XC800 Family

AP08115

Design Guideline for Capacitive Touch-Sensing Application

Application Note

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XC82x,XC83x
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Page	Subjects (major changes since last revision)
6	Change chapter title
10	Add comments on ground plane behind the touch pad
15	Add recommended touch-sense PCB layout example
16	Add recommendation on star connection for ground layout

Table of Contents

1 Introduction

This application note is for the XC82x/XC83x family of products and describes the PCB layout, overlay material and LED considerations for capacitive touch-sensing applications. For detailed descriptions of the XC82x/XC83x products, please refer to the XC82x/XC83x User's Manual.

1.1 Overview

Key-pad/switch is a very common human-machine interface and a capacitive touch button is a practical and value-added alternative to the mechanical switch in a wide range of products. The XC82x/XC83x provides a total on-chip solution (LED and Touch-Sense Control Unit (LEDTSCU) hardware and LEDTS ROM Library software) for capacitive touch sensing and LED driving. The LEDTSCU provides a time-multiplexed control for capacitive touch sensing and matrix LED driving which results in a low-pin count device.

A typical capacitive touch-sensing application will consist of a set of conductive sensing elements formed by PCB copper traces, a protective layer on top of the sensing elements and LEDs for status indication for example.

Figure 1 shows the cross-section of a touch button in a typical capacitive touch-sensing application. C_f symbolises the finger capacitance while C_p symbolises the parasitic capacitance of the touch button.

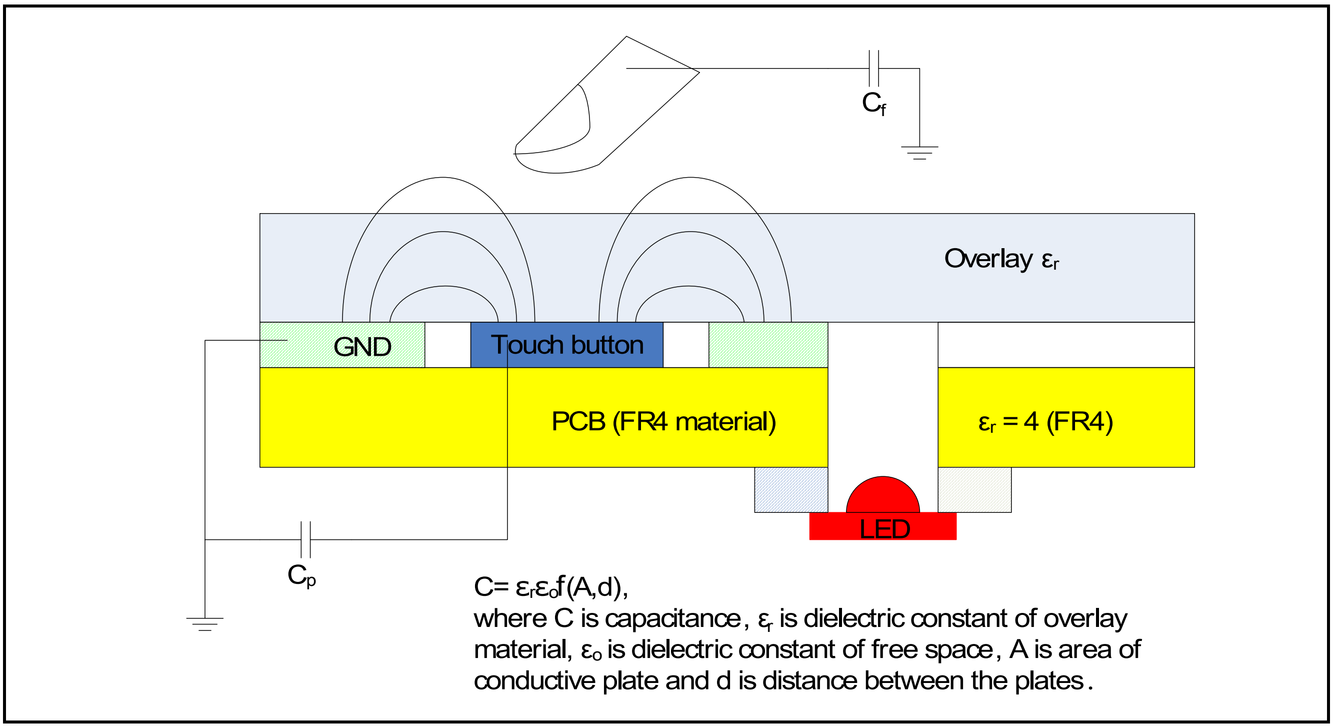


Figure 1 Cross-Section of a Touch Button

In general, the capacitance of a touch button can be expressed using **Equation (1)**:

$$C = \varepsilon_r \varepsilon_o f(A, d) \tag{1}$$

The finger capacitance (C_f) is directly proportional to ε_r. When a finger comes into proximity, the additional capacitor C_f is introduced and in parallel to the C_p.

There are many factors that will affect the finger and parasitic capacitance. Resistors and LEDs for example add parasitic capacitance to the connected touch buttons. The dielectric constant and thickness of overlay will affect the finger capacitance. All the factors which influence touch button sensitivity are discussed in detail in **Chapter 2**.

2 Touch Pad Sensitivity And Noise Resistance

When a person touches a button, that person's finger introduces additional finger capacitance to the current touch button. The basic capacitive touch-sensing mechanism is to detect this capacitance change of the touch button between touched and untouched state. The LEDTSCU implements the relaxation oscillator methodology and measures the number of oscillations within a period. The oscillator frequency will be decreased by the introduction of finger capacitance. A change in the number of oscillations is detected by the LEDTS ROM Library. 'Sensitivity' measures the change in the number of oscillations (as a percentage) between the idle (untouched) and active (touched) state of the button being evaluated. The larger the value, the greater the sensitivity.

However, when a button is touched the finger capacitance is not only added to the current touch button, but also to any other adjacent buttons, although to a lesser effect. 'Crosstalk' is used to measure the change in the number of oscillations (as a percentage) between the idle (untouched) state of the button being evaluated and the active (touched) state of its adjacent touch buttons. A larger value indicates more crosstalk.

In order to achieve a reliable touch detection, the sensitivity needs to be maximized while the crosstalk needs to be minimized. Various factors affecting the touch button sensitivity and crosstalk therefore need to be evaluated, such as the touch button design, the ground plane, the LED layout, and different overlay materials.

