profile to a centroid algorithm. Tao has been issued 15 US Patents. He built and managed the sensor design team at Cypress Semiconductor prior to joining TI. For questions about this article, contact Tao at: ti_taopeng@list.ti.com.

Wei Feng is an application engineer at TI’s touch screen applications team. Wei has extensive
firmware and hardware experience in trackpad, capacitive button and touch screen products from design-in to mass production. He was the lead engineer developing the world’s first ultra-low power MCU-less multi-touch solution hosted on a Bluetooth Low Energy (BT 4.0) and proprietary 2.4G dual-mode wireless mice. Wei has been issued one patent in China.