AN11623

LPC82x Touch Solution Hardware Design Guide

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Document information

Info	Content
Keywords	Capacitive Touch, Touchpad, Sensor, Electrode, Drive/Sensing lines, Dielectric, Overlay panel, Sensitivity, Touch, False Touch.
Abstract	This application note describes the overall hardware design aspect of NXP's Capacitive Touch solution, shows the schematic design, materials, and PCB design including the most critical Touch sensor design.

Revision history

Rev	Date	Description
1.0	20141222	Initial version

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1. Introduction

Appropriate hardware design is critical to a robust implementation of capacitive Touch detection. The key is to achieve optimum signal-to-noise ratio, ideally more the better. To achieve optimum performance, a lot of factors have to be considered, resulting in multiple design iterations. However, one can easily reduce the number of design iterations by knowing the pros and cons upfront or following some of the best design practices. This application note describes the overall hardware design aspect of NXP's Capacitive Touch solution, technology overview, the schematic design, the PCB design, the materials, and finally, the most critical Touch sensor design.

1.1 Overview

A capacitor is a passive two terminal electrical component used to store the energy in an electric field. It has a large uniform field and a small fringe field which helps to get a deterministic performance without any external influence.

In capacitive Touch sensing, the ultimate goal is to detect a Touch using relative change in the capacitance of capacitive Touch sensor that calls for an external influence.

A good capacitive Touch sensor is basically a capacitor having a small uniform field and a large fringe field, resulting in a high external influence on the capacitance. See Fig-1.

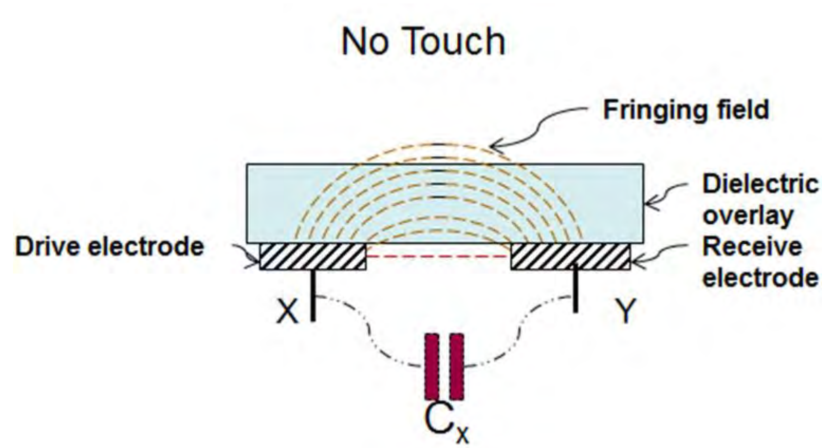

Fig 1. Touch Sensor

The maximal inter-leaving of X and Y electrodes in T sensor forms a capacitor Cx. When a DC voltage is applied between the X-electrode (driving electrode) and the Y-electrode (receiving electrode) a charge current flows until sensor capacitor Cx is fully charged. The amount of charge flowing into sensor capacitor Cx depends on its capacitance and the applied voltage.

The fringe field lines of the capacitor Cx arc through the dielectric overlay material. With a Touch in a grounded system the human finger distracts some of the charge during a charging condition. See Fig-2. As a result, the sensor capacitance Cx is effectively reduced (Cx-ΔCx).