2.1 Sensitivity Evaluation Test Setup

Figure 2 shows the sensitivity evaluation test setup. The Mother board contains the touch-sensing controller XC836MT device and the USB-UART bridge IC which communicates directly with a PC via a virtual COM port. The number of touch button oscillations is observed from the U-SPY calibration tool. Daughter boards with round touch buttons of different diameter, gap size, ground plane pattern (solid/hatch) and LEDs are used for the evaluation.

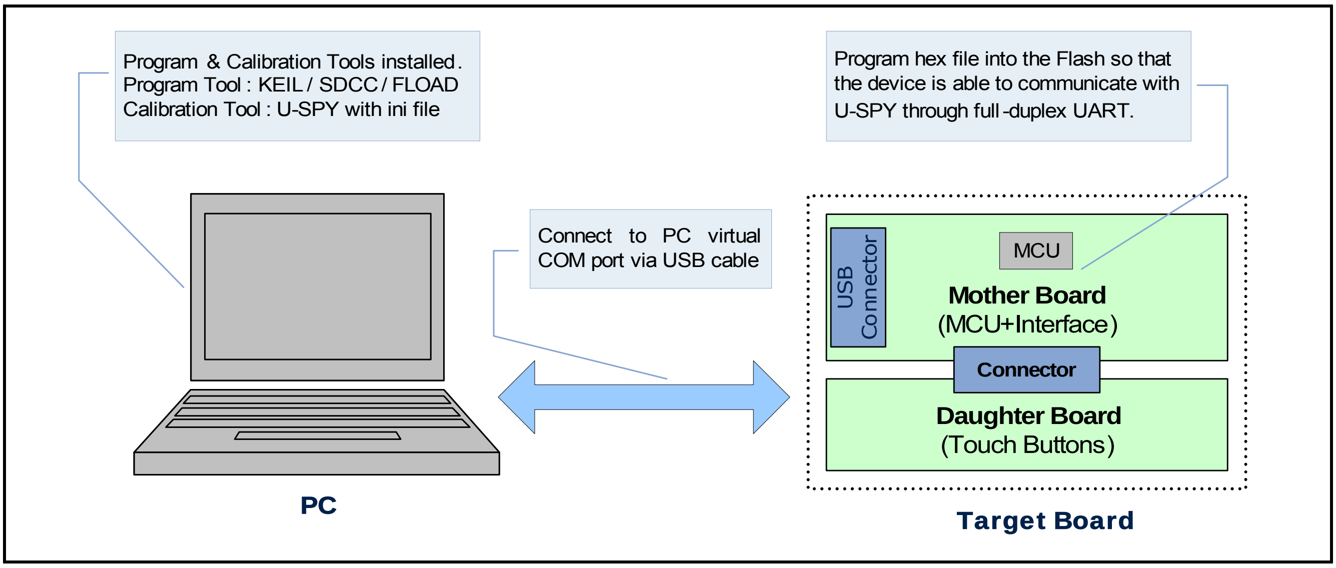


Figure 2 Sensitivity Evaluation Setup

The features of the daughter board (**Figure 3**) are:

- PCB (printed circuit board) is 1.6mm thick FR4 material with 1oz copper
- Touch buttons are on the top PCB layer
- Touch button diameter is 10mm except for touch button size related tests
- Touch button gap is 6.5mm except for touch button gap related tests
- No ground polygon on top and bottom layers except for touch button and ground layout related tests
- Internal pull-up is used except for external pull-up related tests
- No LED is connected except for LED layout related tests
- Overlay material is 2mm acrylic except for overlay material related tests

"Sensitivity (signal)" and "Crosstalk (noise)" are the two criteria for evaluating the sensitivity of the touch button.

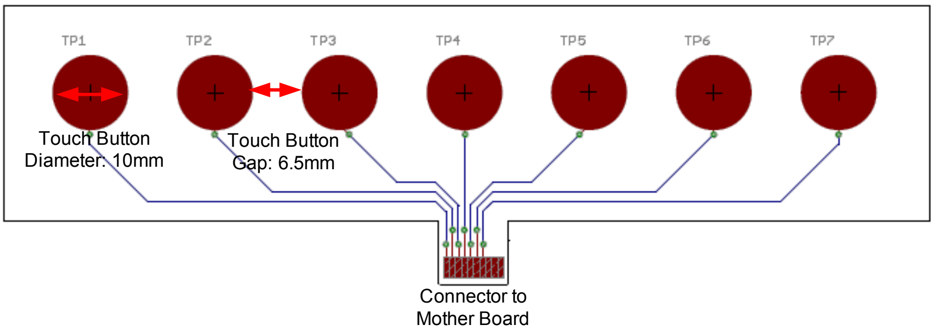
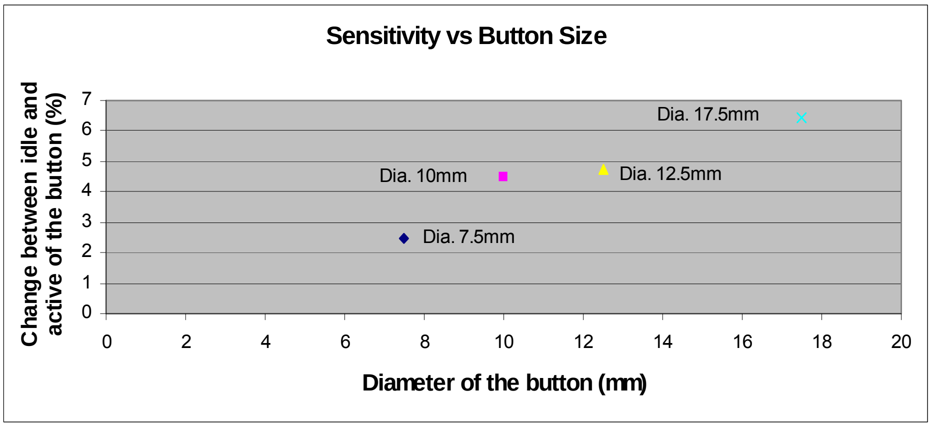


Figure 3 A typical Daughter Board

2.2 Touch Button Size

Since the capacitance is proportional to the overlapping area of the 2 conducting surfaces, a larger overlapping area will result in a bigger capacitance. Hence better sensitivity can be observed on a bigger touch button with bigger finger capacitance C_f. However, the increase in the capacitance, due to increase in the surface area of the touch button, is limited by the surface area of the finger contact with the touch button. Different shapes do not affect the sensing characteristics.

