Electrode design in capacitive touch sensor applications

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Introduction
Capacitive sensors work by detecting the change of capacitance introduced by the finger touching near the electrode. Such change is so small that detecting it unambiguously is challenging, and has become the primary task for the application design.

For the surface capacitive sensor, the sensor IC measures the capacitance of a sensor port with respect to the circuit ground. Two conductive plates are required, one connected to the sensor port and the other one to the circuit ground to form a capacitive transducer. So the ground plane is not just like a shield in the standard PCB layout design, but it is also an indispensable part of a two-plate capacitor.

Being the front end of the sensor, the electrode’s ability pick up the signal from the finger has a direct and significant impact on the overall performance.

Basic principle
The reason an external object would increase the capacitance of the transducer, is that the electric field projected from the transducer polarizes the object, and the polarized charges in return attract more charges from the source to join the transducer (see Figure 1). The increase in the charge storage on the electrodes means the increase in the capacitance.
Figure 1: Charge distribution on the electrodes (horizontal plates) and the external object (vertical plate), as simulated by Method of Moment. The polarization on the vertical plate is x10 to enhance visibility.

The capacitance is more sensitive to the external object, if the electric field is projected more into the air to reach the object. The electric-field projection or distribution depends on the transducer’s layout design, and therefore the layout design has a direct effect on the transducer’s sensitivity.

In the classic parallel plate capacitor, the electric field is so confined in between the plates that the capacitance could hardly be influenced by the external object. This means that a touch pad directly above the ground plane is a poor capacitive transducer.

When the plates are shifted apart from overlapping, more electric field will project into the air, and the capacitance will be more sensitive to the finger’s influence.

Figure 2: Non-overlapping plates project electric field into the air, result in higher sensitivity. (Simulated by Method of Moment).
In a simulation for a pair of shifted electrodes with equal size, the change of capacitance due to a finger 2mm above the touch pad is as much as 31%, an amount that is unambiguous to the sensor IC (see Figure 3). But when the finger moves to the ground plane, 2mm above, the same amount of signal can also be read. With similar signal levels, the sensor IC cannot differentiate the touch on the touch-pad, from the touch on the ground plane.

**Figure 3: Simulation of a finger touching above an electrode.**

**Methods to control sensitivity of electrodes**

As the objective is to make the touch-pad the only sensing port, methods to sensitize the touch pad, and to desensitize the ground plane is very much needed.

One common method is by putting the touch pad closer to the user, and hiding the ground plane deeper inside the housing.

Another method which is the centre piece of this article is by having a bigger ground plane compared to the touch pad. Automatically, the sensitivity will shift to the smaller plate which is the touch pad.

Since the total charges on both plates are the same, the plate with the smaller area will have a higher charge density, more concentrated flux lines, stronger e-field, more polarization force, and therefore more sensitive to influence from the external object (see Figure 4).

**Figure 4: The electric field at the smaller plate is stronger than the electric filed at the bigger plate.**

**Numerical simulation for touch pad with big ground plane**
Numerical simulation for touch pad with big ground plane
As seen in the next simulation for a pair transducers with unequal plate size, a touch 2mm above the touch-pad yields a 62% change in capacitance (see Figure 5), compared to an 7% change for the touch above the ground plane (see Figure 6). With such distinctive signal levels, an appropriate threshold level will differentiate the touch on the touch-pad, from the touch on the ground plane.

Figure 5: A strong signal is produced when the finger is above the touch pad.

Figure 6: A weak signal is produced when the finger is above the big ground plane.

Mutual capacitances behind capacitive sensing
A rigorous explanation for the unbalanced sensitivity is by means of mutual capacitance formed between the human and touch-pad $C_{TF}$, and mutual capacitance between human and ground plane $C_{GF}$. 
As these two mutual capacitances vary with the human movement, they disturb the overall capacitance. The disturbance pathway is in series, so $C_{TF}$ and $C_{GF}$ each imposes a limit on the disturbance. When the finger closes the gap at the touch pad and so $C_{TF}$ provides a good link, the bottleneck of the disturbance rests on the remaining link, $C_{GF}$.

By having a bigger ground plane constantly coupled to the human, the bottleneck $C_{GF}$ is eased, and the influence on the overall capacitance (signal for the touch) will be stronger (Figure 7b). When the finger moves towards the ground plane, the loop is not close properly, so the signal will be weak (Figure 7c). This is the mechanism behind the inverse property which gives higher sensitivity to the smaller plate.

In summary, a big ground plane, non-overlapping with the touch pad, will yield two positive effects; the increase in the overall sensitivity (picking up more signal), and the shift of the sensitivity towards the touch pad.

Such advantages can be fully exploited by connecting the circuit ground to the mains wiring, which is the biggest ground plane readily available. Naturally, the signal captured will be the strongest, and the sensitivity will occur at the touch pad because of its relative smaller size.

The grounded chassis or the mains wiring, though a bigger part of the transducer, will produce minimum signal when touched due to the inverse property. It is indeed amazing that the inverse property exists to help achieving our goals; sensitivity on touch button and immunity on the chassis and the mains wiring. Had the inverse property not exist, an earthed circuit will pick up false signal when the earth-line is touched.

Conclusion

Two mutual capacitances are the main contributors to the influence of capacitance in the surface capacitive sensor. The mutual capacitance from the touch pad to the human has always been known to control the sensitivity of the sensor. Equally important but less mentioned, is the mutual capacitance from the ground plane to the human, that controls the overall sensitivity and the shift of focus point. By having a large ground plane, the overall sensitivity increases and shifts towards the touch pad.

Future work

The effect of ground plane as presented in this article is tested and verified for the surface capacitive sensor. The same effect is expected to be present in the projected capacitive sensor as
well, even though the electrode configuration is more complex, consisting of a transmitter and a receiver. For such configuration, the interaction between conductors and human, and the resultant capacitance must be simulated with a 4-body MoM engine, which the author is currently developing. The author hopes to follow up with another article to present the simulation result for the projected capacitive sensor.

About the author
Dr. Cheok Thng worked on numerical analysis for electromagnetism for his thesis and his early career. In the last few years, his interest and responsibility are on the application of capacitive sensor in embedded system. Currently Cheok Thng is the Chief Technologist in Locus Marketing Pte Ltd, and can be reached at cheok@locus.com.sg or soup.pebble@gmail.com.

References