AN11155

General design guidelines for the NXP capacitive sensors

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Document information

Info	Content
Keywords	Design, Guidelines, PCF8885, PCA8885
Abstract	This document describes design aspects which should be considered for application circuits using NXP capacitive sensors.

Revision history

Rev	Date	Description
1	20120203	new application note, first revision

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1. Introduction

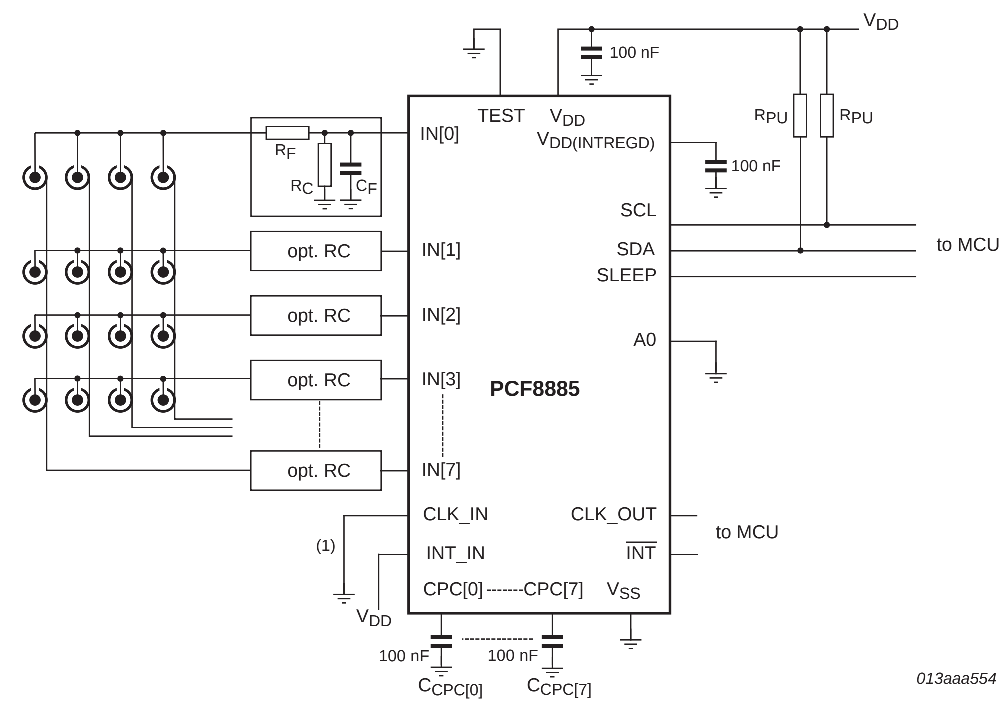
In order to obtain proper function when using touch sensors, certain design guidelines must be followed for the application circuit and the design of sensor plates.

This application note considers the typical application circuit on a pin-by-pin basis and recommends appropriate components.

A theoretical background for the design of sensor plates is given and applies also on sliders and key matrices.

2. Typical application circuit

Figure 1 illustrates the application circuit for PCF8885. A cascaded solution may be implemented easily by following the data sheets Ref. 4 “PCA8885” and Ref. 5 “PCF8885”. Pin description is found in Table 1. It also contains some remarks in addition to the data sheets.



(1) Pin CLK_IN can be tied to V_{SS} or left open.