Four different sized touch buttons have been evaluated. The sensitivity results are shown in **Figure 4**.



Test conditions

Button diameter: variable	Button gap: 6.5mm	GND polygon: no
Overlay: 2mm acrylic	Ext. pull-up: no	LED: no

Figure 4 Sensitivity versus Touch Button Size

As shown in **Figure 4**, the 17.5mm diameter touch button has the highest sensitivity out of the four sizes tested. However a minimum 10mm diameter button is recommended in terms of the trade-off between sensitivity and space constraints.

2.3 Touch Button Gap

Maintaining a gap between the adjacent touch buttons provides insulation from the finger's capacitance and minimizes unwanted interference between the touch buttons.

Three different button gaps have been evaluated. Sensitivity and crosstalk results are shown in **Figure 5**.

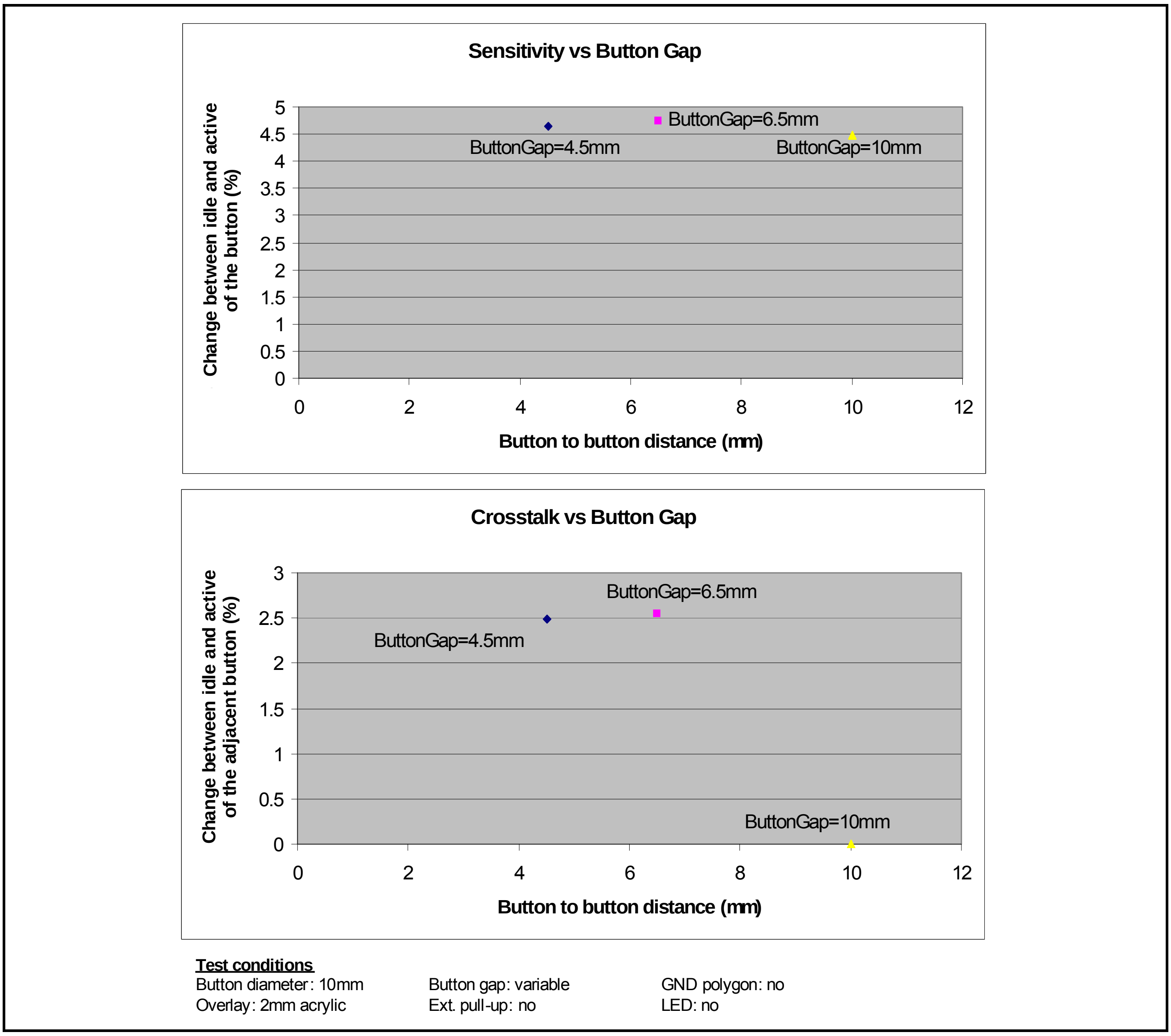


Figure 5 Sensitivity and Crosstalk versus Touch Button Gap

As seen in **Figure 5**, a touch button gap of 10mm has the least coupling effect (crosstalk), while providing reasonably good sensitivity.

2.4 Touch Button and Ground Plane Layout

In general touch buttons should be kept away from ground, because sensitivity will be reduced by increasing C_p when ground is close by. However a layer of ground between the touch buttons will reduce the interference between adjacent buttons (crosstalk). Therefore there is a trade-off between maintaining a high-level of sensitivity and increasing the noise immunity of the system.

In a noisy environments, a ground plane can help to reduce noise interference but at the same time will decrease the touch button sensitivity. If possible, the ground plane should not be placed too close to the touch buttons. When

a ground plane is placed under a touch button, the solid ground will have better shielding effect but will have a larger C_p value compared to the hatched ground.

Figure 6 illustrates the combinations of 2 types of ground polygon (solid & hatched) with 2 different clearances (1mm & 3mm) surrounding the touch buttons.

Several combinations of different ground patterns on top and bottom PCB layers have been evaluated. The sensitivity and crosstalk results are shown in Figure 7.

