AZD076 - How to design touch electrodes for non-uniform and curved surfaces: 3D touchpads

Abstract

Over the last few years, touchpads have become a standard input method for next-generation user interfaces for everyday applications, from white goods to smart phones, computer peripherals, and remote controls. Touchpad design requires a thorough understanding of capacitive sensing, from electrical to the mechanical stack-up, as the entire device and the user interaction with it need to be understood, especially for hand-held or battery-operated devices. It can be challenging to add touchpads to designs that are not flat or are made with three-dimensional shapes and multiple parts. This article, the second in a two-part series, discusses the design and implementation of 3D touchpads on non-uniform surfaces.

Table of Contents

1 INTRODUCTION 2

2 SELECTING THE SUBSTRATE 2

Table 2.1 Material properties(estimated for reference purposes only – actual values to be inserted by the designer) 3

2.2 Overlay considerations 3
- 2.2.1 Manufacturing limits 4
- 2.2.2 Channel pitch 4

2.3 Mutual and parasitic capacitance (C_M and C_P) 4

Figure 2.2 Side view of a channel 4

Figure 2.3 Top view of a channel 4

Figure 2.4 Simplified equivalent circuit of a single channel 5
- 2.3.2 Trace routing considerations 5

Figure 2.5 An Rx trace running underneath a Tx pad can add a significant amount of unwanted parasitic capacitance to the channel 5

Figure 2.6 How the capacitance increases when the base material thickness decreases 6

2.4 Interconnections 6

2.5 Touch deltas 6

Figure 2.7 FR4 touchpad PCB mounted behind a curve overlay of non-uniform thickness, showing the E-fields available for the user to interact with 7
- Overlay thickness considerations 7

2.6 Touchpad Sensitivity 7

Figure 2.8 FPC touchpad stuck to the underside of the curved overlay of uniform thickness 8

3 CONCLUSION 8

4 REFERENCES 8

1 Introduction

A touchpad is a collection of individual touch buttons arranged in rows and columns, called channels. As the user moves his or her finger over these channels, a delta is sensed in the measured count values and can be used to determine the XY touch co-ordinate.

Traditionally, touchpads are flat with a uniform overlay thickness. One of the main reasons for this is that, with a uniform pattern and a uniform thickness, the touch strength when the user's finger touches the surface would be uniform over the entire touchpad. If, however, the overlay were not of uniform thickness, the mutual capacitance and therefore the touch deltas would no longer be uniform.

The following article illustrates the most important design choices that need to be made when designing a touchpad for a 3D surface.

2 Selecting the substrate

The choice of substrate is no longer limited only to flexible circuit boards (FPCs). Depending on the overlay shape and the interconnects to the main board, the designer also has the option of an FR4 PCB. The high sensitivity of the Azoteq Trackpad ICs allows the designer to even place the touchpad or slider on the main PCB. This would lower the cost of the solution significantly, as the additional FPC and connector would no longer be needed. However, there are a few factors that must be considered by the designer when selecting the substrate, and these are described in the following sections. Below is a list of dielectric constants/permittivity for materials that are commonly used for touchpads, .

Table 2.1 Material properties[1](estimated for reference purposes only – actual values to be inserted by the designer)

Material	Permittivity (ε_r)	Breakdown voltage (V/mm) (approx.)
Air	1	1,180
Glass (standard)	7.6 – 8.0	7,800
Plexiglass	~2.8	17,700
Rubber	2 – 7	-
ABS (plastic)	2.0 – 3.5	32,000
FR4	4.7	27,500
Polyimide (PI)	3.5	200,000
Polyester (PET)	~3.4	17,000

Equation 1 below shows the parallel plate capacitance equation, where A is the area of the pad, ε_0 is the permittivity of the air, ε_r is the relative permittivity of the overlay material, and d is the thickness of the overlay.

Equation 1

$$C = \frac{\varepsilon_0 \varepsilon_r A}{d}$$

2.2 Overlay considerations

The overlay, which is stuck on top of the sensor pattern, is the user interaction area. It is a critical component of touchpad design and determines the design direction. Overlays can be of various shapes, such as round, square, rectangular, etc., and can have thicknesses ranging from 0.2mm to 5mm.

Touchpad and overlay types include:

- Multi-tier touchpads and touchpads with finger guides
- Multi-tier touchpads with either one or both moving
  - The fewer the interconnects between the different PCBs, the lower the overall cost
- Curve in one direction – cylindrical or cone-shaped designs
- Curves in both x and y for a 3D shape – concave or convex designs

[1] Material properties are estimated for reference purposes only – actual values to be confirmed by the designers.