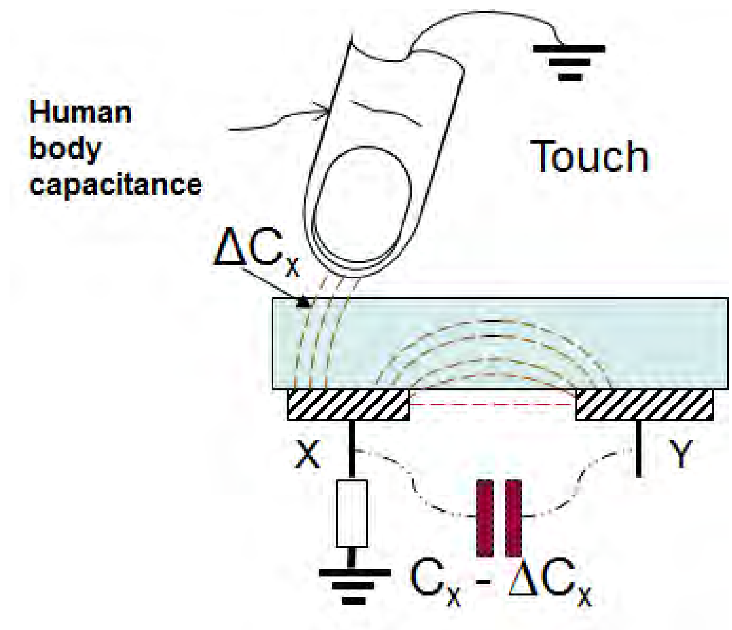

Fig 2. Touch Sensing (Grounded System)

While in the groundless system (see Fig-3), the human finger adds up (+ΔCx) to the sensor capacitance Cx and the effective capacitance is increased (Cx+ΔCx).

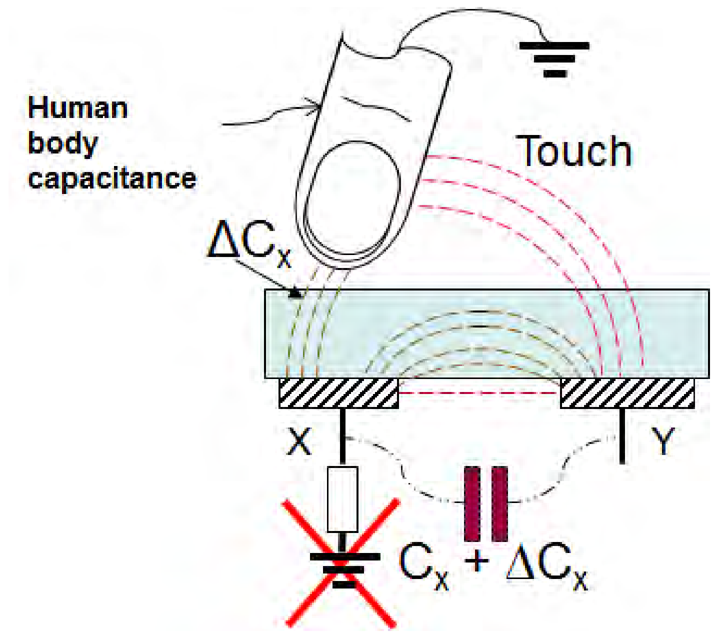

Fig 3. Touch Sensing (Groundless System)

This very small relative change (-ΔCx or +ΔCx) in the sensor capacitance is detected as a Touch. In addition, there's a lot of post processing involved to increase the robustness, to filter out the noise/jitter, to control the sensitivity, and to compensate for the environmental changes, such as, change in humidity, temperature, or operating voltage.

2. Schematic Design

NXP's capacitive Touch implementation is based on the Switched Capacitor Integration technique. Fig-4 outlines the equivalent circuit.