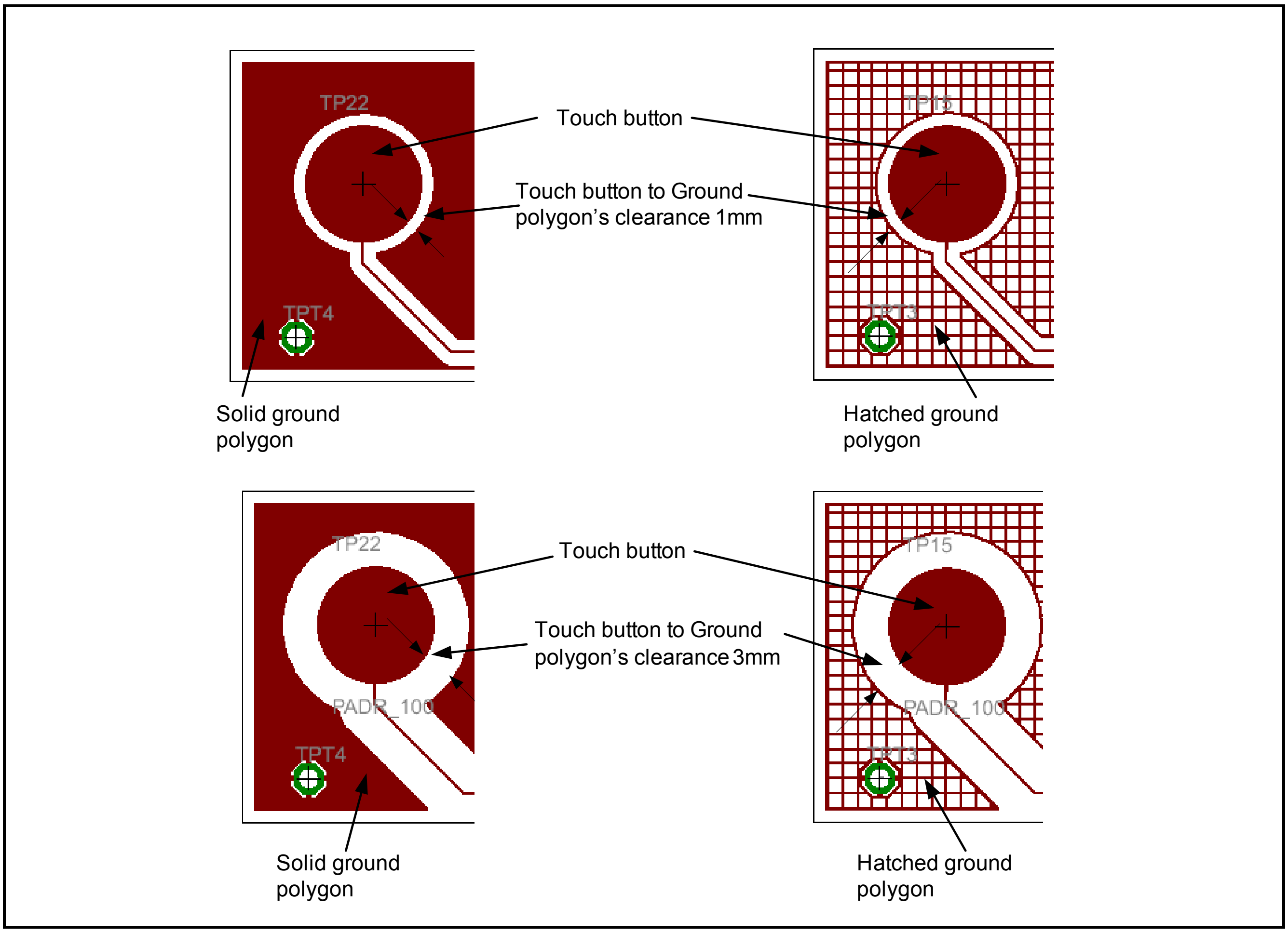
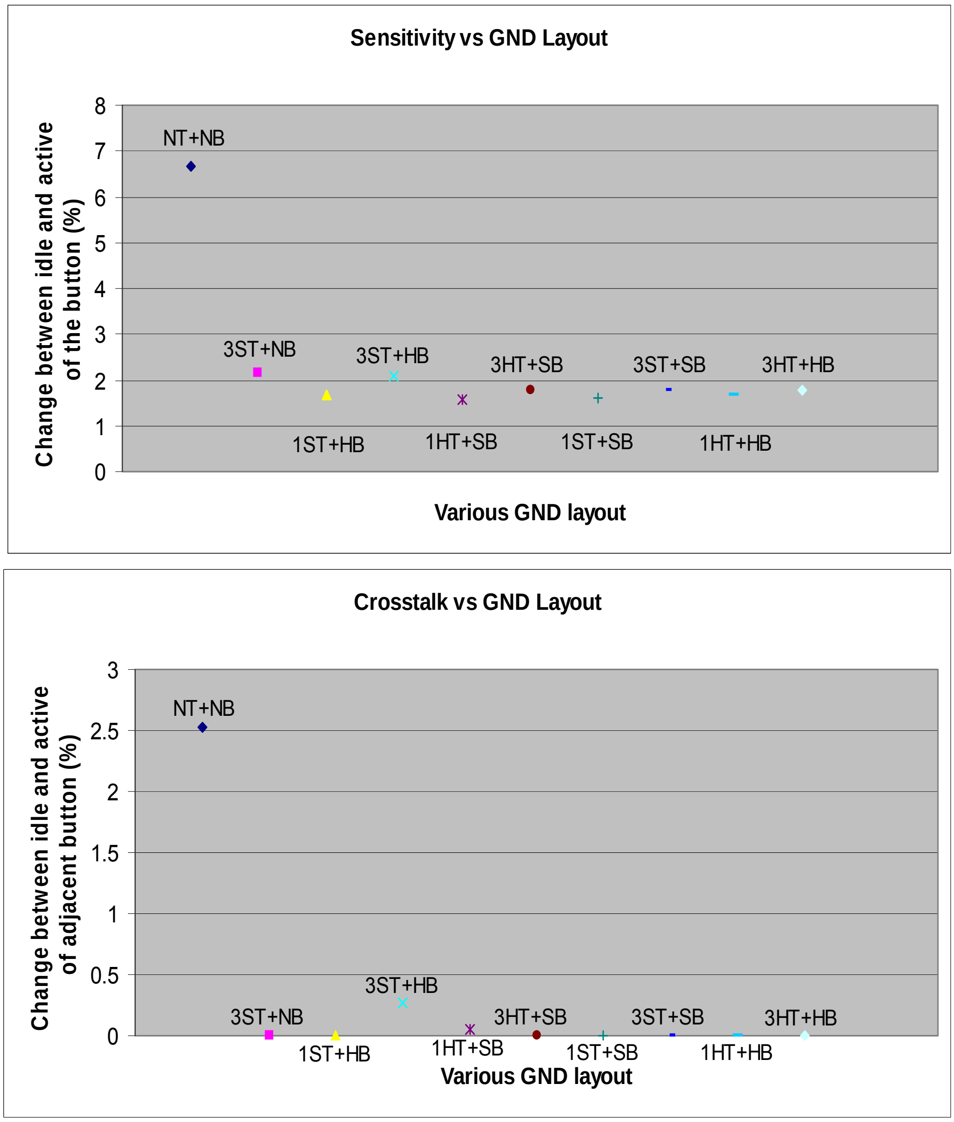