Fig 1. Single device application diagram

Table 1. Additional information on the pins of the PCx8885

Symbol	Pin	Type	Description
CLK_OUT	1	output	clock output for chip cascading and synchronization; if not used: this output should be disabled in register CLKREG; it is recommended to be decoupled with 100 nF for highest immunity but can be floating in less noisy environments
$V_{DD(INTREGD)}$	2	supply	internal regulated supply reference voltage; this pin must be decoupled with a 100 nF capacitor also when not used
IN	3 to 10	analog input/output	sensor input, channel 0 to 7; for higher RF noise immunity, the low-pass filter described in Ref. 3 “AN11157” (EMC) may be implemented; for higher ESD level, the 8-ch PRTR5V0U8S described in Ref. 3 “AN11157” (EMC) will provide protection up to 8 kV; the input capacitance range of the PCx8885 is 10 pF to 40 pF. In the case that the parasitic capacitance of the sensor pads and the routing is lower than 10 pF, 10 pF capacitors have to be used in parallel with the inputs
CPC	11 to 18	analog input/output	reservoir capacitor, channel 0 to 7; these capacitors should be low leakage X7R or C0G capacitors with insulation resistance larger than 5 GΩ
V_{SS}	19	supply	ground supply voltage
SCL	20	input	I^2C serial clock line
SDA	21	input/output	I^2C serial data line
TEST	22	input	test pin; must be connected to V_{SS}
A0	23	input	I^2C subaddress
SLEEP	24	input	sleep mode; connect to V_{DD} to force the circuit into low-power sleep mode; if not used, this pin should be decoupled with a 100 nF capacitor
$\overline{INT}$	25	output	interrupt output; if not used, it should be disabled with the clear-int command and decoupled with 100 nF for highest immunity

Table 1. Additional information on the pins of the PCx8885 *...continued*

Symbol	Pin	Type	Description
V_{DD}	26	supply	supply voltage
$\overline{\text{INT\_IN}}$	27	input	interrupt input for chip cascading; connect to V_{DD} if not used
CLK_IN	28	input	clock input; for the secondary chip when the primary chip provides the clock signal; if not used, it should be configured accordingly and decoupled with 100 nF for higher noise immunity

2.1 Sensitivity - design considerations

In order to design sensor plates for highest sensitivity, some NXP touch sensor specific features and general understanding of electrical fields as well as capacitive coupling have to be recalled.

2.1.1 Steady state capacitance

One of the major differences between the NXP touch sensors and competitive parts in the market is, that NXP sensors react on certain changes in capacitance instead of measuring absolute capacitance. Providing the capacitive load is in the specified range of 10 pF to 40 pF, any capacitance change at the speed of a typical moving finger will be detected.

Remark: The steady state capacitance originating from the layout, slowly changing environmental conditions, accumulating dirt, and so on, will be compensated for by the auto-calibration mechanism.

2.1.2 Approach sensitivity

The definition of normal approach speed is application-dependent. The approach to touch buttons on a control panel is much slower than to key pads, wheel-switches or sliders.

In the default settings, the oscillator frequency is 70 kHz. The clock frequency derived from the oscillator with the default divisor is: $70\ kHz / 16 = 4.4\ kHz$. As the sensor input channels are sampled sequentially, it will result in $4.4\ kHz / 8 = 0.55\ kHz$ sampling frequency.

To define a capacitive event, 64 consecutive samples are required. With a sampling frequency of 0.55 kHz, it will take 117 ms. The lower the frequency, the longer is the switching time. The sampling frequency may be set to higher values to detect quick movements, for instance for a keypad.

Remark: The approach sensitivity can be adjusted for every application with two configuration commands. With m = 1 being the default value, the oscillator frequency (f_{osc}) can be tuned in the range 0.5 < m < 1.75 in eight steps.

The clock frequency can be derived from $f_{osc} / n = f_{clk}$ where n = 1, 4, 16, or 64. The switching time vs. sampling frequency is shown in Figure 2.