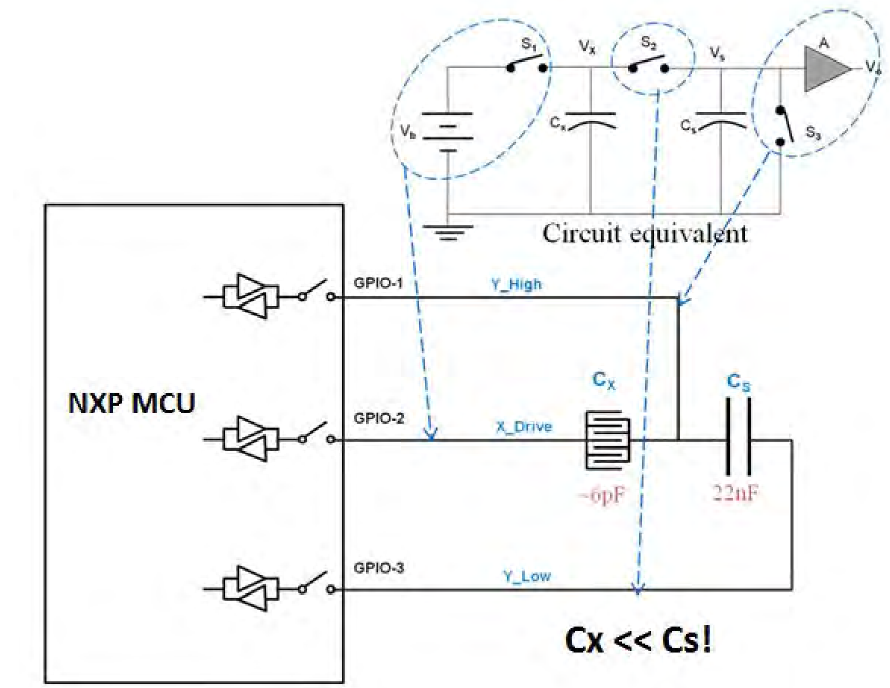

Fig 4. Equivalent Circuit

The sensor capacitor Cx forms a part of switched capacitor integrator. The CMOS tri-state drivers connected to the nodes X, Y-H and Y-L are controlled by trains of pulses, resulting in the emulation of integrator switches. The applied pulse sequence causes a repeated charge transport through the sensor capacitor Cx into sample capacitor Cs. With advancing number of integration cycles, an integration voltage Vcs develops across the sample capacitor Cs.

In summary, the voltage at X-line drives the charge, and charges the external sampling capacitor Cs through the Touch sensor capacitor Cx. The Touch sensor capacitor (Cx=~6pF) is much smaller than that of the external sampling capacitor (Cs=22nF).

In more detail, the sensor capacitor Cx is charged in every integration cycle to a voltage equivalent to the difference between supply voltage (Vdd) and the voltage across the sampling capacitor (Vcs). The same charge is also transferred into the series connected sampling capacitor (Cs), resulting in an increase of the voltage across sampling capacitor (Vcs). This integration process is repeated until the voltage Vcs reaches a fixed threshold voltage, see Fig-4. The number of integration cycles required to reach that threshold voltage is a measure for the capacitance of sensor capacitor Cx. The integration cycle count performed with no-touch is the reference and forms the basis for Touch detection.

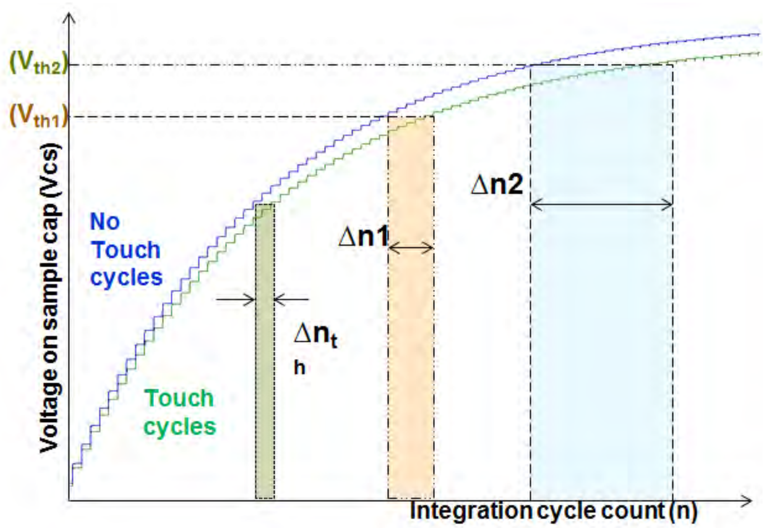

Fig 5. Switched Capacitor Integration Process

With a finger touch, the effective sensor capacitance (Cx-ΔCx) is reduced as the finger distracts some charge. Hence, it takes more integration cycles until the voltage across Cs reaches the threshold voltage. And that is the indication of a Touch. After the Touch has been detected, further filtering and processing techniques are deployed to ensure the validity of Touch. The sensitivity of the Touch sensor is determined by the threshold voltage (Vth) as well as the capTouchacitance of the sample capacitor Cs.

2.1 Clean Supply (Vdd)

Special care must be taken while deriving the supply (Vdd) for Touch application. A dedicated voltage regulator (LDO) is always preferred. In case the voltage regulator is shared with other circuitry, proper filtering is recommended in supply path to isolate/filter noise from other circuitry getting into Touch sensing. The maximum ripple in supply should not exceed 20mV peak-to-peak.