Figure 6 Combinations of Different Ground Polygon with 1mm and 3mm Clearances



Test conditions

Button diameter: 10mm | Button gap: 6.5mm | GND polygon: variable

Overlay: 2mm acrylic | Ext. pull-up: no | LED: no

Legend

1/3ST: **S**olid ground polygon on **T**op layer with **1/3**mm clearance around the touch pad
1/3HT: **H**atch ground polygon on **T**op layer with **1/3**mm clearance around the touch pad
NT/NB: **N**o ground polygon on **T**op / **B**ottom layer
HB/SB: **H**atch / **S**olid ground polygon on **B**ottom layer

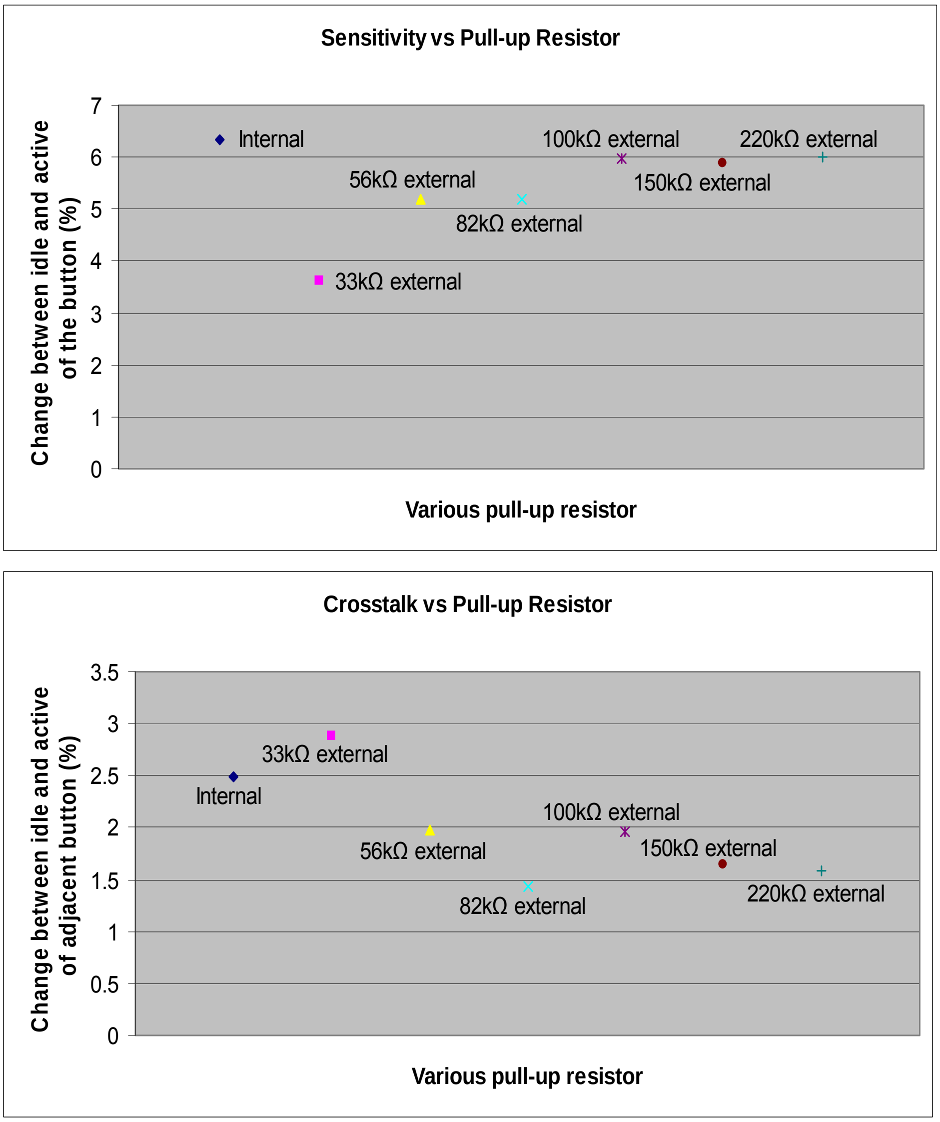
Figure 7 Sensitivity and Crosstalk versus Different Ground Layout

As shown in Figure 7, a touch button with 3mm clearance has better sensitivity when compared to one of 1mm clearance. A solid or hatch ground polygon on the top or bottom PCB layer does not make a significant difference in sensitivity or crosstalk performance, but the ground polygon improves the noise immunity of the system. Especially putting a ground plane behind the touch button significantly improves the noise resistance but comes at the cost of severely reduced sensitivity.

2.5 External Pull-Up Resistor

Touch button oscillation frequency changes when the value of the external pull-up resistor (connected to the COLA pin) changes. This results in different sensitivity of the touch button as well as the crosstalk between the adjacent touch buttons. The user should select a suitable pull-up resistor in order to balance the sensitivity of the touch button and the accuracy of the detection.

A number of different external pull-up resistors have been evaluated. The sensitivity and crosstalk comparison results are shown in **Figure 8**.