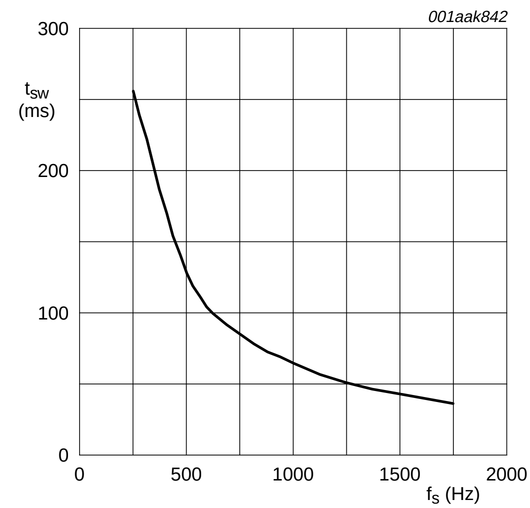


Fig 2. Switching time (t_{sw}) with respect to sampling frequency (f_s)

A typical human touch in push-button applications has approximately the course shown in Figure 3. A sampling frequency about 1 kHz is recommended as a start value for optimizing the approach sensitivity.

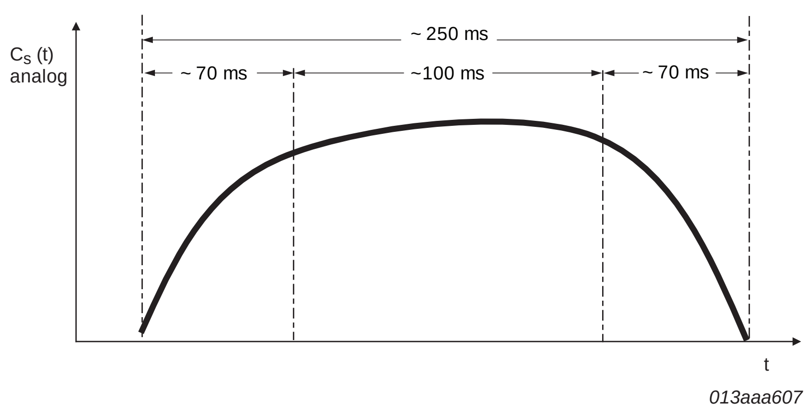


Fig 3. Typical human touch on push button

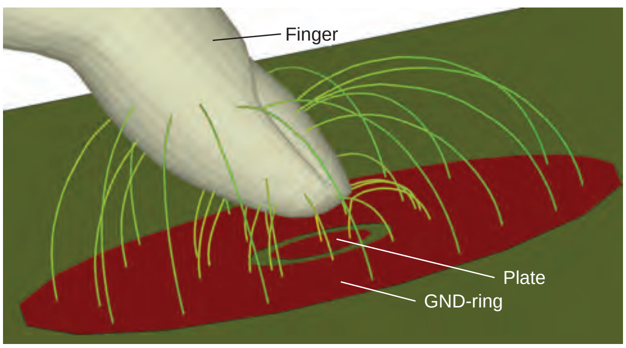
2.2 Unused sensor channels

In case, a sensor channel is not used, the sensor input pin has to be left floating and the corresponding CPCx capacitor pin must be tied to GND. The corresponding bit in the MASK register must be logic 0 and the MSKMODE bit in the CONFIG register has to be logic 1 to permanently mask a channel.

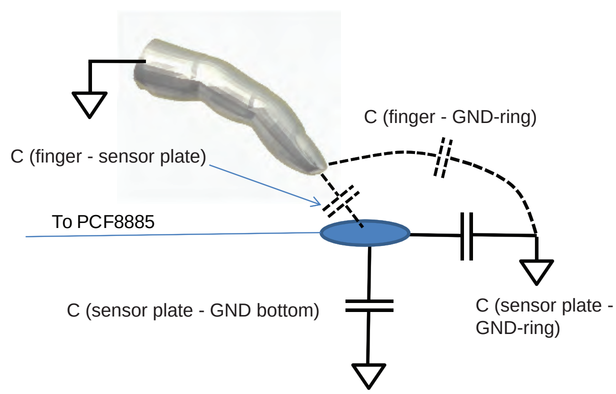
If the MSKMODE cannot be set logic 1 for whatever reason, there will be sampling pulses even on the masked-out channels. Then the CPC pins have to be left open or even better decoupled with a few nF. Otherwise the channels remain in fast-start mode and the overall current consumption is far above the normal idle current.