2.2 X (Drive) Lines

No special consideration is needed while selecting the drive (X) lines. GPIO pins used should be able to switch between High Impedance, Input & Output (High/Low) and shall preferably have low pad/stray capacitance.

The series resistors (Rs) on all the X lines can come in handy to increase the conducted immunity in noisy environments. While experiencing noise issues, one can try with the series termination resistors of 1k Ohm.

2.3 Y (Sense) Lines

These GPIO pins should be able to switch between High Impedance, Input and Output (High/Low) and shall preferably have low pad/stray capacitance. Selecting the proper sense (Y) line pins, especially Y-H pins is very critical to achieve good sensitivity levels on Touch sensors. One must ensure that these sense pins are not multi-function or heavily multiplexed.

The multi-function pins usually will have more stray (parasitic) capacitance which can cause increased loading and hence poor sensitivity.

We should not even add any external circuit on these lines which could in turn affect the sensitivity. In particular, switching LEDs can cause the Touch measurement to be much really noisy.

2.4 Sampling Capacitor (Cs)

Sampling capacitor (Cs) is the only critical external component in the circuit. And since Cs decides the overall Touch sensitivity, stability of this capacitor is important in achieving a consistent and repeatable measurement. A capacitor with X7R dielectric or better has a low temperature co-efficient and will be more stable.

2.5 LEDs

The changing capacitance from switching LEDs can cause detection instability and stuck-on state in nearby sensors. This is particularly true if LEDs are pulled down or up to switch on, but are allowed to float when off. If such LEDs are less than 4mm away from capacitive sensors, they must be bypassed with a small capacitor that has a typical value of 1nF. Mounting LEDs or having lighting guides in between the sensors is not recommended in touchpad applications.

2.6 Ground Pins

When sensor (touchpad) board is isolated from Touch MCU board, prefer using multiple ground pins in the connectors for effective return path.

3. PCB Design

3.1 PCB Material

The capacitive Touch circuits or sensors are usually constructed on printed circuit boards. And the most commonly used PCBs are FR4. Whenever the end products/applications demand flexibility and/or transparency, flexible PCBs are generally preferred. The ITO (Indium Tin Oxide) is also commonly used with silver ink to lay the sensors and traces wherever transparency (look and feel) is more important.

3.2 Sensing Components

The sensing components, like sampling capacitor (Cs) and series resistor (Rs) should be placed close to the Microcontroller pins to get the best results.

3.3 Sensor Placements

The sensors should be placed on the layer closest to the Touch in order to maximize the sensitivity. One should not place the MCU or any other components directly under the sensor or even in the proximity. The Touch sensors (touchpad) should be placed away and well isolated from other circuitry to avoid any sort of noise affecting the Touch measurements. Preferably, no other circuit connections should pass through sensing (touchpad) area even on a different layer in the PCB stack-up.

3.4 Sensing (Y) Lines

Special care must be taken while routing the sense (Y) lines, especially Y-H lines. These lines being very sensitive analog sensing lines must be thin (0.1mm to 0.5mm) and routed as short as possible. Having long traces will be more prone to external noise and loading from nearby circuit. Also, to prevent false touches, it is always preferred to keep these traces thin and short. Normally, these Electrodes drive very small loads (in few pF), therefore, minimum trace widths are just sufficient. The sense tracks, being sensitive to touch, must be routed through the bottom layer of the two-layer PCB. This prevents false detections on the Touch surface. One must also avoid VIAs on these sense lines to avoid any pick-up from the external world.

The GND tracks should not be placed near the sense lines. They will have loading effect which will reduce the overall sensitivity of Touch sensors. If it cannot be avoided, one must ensure that the sense lines are separated from GND tracks by at least T/2, where T is overlay panel thickness. To reduce loading, the sense lines and GND track should cross at 90° on separate layers. As a rule of thumb, the sense lines should not be placed near other tracks and components, as this may cause loading and/or interference. The tracks with switching signals can inject noise in the sense lines if they are placed too close. Again, the minimum separation between the sense lines and all other tracks or components should be at least T/2, where T is overlay panel thickness.