Test conditions
Button diameter: 10mm | Button gap: 6.5mm | GND polygon: no
Overlay: 2mm acrylic | Ext. pull-up: variable | LED: no

Figure 8 Sensitivity and Crosstalk versus Different Ground Layout

As the results in **Figure 8** show, the larger 220kΩ external pull-up resistor provides good sensitivity and crosstalk isolation.

2.6 LED Layout

LEDs, commonly placed near to the touch buttons, light up to reflect which touch buttons are pressed. With the time-multiplexed control provided by the LEDTSCU, each touch button can be connected to a maximum of 7 LEDs. This will increase the parasitic capacitance of the touch button and result in a reduction in sensitivity.

Two cases have been evaluated (**Figure 9**), and the sensitivity results are shown in **Figure 10**.

- Each touch button has 1 LED being connected;
- Each touch button has 3 LEDs being connected.

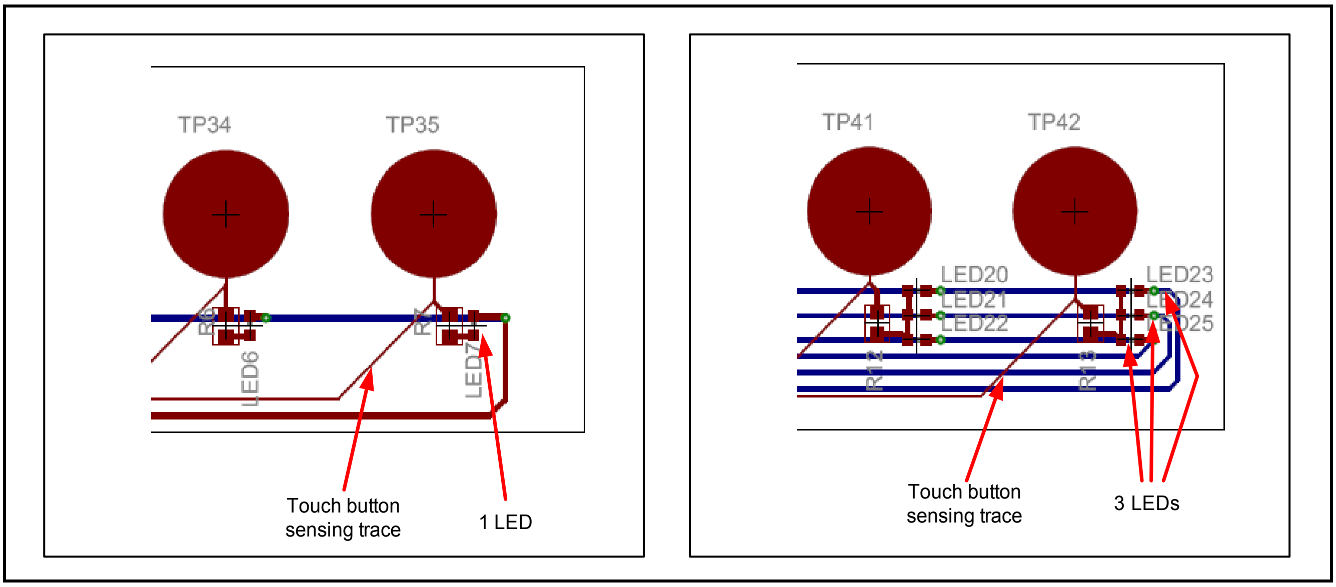
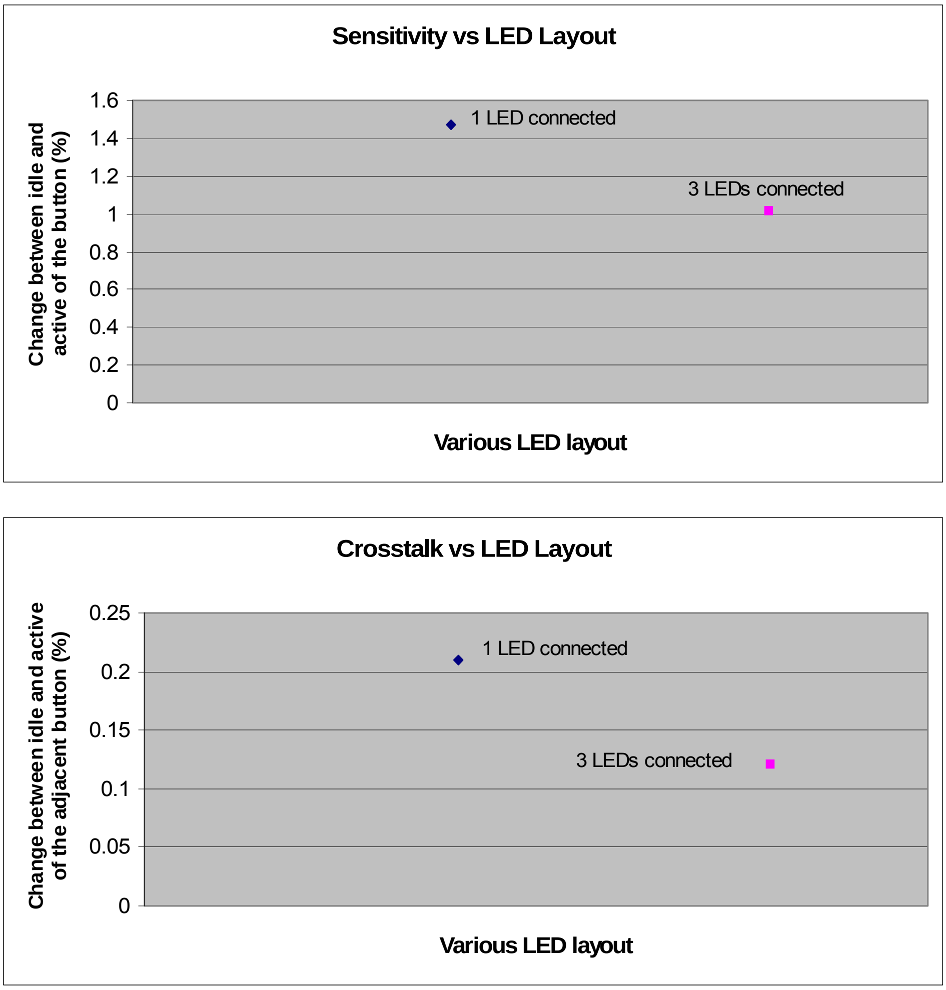


Figure 9 Two Cases of Touch Button and LED Layout



<u>**Test conditions**</u>

Button diameter: 10mm	Button gap: 6.5mm	GND polygon: no
Overlay: 2mm acrylic	Ext. pull-up: no	LED: variable

Figure 10 Sensitivity and Crosstalk versus Different LED layout

The results shown in **Figure 10** indicate that a touch button with 3 LEDs connected is less sensitive than a single LED, but has better crosstalk isolation.