3. Design of sensor plates

The steady state capacitance between the sensor plates, traces, and GND is compensated for by the auto-calibration mechanism. Therefore the primary condition to consider for design of sensor plates is to maximize the capacitance between the approaching finger and the sensor plate. Likewise the capacitance between the finger and any GND has to be minimized.



a. Field lines between finger, sensor plate, and GND



b. Electrical schematics of finger, sensor plate. and GND

Fig 4. Electrical field with an approaching finger

In order to provide the basics behind layout considerations, the simple round sensor plate in Figure 4 is studied with CST EM Studio, a simulation tool from Computer Simulation Technology. The sensor plate is realized on a 1.5 mm thick PCB with solid GND on the rear side and the sensor plate is surrounded by solid GND. The diameter of the sensor plate is 10 mm, the gap to GND-ring is 2.2 mm and the overlay acrylic is 3 mm thick.

From the model and electrostatic simulation, it is apparent that there will be a significant stray capacitance between the finger and the GND-ring besides the intentional capacitance between the finger and the sensor plate. Table 2 shows that the capacitance between an approaching finger and any GND nearby the sensor plate will be higher than between the finger and the sensor plate. This highlights the need of minimized stray capacitance between an approaching finger and conductors nearby. In the capacitance table (Table 2), the elements between different conductors indicate the mutual capacitance between those conductors.

Table 2. Capacitance between finger, sensor plate, and GND

Finger to Plate	Finger to GND-ring	Plate to GND-ring	Plate to GND-bottom	Unit
0.5	1.2	0.7	3.8	pF

In the following sections, the parts of a sensor plate layout are studied in detail.

3.1 Overlay

The overlay between the finger and the sensor plate should be kept as thin as possible. Higher relative permittivity of the material will increase the sensitivity. To understand this, the simple parallel plate capacitance expression can be studied.

$C = (\varepsilon A)/d$, where the dielectric contact ε is a product of the free space permittivity (ε_0) and the relative permittivity (ε_r) of the media. 'A' is the area of the plates and 'd' is the thickness of the insulation media. Table 3 shows some materials and their relative permittivity for reference.

Table 3. Relative permittivity of some overlay materials

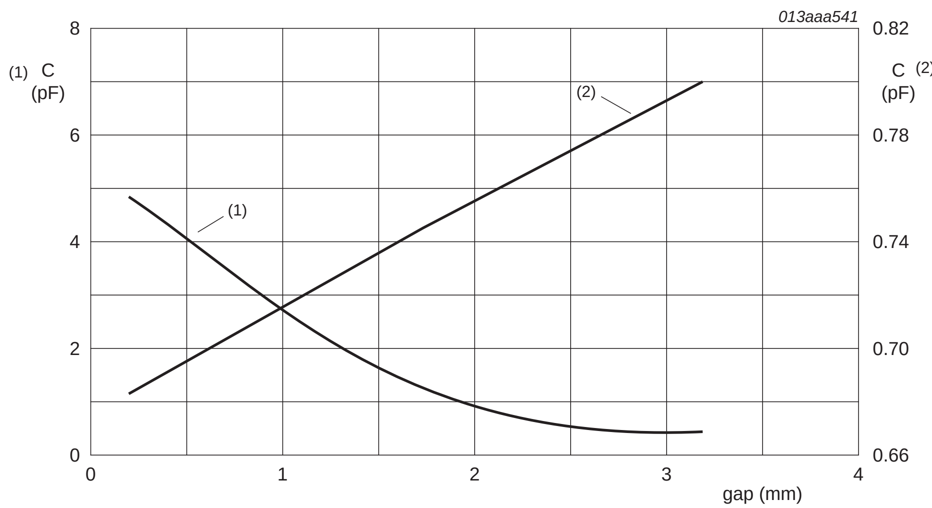
Material	Relative permittivity (ε_r)
Air	1
FR-4	4.7
Glass	5 to 10
Acrylic	3
Water	80

3.2 GND-ring

GND-ring around sensor plates will increase noise immunity but decrease the sensitivity due to the finger-to-GND stray capacitance. So what is the optimal separation? A rule of thumb is that the separation should be greater than the overlay thickness. However having 5 mm separation for 5 mm overlay would result in a total sensor plate and GND-ring of more than 20 mm in diameter which would be difficult to implement due to space constraints.