2.2.1 Manufacturing limits

Mechanical manufacturing limits also need to be taken into consideration for overlay design. In the case of plastic injection molding, there is a limit to the thickness that can be manufactured without resulting in uneven shrinkage. Warping is caused by uneven shrinkage due to the variations in thickness of the part, resulting in cooling at different rates. This warping could lead to an uneven surface between the touchpad and the underside of the overlay, resulting in air gaps between the two layers. Air, with its low permittivity, would reduce the sensitivity significantly in these areas. Determining shrinkage ratios for specific plastics is beyond the scope of this article.

2.2.2 Channel pitch

The pitch [distance between channels or the channel size] of the pattern used must be larger than the overlay thickness, otherwise the E-fields would tend to blur and it would not be possible to determine the touch peaks accurately. This would lead to an increased linearity error.

2.3 Mutual and parasitic capacitance (C_M and C_P)

The mutual capacitance between the sensing (Rx) and driving (Tx) electrode is the sum of all the individual components, equation 2. When the user touches the touchpad, the C_{M_touch} component is lowered and approaches 0 when saturated by the touch.

$$total\ C_M = \sum C_M + C_{M\_touch}$$

Equation 2

A simplified single channel is shown in Figure 2.2 and Figure 2.2.

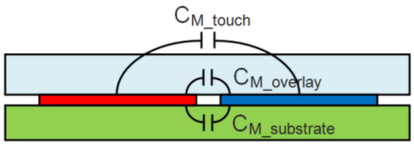

Figure 2.2 Side view of a channel

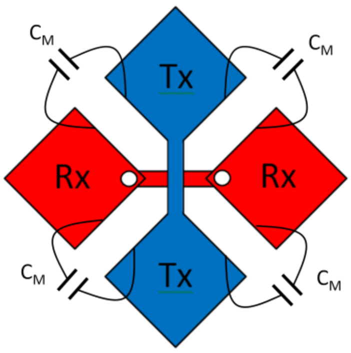

Figure 2.3 Top view of a channel

A simplified equivalent circuit is shown in Figure 2.4, with the transmitter (Tx) driving the mutual capacitance and a receiver (Rx) sensing the mutual capacitance.

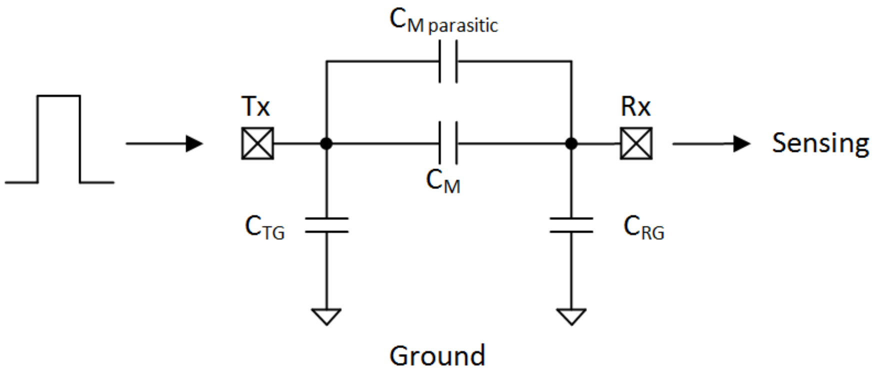

Figure 2.4 Simplified equivalent circuit of a single channel

2.3.2 Trace routing considerations

Trace routing for touchpads on Flex PCB is critical for minimizing parasitic capacitance and maximizing the touch delta. For rigid FR4 PCBs, this limitation can be relaxed, however, as the two copper layers are sufficiently far apart and the capacitance is small enough in relation to the mutual capacitance.

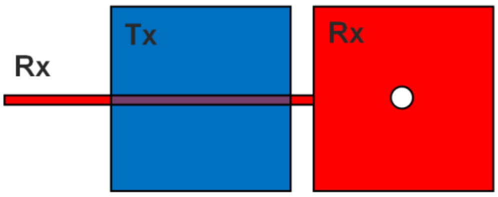

Figure 2.5 An Rx trace running underneath a Tx pad can add a significant amount of unwanted parasitic capacitance to the channel

A theoretical comparison of the parallel plate capacitance of two 4mm-long tracks of 0.1mm and 0.2mm thicknesses with different base material thicknesses is shown in Figure 2.6.