2.7 Overlay Material

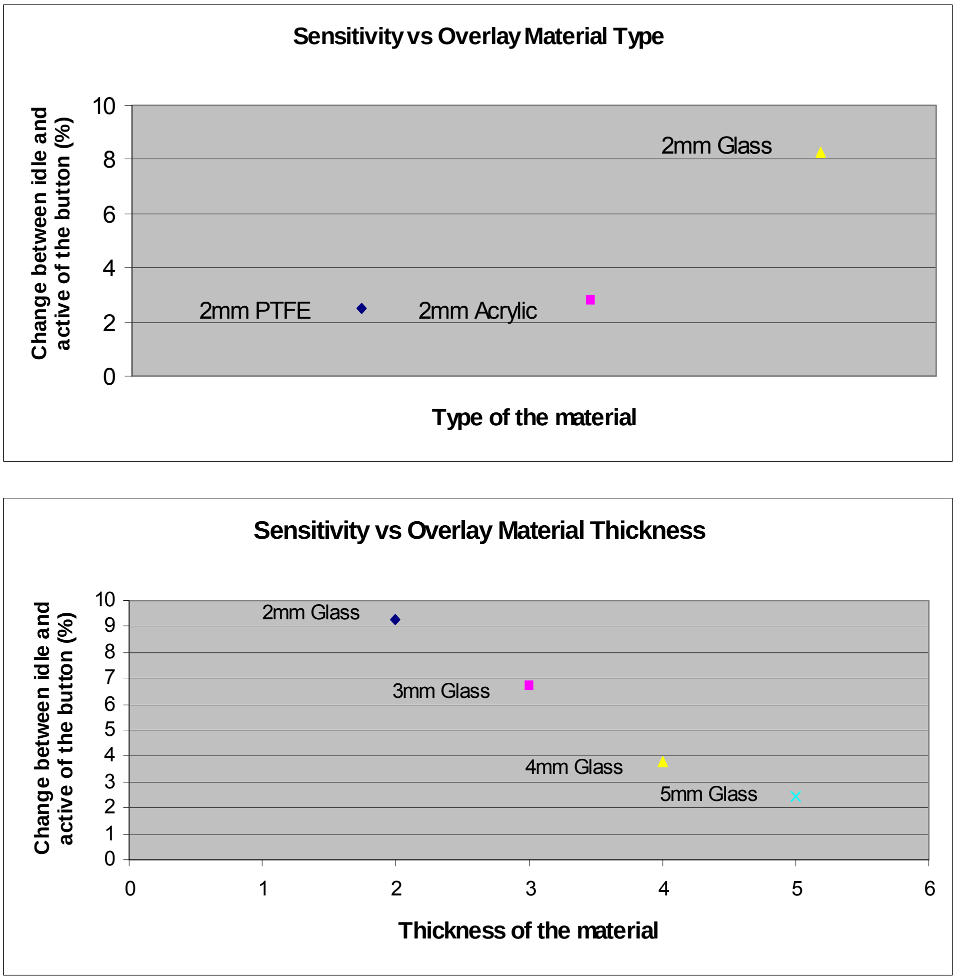
In most products, the touch buttons are not directly exposed to the user. They are usually covered by a layer of plastic or glass (overlay) for aesthetic and protective reasons.

From **Equation (1)**, the capacitance is proportional to the dielectric constant of the material between two conductive plates and inversely proportional to the distance of dielectric (refer to **Table 1** for the dielectric constants of various materials). Hence, the finger capacitance is proportional to the dielectric constant of the overlay material and inversely proportional to the thickness of the overlay. Thinner overlay with higher dielectric constant is ideal from a capacitive touch-sensing perspective.

Glass and acrylic are common materials used as touch button overlay. The glass overlay is about 3 times as thick as an acrylic overlay for the identical sensitivity. This is because the dielectric constant of glass is approximately 3 times the dielectric constant of acrylic.

Air is not well suited to capacitive touch-sensing applications because its dielectric is 1.0, therefore an air gap between the touch button and overlay material is not recommended.

Three different overlay materials and various thicknesses of glass overlay have been evaluated. The sensitivity comparison results are shown in **Figure 11**.



Test conditions

Button diameter: 10mm	Button gap: 6.5mm	GND polygon: no
Overlay: variable	Ext. pull-up: no	LED: no

Dielectric Constants

Glass: 7.6	Acrylic: 2.6	PTFE: 2.1

Figure 11 Sensitivity and Crosstalk versus Different Overlay Material

From the results shown in **Figure 11**, we can state that with a thickness of 2mm, a touch button with glass overlay has the best sensitivity when compared to PTFE (Polytetrafluoro ethylene) and Acrylic overlays. When increasing the glass overlay thickness from 2mm to 5mm, the touch button sensitivity is reduced.

2.8 Sensing Trace

Sensing trace adds parallel capacitance to the connected touch button, but has a negative effect on the sensitivity.

The longer and wider the sensing trace is, the greater the parasitic capacitance will be. Furthermore, noise can be easily coupled if the sensing trace is long which further decreases the sensitivity performance. Therefore the sensing trace from the touch button to the touch-sensing controller device should be kept as short and narrow as possible to reduce the parasitic capacitance. In this touch button sensitivity study, a 0.3mm width sensing trace was used.

The placement of capacitive sensing traces must minimize the interaction with other touch buttons, including other capacitive sensing traces whenever possible. If there is more than one sensing trace, a certain space should be kept between the sensing traces. For this touch button sensitivity study, the space between sensing traces is 3 times the trace width. Furthermore, the sensing trace should avoid running directly underneath the touch button.

Communication lines such as I2C or SPI are high-frequency traces, that can impact the performance of the capacitive touch buttons. It is desirable to keep high-frequency traces away from sensing traces. If it is necessary to cross communication lines with sensing traces, it is preferable to keep the noisy, high-frequency traces perpendicular to the sensing traces for minimal RF interference.