Electrostatic simulations show that the major decrease of stray capacitance obtained once the sensor plate–to-GND separation is over 2 mm.

Figure 5 illustrates the mutual capacitance between a touching finger, sensor plate, and the GND-ring as function of the separation. The overlay is 3 mm thick acrylic.



Capacitance between a touching finger, sensor plate, and GND-ring as function of the gap to the ground ring.

(1) Plate to ground ring.

(2) Finger to plate.

Fig 5. Capacitance between a touching finger, sensor plate, and GND-ring

3.3 Sensor plate

The sensor plate size is per definition a major element in the sensitivity as it is defining the size of the parallel plate capacitor and the touching finger.

The ideal sensor plate diameter for a normal sized finger is about 11 mm allowing an overlay thickness of 3 mm and GND separation of approx. 2 mm.

The relation between the sensor plate diameter and the overlay thickness should be about $sensor\ plate\ diameter = overlay\ thickness + 8\ mm$.

Round-shaped sensor plates will have a maximized sensing area and are recommended.

3.4 Air gaps and extensions

The overlay material should ideally be stiff and the capacitive event should be defined by touching the overlay and not deforming it. The consequence of the latter case would be a capacitance change for neighboring buttons and therefore false switching.

Likewise, air gaps between overlay and the sensor plates should be avoided to get a well-defined structure.

As a matter of fact, in many applications the overlay is not directly put on the PCB and the sensor plate is physically extended with a conductive material. The advantage of this implementation is that the stray capacitance to surrounding GND conductors is reduced but the disadvantage is that the noise immunity is reduced as well.

Figure 6 illustrates how the sensor electrode is extended to avoid air gaps and allow relaxed front panel design.

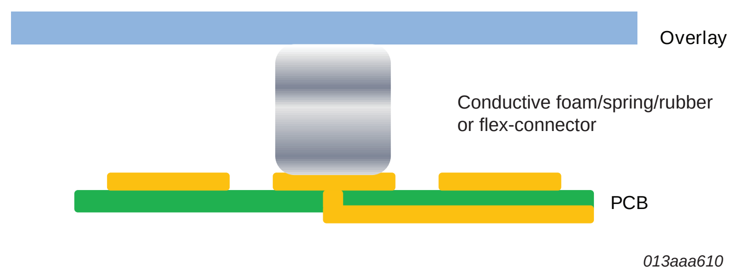


Fig 6. Extension of sensor electrode for front panels

3.5 Profiled overlay for higher sensitivity

In applications where the sensor plates are densely placed and high noise immunity is desired, the GND separation might be reduced down to 0.2 mm. In order to reduce the negative impact of the GND on the sensitivity, the overlay may be profiled as illustrated in Figure 7. The air gap over the GND will reduce the stray capacitance while the finger-to-sensor plate capacitance is preserved.

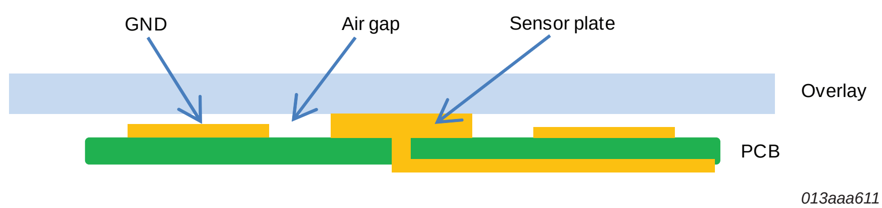


Fig 7. Profiled overlay for reduction of stray capacitance

3.6 Flexible substrates

In most applications, the front panel is not a flat plastic cover but rather a rounded or a bent shape. For such cases, it is beneficial to use a flexible single-sided substrate. Thanks to small thickness of such substrates and high relative permittivity, the substrate can be attached to the front panel efficiently with double-sided adhesive films or other means available.