It can be seen that the capacitance increases greatly for thin base material thicknesses, and each channel the track runs under adds additional unwanted parasitic capacitance (C_P).

It also is necessary to take the RC time constant into account for the driving electrode; this is especially important for ITO and PEDOT touchpads, as the resistance on the traces is large.

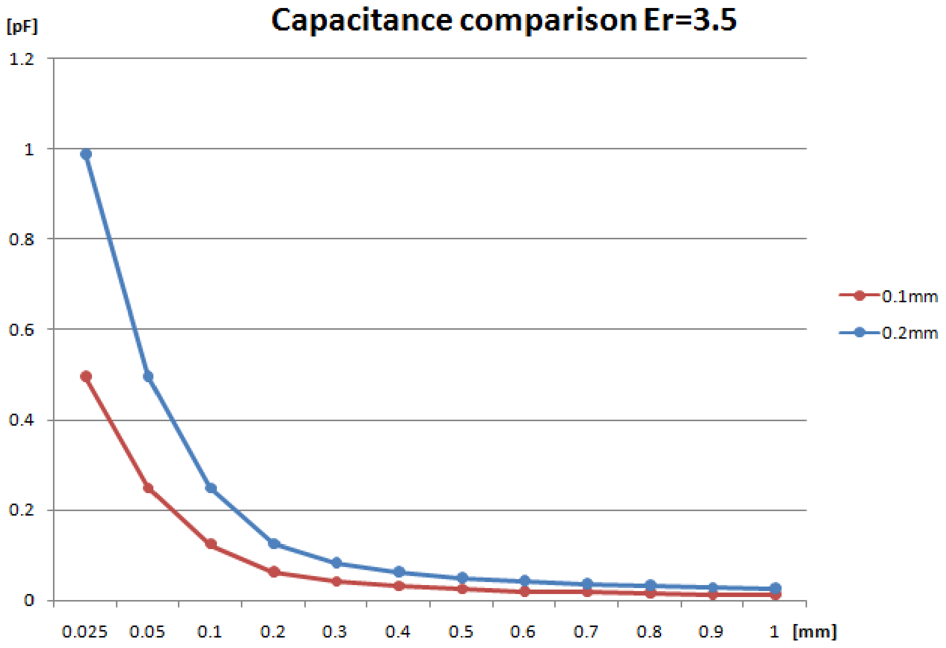

Figure 2.6 How the capacitance increases when the base material thickness decreases

2.4 Interconnections

Hot bar soldering and ACF (anisotropic conductive film) bonding are mature technologies used to connect FPC to FR4 PCBs, while ZIF connectors are also used for the same purpose. If two separate touchpad areas are used and driven with the same IQS5xx IC, then in order to lower the parasitic capacitance the connecting cable must be kept as short as possible, with Tx and Rx tracks separated with a ground track. Multiple cables are not advised, as the probability of a defective solder joint or connection increases with each interconnect.

2.5 Touch deltas

When the user brings his or her finger close to the touchpad, the mutual capacitance decreases, and if the touch threshold is chosen correctly, a touch event will be triggered when the user touches the overlay. The change in these counts above the long-term average (LTA) is referred to as the delta. The deltas of all the touched channels form a touch image, and the weighted sum is taken to calculate the XY touch co-ordinate (the sum of all the deltas would give the touch strength). If, however, the sensitivity of each channel were not equal, such when one channel has a lower sensitivity than its adjacent channel, the XY touch point would be distorted and have a position error relative to the amount of distortion.

At the extreme, if the sensitivity differential is large enough, a split touch will be detected (a touch on either side of the channel that was actually touched) when only one should be detected. This could be compensated for to some extent with post-processing and track pad characterization.

However, this is not always ideal as it will be dependent on finger size. Another alternative would be to use the ProxSense engine compensation settings to increase the sensitivity of the problem channel. Different overlay thicknesses would also produce a different touch delta in the thin and thick areas.

Figure 2.7 is a representative image of the E-field lines that can couple with the user's finger, with the touch delta being larger in the areas with a thin overlay thickness, $\Delta_1 > \Delta_2$.