3.5 Drive (X) Lines

Avoid close parallel X lines, otherwise, you might experience crosstalk effects like “ghost” touches. In this case, driving one sensor easily induces charge onto the other one. So, if you are touching on one sensor you will receive the signal on another sensor too. The safe distance between the X lines should be >3*width of X line to avoid any crosstalk.

3.6 No (close) parallel X and Y Lines

The drive (X) and sensing (Y) lines should be well separated or isolated from each other.

Strictly avoid running (close) parallel X and Y lines, this will form false (un-intended) Touch areas. And the actual sensors (touchpad) might be adversely affected on sensitivity. If at all X and Y lines have to cross, they must cross perpendicular in order to avoid noise coupling. It's a good practice to route X and Y lines on different layers if the PCB is multi-layer, similar to the reference design shown in last section.

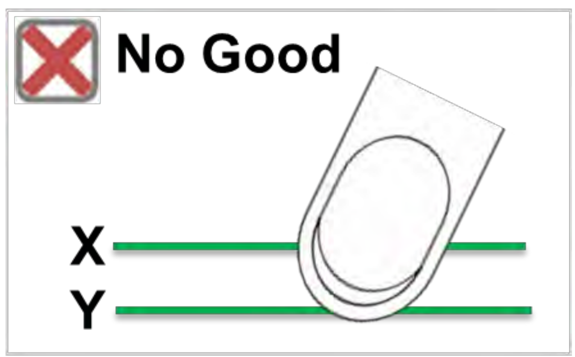

Fig 6. False Touch

3.7 No (close) switching signals

Any clock, data or periodic switching signals should not be routed side by side to the sensor (X or Y) signal traces or sensors. As much as possible, route them far away from the sensor lines or sensors. If at all these other signal traces should cross the sensor lines, they must cross perpendicular to them to avoid any noise coupling.

3.8 Ground near Sensor

Ground plane or traces near the sensors or sensing lines will decrease the sensitivity due to loading effect, but at the same time increases the noise immunity. So, it is always a trade-off between the Touch performance (higher sensitivity) and the noise immunity. If the noise immunity is not a major concern, one must avoid GND nearby. If the application demands for greater noise immunity, there must be optimal separation between the sensor or sensing lines and GND traces or planes. As a rule of thumb, this separation should be greater than the overlay dielectric panel thickness. On similar lines, if GND plane is desired for greater noise immunity, it is preferred to use hatched (mesh) ground instead of solid plane.

4. Materials

4.1 Overlay

The characteristics of an overlay (front panel) material between the touching object (typically a finger) and actual sensor majorly affects the Touch performance. And the deciding factor is relative permittivity (ε), which is a measure of how well the material propagates an electric field. Higher the relative permittivity, better the propagation.

The same can be easily illustrated by simple parallel plate capacitance expression.

$$C = \varepsilon \mathrm{A/T}$$

Where,

- Dielectric constant (ε) = $\varepsilon_0 \, \varepsilon_r$
- ε_0 = Free space permittivity
- ε_r = Relative permittivity of the overlay panel/material
- A = Area of the touched region (in square meters), and
- T = Thickness of the overlay panel/material

So, the thinner overlay panels with higher relative permittivity material yields higher capacitance change during Touch and hence a higher signal and a better sensitivity. Table 1 shows some common overlay materials and their relative permittivity for reference.

Table 1. Relative permittivity of some overlay materials

Materials	Relative Permittivity (ε_r)
ABS	2.0 to 2.35
Polypropylene	2.2 to 2.36
Rubber	3
Plexiglas	3.4
FR-4 (Glass fiber + Epoxy)	4.2
Mica	4 to 8
Glass	3.7 to 10
Silicon	11 to 12

Air gaps in any form should be strictly avoided in the overlay panel stack ups. The overlay panel/s must be glued with 3M adhesive transfer tapes or similar material.

4.2 Substrates

The substrate is a base material on which the Touch sensors/electrodes are laid out. Generally, any insulating material with low-loss can be a good substrate. Commonly used substrates are PCB materials (FR-4, CEM-1, Polyamide, or Kapton), acrylics, and Glass. The materials whose relative permittivity (ε_r) changes with enivronmental changes should be strictly avoided.