In order to further reduce parasitic capacitance of the touch button, the number of vias on the sensing trace needs to be minimized.

2.9 Ground Domain

A voltage regulator can filter out a significant portion of the conducted noise from the power supply. It is therefore highly recommended to use a voltage regulator to power-up the touch sensing device. However, the voltage regulator should be placed as far as possible from the sensing device and traces.

It is also recommended to divide the PCB layout into several separate domains/areas. For example, LEDTSCU signals and ground should form their own domain. The same is true for the ADC and power modules, and so on. All signals should be shielded by their respective ground planes to reduce radiated noise. The ground of each domain needs to be connected separately and be placed apart from each other, with no overlap on differenct PCB layers. The intention is to de-couple the sources of noise as much as possible; i.e. radiated, conducted, core supply, pin activity, and so on.

Since XC82x and XC83x devices have only one ground pin (VSSP), all domain grounds must be connected to it in the end. To minimize the coupling effect, a star connection should be formed at VSSP, with the de-coupling capacitors placed as shown in **Figure 12**. Please refer to the Application Note AP08110 “XC82x XC83x PCB Layout” for further information.

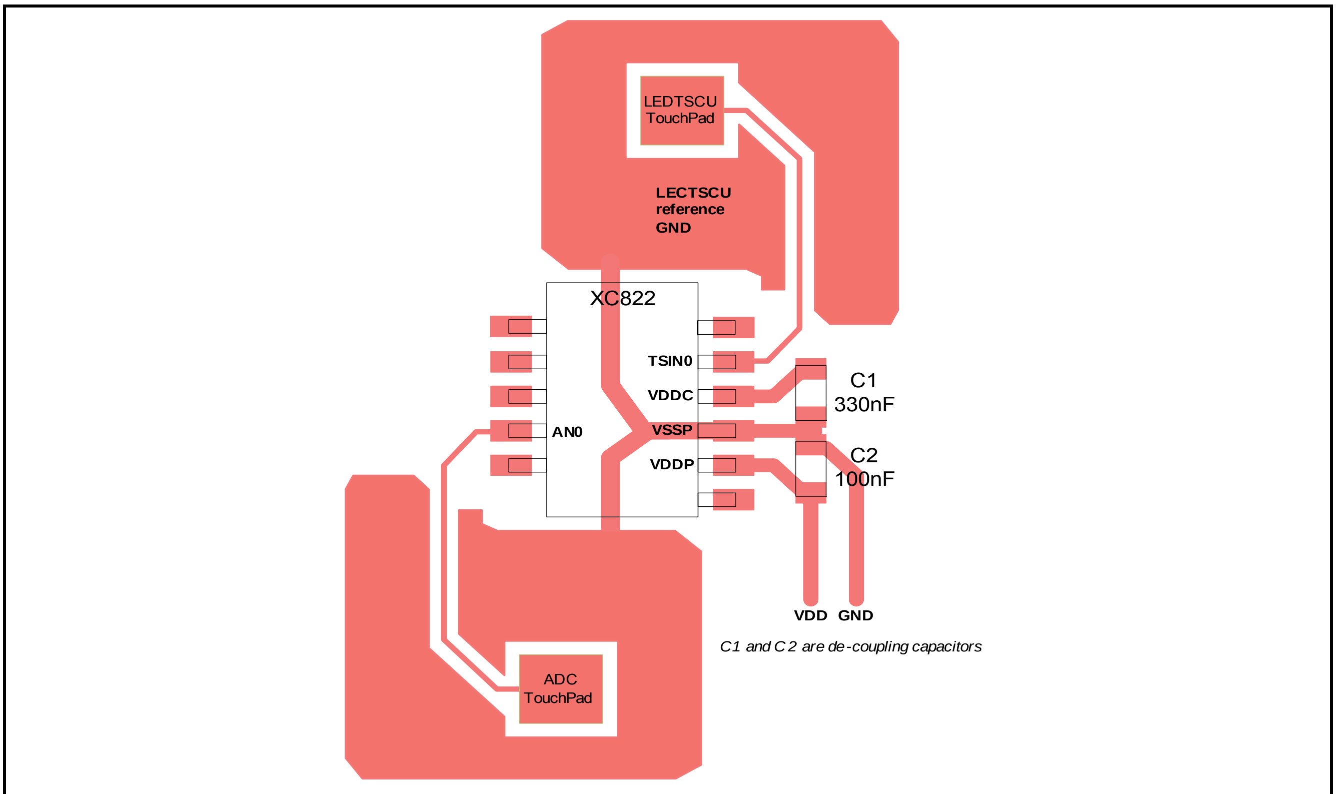


Figure 12 Touch-Sense PCB Layout Example

3 Conclusion

To summarize, as a general rule, the layout of a capacitive touch-sensing system should use minimal ground and keep route wires short, narrow and far away from other potential interference sources whenever possible.

From the results gathered, the following recommendations should be taken into account when designing a PCB:

- Use larger touch buttons to maximize sensitivity. A 10mm minimum diameter is recommended
- Use a larger touch button gap to maximize the crosstalk isolation
- Use a solid ground polygon with a large clearance to get the best noise immunity if there is no LED connected to the touch button
- Reduce the number of LEDs and position them close to the touch button to minimize the sensitivity reduction
- Use a thinner overlay with a high dielectric constant to achieve the best sensitivity
- Keep sensing trace short, narrow and far away from high frequency signals whenever possible
- Use star connection for ground layout

The layout and design of a capacitive touch-sensing system often presents a series of trade-off questions. The main goal is uniformity and balance (similar sensitivity and crosstalk) touch button design. The information presented in this document can be used as general guidelines, but personal judgement must be exercised when trade-off situations are encountered.

4 Appendix

Table 1 Dielectric Constants of Various Materials

Material	Dielectric Constant
Air	1
Glass	3.8 ~ 14.5
Mica	4 ~ 9
Nylon	3.4 ~ 22.4
Plexiglas	2.6 ~ 3.5
Polyethylene	2.5
Pyrex Glass	5.6
Rubber	2 ~ 4
Silicon	3.2 ~ 4.7
Teflon	2.1
FR4 (fiberglass + epoxy)	4.2
Typical PSA (pressure sensitive adhesive)	2.5 ~ 3

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