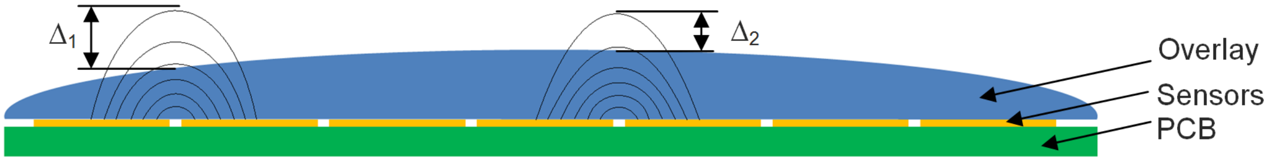

Figure 2.7 FR4 touchpad PCB mounted behind a curve overlay of non-uniform thickness, showing the E-fields available for the user to interact with

Overlay thickness considerations

As the overlay thickness decreases, the mutual capacitance increases and so does the capacitance available to be removed by a touch, resulting in higher touch strength. For a variable thickness overlay, this touch strength or delta will need to be scaled so that the same-sized touch on each area will produce the same touch strength. This is referred to as mutual capacitance balancing. (Azoteq designers will normally assist designers with this step.)

2.6 Touchpad Sensitivity

The amount of mutual and parasitic capacitance can vary greatly over the touchpad area as a result of the variable thickness overlay, dielectric permittivity, track routing and pattern design, etc. The difference in parasitic and mutual capacitance directly influences the sensitivity and uniformity of touch detection by the touchpad.

The sensitivity can be compensated for either with routing or capacitive loading in the hardware design, or with tuning of compensation settings with firmware. The ProxSense engine variables, such as parasitic cancelation (PCC) and ATI target, can be used for each channel to achieve uniform sensitivity to tune the target and baseline as needed.

Equation 3

$$gain\ in\ sensitivity \equiv \frac{target}{baseline}$$

The above relationship shows that the areas with a lower baseline would have higher parasitic capacitance. In this case the sensitivity of those channels would need to be made higher by increasing the amount of compensation. Adjusting the sensitivity in the thick areas to produce the same touch delta can be achieved by increasing the PCC or lowering the ATI base. As the capacitance over the channel decreases, the count values increase. Thus the mutual capacitance is inversely proportional to the capacitive count values.

Equation 4

$$C_{xeff} \propto \frac{1}{CS_x}$$

where C_{xeff} is the effective capacitance and CS_x is the count values for that channel. Increasing the compensation also improves the SNR.

For FPC touchpads, the parasitic capacitance from routing traces has a higher impact on the channel's sensitivity, whereas with FR4 touchpads these layout constraints on trace routing can be relaxed. However, with overlays of variable thickness, the amount of mutual capacitance that can be removed during a touch would be different between the thin and thick areas, as described in section 2.4.

The same overlay profile is shown in Figure 2.8, but with a uniform thickness and an FPC touchpad design.

Figure 2.8 FPC touchpad stuck to the underside of the curved overlay of uniform thickness

Theoretically, the above profile would have a similar sensitivity range over the touchpad area and result in similar touch deltas. However, with this profile the FPC would need to conform to the 3D shape and, in order to achieve this, relief cuts would need to be placed in certain areas. The relief cuts are needed to prevent any surface mismatch to ensure that no air bubbles occur between the FPC and the underside of the overlay. These cuts should also be long enough so that no delimitation occurs over the lifetime of the touchpad.

Remember to keep the minimum bend radius of the FPC in mind to avoid folding and breaking the tracks.

The relief cuts should be placed between channels, as this is already the area of lower sensitivity, while maintaining the sensitive channel center. The tracks that need to be routed around the cut need to be shielded to prevent unwanted user coupling; this can be a ground track placed on the top layer of the FPC. Cuts can also be placed in the channel intersections, but this would result in the peak being flattened, creating an area of lower sensitivity.

3 Conclusion

Following these design guidelines, the designer's imagination can be set free to create new and exciting touch interfaces in areas not thought of before.

4 References

AZD068 – Trackpad Design Guide Application Note

IQS5xx-A000 Datasheet

IQS333 Datasheet

Parasitic capacitance cancellation in capacitive measurement applications- Patent Number: WO2010045662A9

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The following patents relate to the device or usage of the device: US 6,249,089 B1, US 6,952,084 B2, US 6,984,900 B1, US 7,084,526 B2, US 7,084,531 B2, EP 1 120 018 B2, EP 1 206 168 B1, EP 1 308 913 B1, EP 1 530 178 A1, ZL 99 8 14357.X, AUS 761094, HK 104 14100A, US13/644,558, US13/873,418

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