The advantage of such a solution is that the component and sensor plate side of the substrate can be inside the instrument and the electrical field propagates through the flexible substrate and the hard instrument cover without any significant attenuation.

As shown in Figure 8, flexible substrates can efficiently be used to realize advanced mechanical shapes as well as openings for illumination.

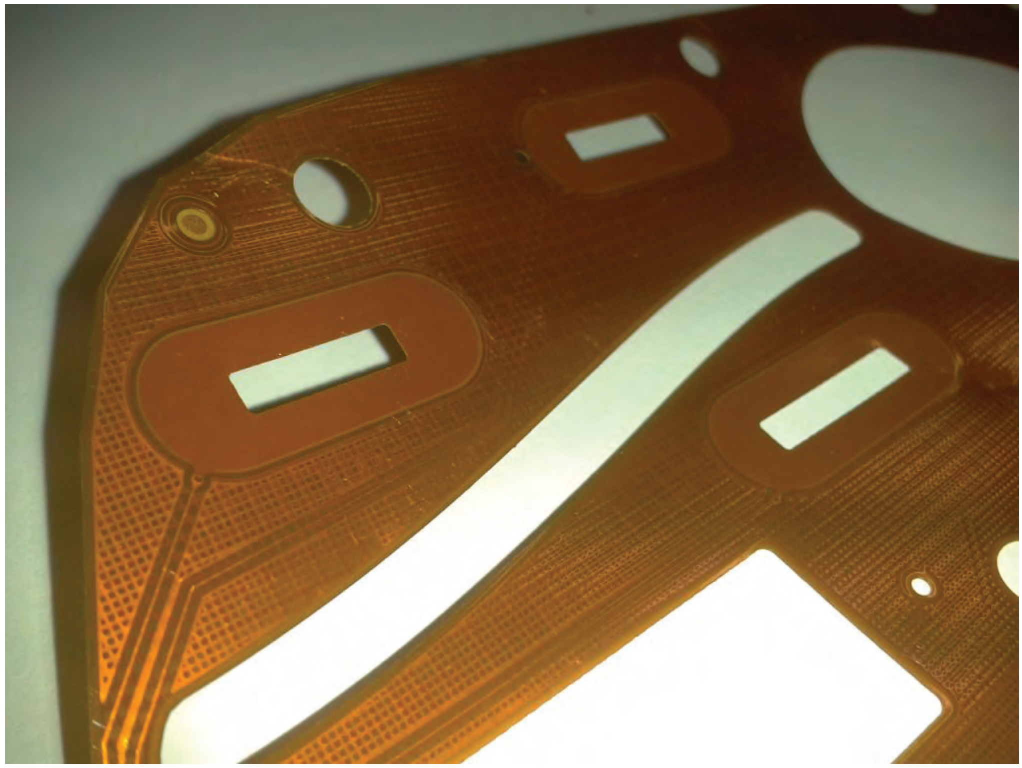


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Fig 8. Sensor plates on flexible substrates

4. References

[1] **AN10832 —** PCF8883 - capacitive proximity switch with auto-calibration

[2] **AN11122 —** Water and condensation safe touch sensing with the NXP capacitive touch sensors, Application Note

[3] **AN11157 —** Capacitive touch sensing with high EMC performance, Application Note

[4] **PCA8885 —** Capacitive 8-channel proximity switch with auto-calibration and very low-power consumption, Data Sheet

[5] **PCF8885 —** Capacitive 8-channel proximity switch with auto-calibration and very low-power consumption, Data Sheet

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