5. Sensor Design

Designing good Touch sensors is very critical to achieve optimum Signal-to-Noise ratio which depicts the performance in capacitive Touch applications. A good Touch sensor should have a large fringe field resulting in a high external influence on the capacitance.

5.1 Sensor Layout

In a sensor, the Y-Electrode is completely surrounded by the X-Electrode. Hence, the electric field only exists in the gap between X-Electrode and Y-Electrode. Surrounding the Y-Electrode with X-Electrode also keeps the field contained and touch sensitive area can be precisely defined. It's always preferred to have maximum inter-leaving of X and Y electrodes to achieve the optimum Signal-to-Noise ratio, more the better.

The Y-Electrode should be formed with the thinnest trace possible to minimize the noise coupling during the Touch, while thicker X-Electrodes are much better as they maximize the fringe field as well shields the Y-Electrode.

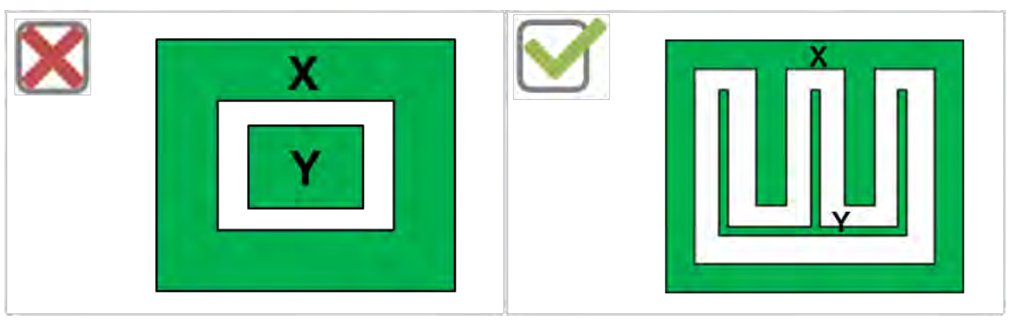

Fig 7. Sensor Layout

The spacing between X and Y electrodes needs to be at least half the overlay panel thickness. If the overlay panel thickness is T, then the X-Y gap should be at least T/2. There should be no other tracks running below the X-Y gap as this can desensitize the sensor.

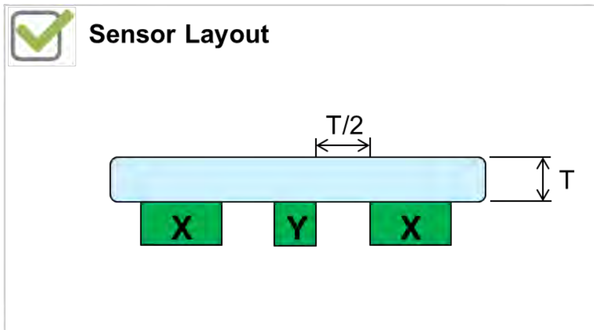

Fig 8. X – Y Separation

An ideal sensor size is slightly larger than a normal finger. It is recommended to have a sensor size that is slightly larger than the item to be sensed (typically a finger). In general larger keys are more sensitive, but avoid oversized keys as they may have a proximity effect. And undersized keys would result in smaller fringe field in-turn the poor sensitivity. Area of contact from a normal sized finger is about 8mm to 10mm in diameter.

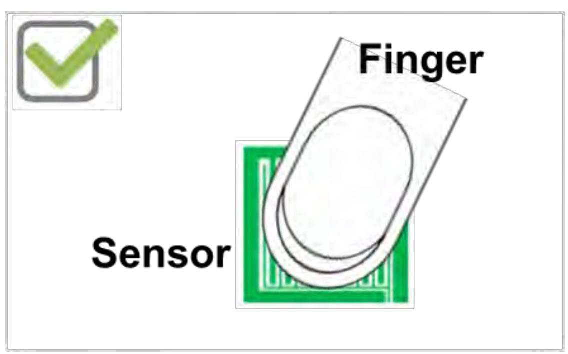

Fig 9. Typical Sensor - Size

5.2 Sensor Shapes

A very typical and most commonly deployed capacitive Touch sensor with large fringe field, resulting in a high external influence on the capacitance is shown in Fig 5.

But any other shapes with maximum inter-leaving of X and Y electrodes should yield similar results and hence can be easily deployed. So, there is no limitation to one's artistic thinking while constructing various types/shapes of sensors.

5.3 Sensor Dimensions

The sensor must be designed for large fringe field (maximal inter-leaving or maximum X/Y fingers). And X trace on the borders should be thicker to ensure that the fields are contained as well Touch sensitive area is precisely defined.

The Y-Electrode should be formed with the thinnest trace possible (0.1mm to 0.5mm) to minimize the possibility of noise coupling during the Touch. Typically, the thickness of X-Electrode traces should be half (T/2) of the overlay panel thickness (T). Given the width of X and Y traces, we must calculate the number of X fingers those will fit in sensor area allowing for the relatively thicker border (at least T wide).

$$Xfingers = (W - 3T - Ywidth)/(1.5T + Ywidth) \tag{1}$$

Where,

- W = Width of the Sensor
- T = Thickness of overlay panel, and
- $Y\ width$ = Y trace width

Any remaining width after considering the number of X fingers must be added to the X border, so the width of X border must also be re-calculated.

$$Xborder = (W - T - Ywidth - Xfingers(1.5T + Ywidth))/2 \tag{2}$$

See the typical example calculations below to get better understanding on dimensions.

W = 9000um (9.0 mm)

T = 500um (0.5m)

Y-width = 100um (0.1mm)

Given the above, we can calculate the number of X fingers using equation (1), as below.

$$Xfingers = (9.0 - 1.5 - 0.1)/(0.75 + 0.1)$$

$$Xfingers = 7.4/0.85$$

$$Xfingers = 8.7$$

Truncating it, gives us $Xfingers = 8$

$$Xborder = (9.0 - 0.5 - 0.1 - 8(0.75 + 0.1))/2$$

$$Xborder = (8.4 - 6.8)/2$$

$$Xborder = 0.8mm$$

The result is a typical sensor shown in Fig-10 with all the dimensions outlined.

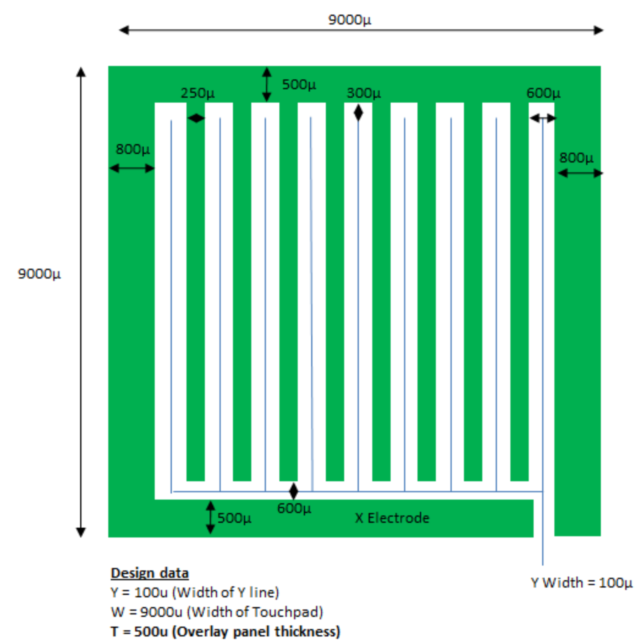

Fig 10. Typical Sensor - Dimensions

One can also use the NXP Touchpad Calculator (xls) to calculate all the sensor and touchpad dimensions.

5.4 Separation between Sensors

Avoid large gaps or separation in between individual sensors of the touchpad. It might lead to problems in Touch position calculation. The typical recommended gap is 1.2mm. This is not a concern for the fixed keys/buttons application.

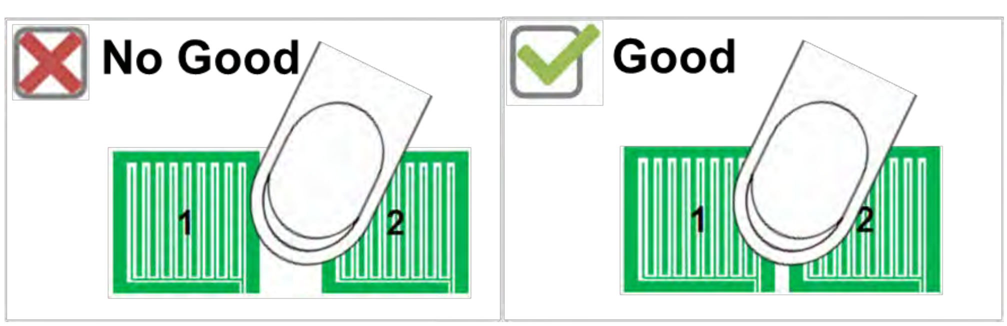

Fig 11. Separation between Sensors

6. Reference Design

The LPC82x Touch Solution board shown in Fig-12 can serve as a good reference for designing Touch interface using NXP Microcontrollers.

It very well illustrates on the touchpad layout, sensor design, sensing pin selection, and X/Y line traces. The circuit schematics and PCB design (gerber) files are available along with this hardware design guide.

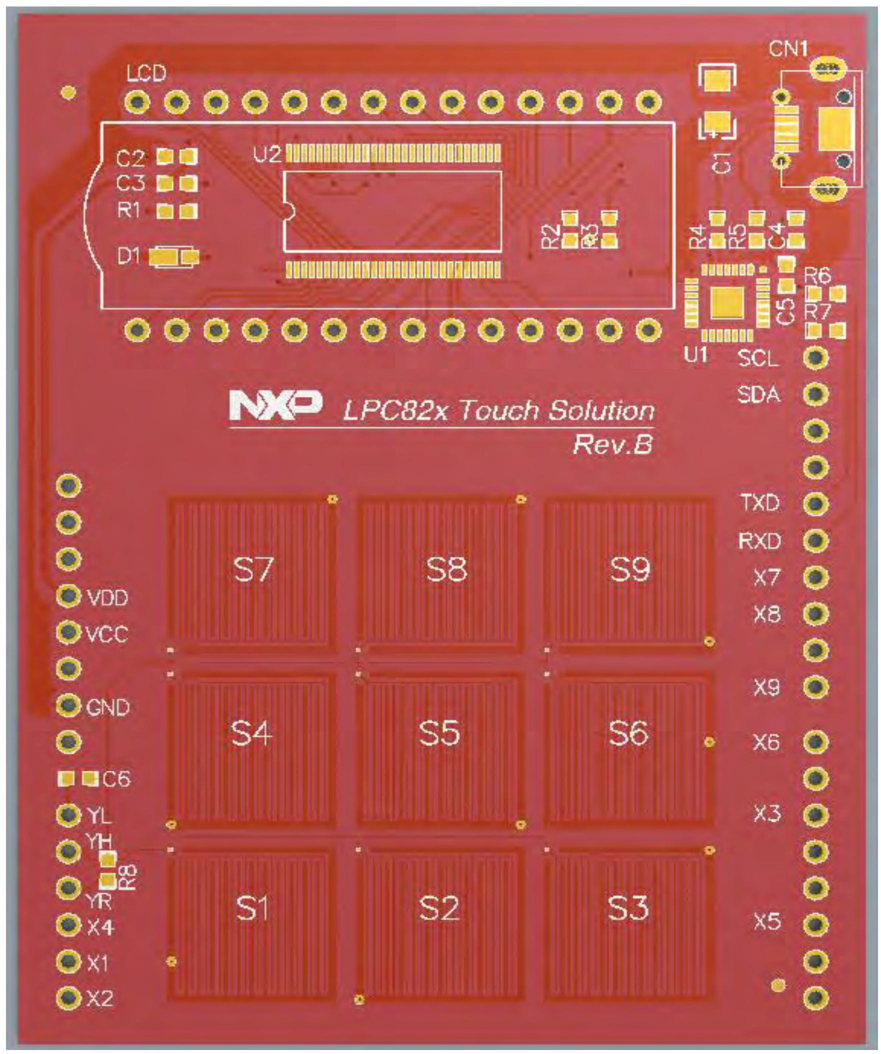

Fig 12. LPC82x Touch Solution

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