Microchip Capacitive Proximity Design Guide

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INTRODUCTION

Proximity detection provides a new way for users to interact with electronic devices without having physical contact. This technology adds to the aesthetic appeal of the product, improves the user experience and saves power consumption. People have used many ways to implement proximity: magnetic, IR, optical, Doppler effect, inductive, and capacitive. Each method has its own benefits and limitations.

Capacitive sensing method is detecting the change of capacitance on the sensor due to user's touch or proximity. For the Microchip solution, a sensor can be any conductive material connected to a pin on a PIC® MCU, RightTouch® or mTouch™ turnkey device through an optional series resistor. Generally, any conductive objects or object with high permittivity presenting nearby the sensor can impact the sensor capacitance. Comparing with other non-capacitive technologies, because of implementation of advanced software and hardware filtering, Microchip capacitive proximity solution can provide a reliable near-field detection. At the same time, it has several benefits over other solutions: low cost, highly customizable, low-power consumption, and easily integrated with other applications. Microchip provides two capacitive acquisition methods for the firmware-based solution: Capacitive Voltage Divider (CVD) and Charge Time Measurement Unit (CTMU). Application notes for CVD (AN1478, "*mTouch™ Sensing Solution Acquisition Methods Capacitive Voltage Divider*"), and CTMU (AN1250, "*Microchip CTMU for Capacitive Touch Applications*") are available on our web site at www.microchip.com/mTouch.

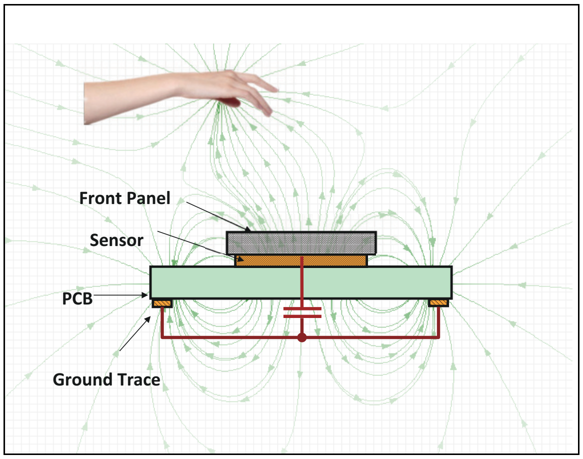
This application note will describe how to use the Microchip capacitive sensing solution to implement capacitive-based proximity detectors, provide hardware layout guidelines and analyze several factors that can have an impact on the sensitivity.

This application note can be applied to the Microchip mTouch turnkey device (MTCH101, MTCH112), RightTouch turnkey device (CAP11XX) and Microchip's general purpose microcontroller with 8-bit, 10-bit, or 12-bit ADC. The mTouch Framework and Library for Microchip general purpose microcontroller are available in Microchip's Library of Applications (MLA, www.microchip.com/mla). The Framework and Library have implemented extensive noise rejection options, which are critical to successful proximity detection appellations.

CAPACITIVE SENSING BASICS

Capacitive sensors are usually a metal-fill area placed on a printed circuit board. Figure 1 gives an overview of a capacitive sensing system.

FIGURE 1: THEORY OF CAPACITIVE SENSING



Capacitive proximity sensors are scanned in the same basic way as capacitive touch sensors. The device continuously monitors the capacitance of the sensor, and watches for a significant change. The proximity signal shift will be significantly smaller than a touch signal, because it must work over long distances and air, rather than plastic or glass, it is most likely to be the medium for the electric field. To maintain a reliable detection, the system needs to keep a good Signal-to-Noise Ratio (SNR). So, proximity applications require more careful system design considerations.

PHYSICAL SENSOR LAYOUT DESIGN

Essential design elements include the size of the sensor, location of the sensor in relation to a ground plane, and/or other low-impedance traces and specific settings within the mTouch/RightTouch device. Adhering to a few simple guidelines will allow the unique design of the device to detect the approach of a user or the movement of nearby metallic and high-permittivity objects.

There are five critical physical design elements needed to achieve maximum range detection with high signal strength and low noise:

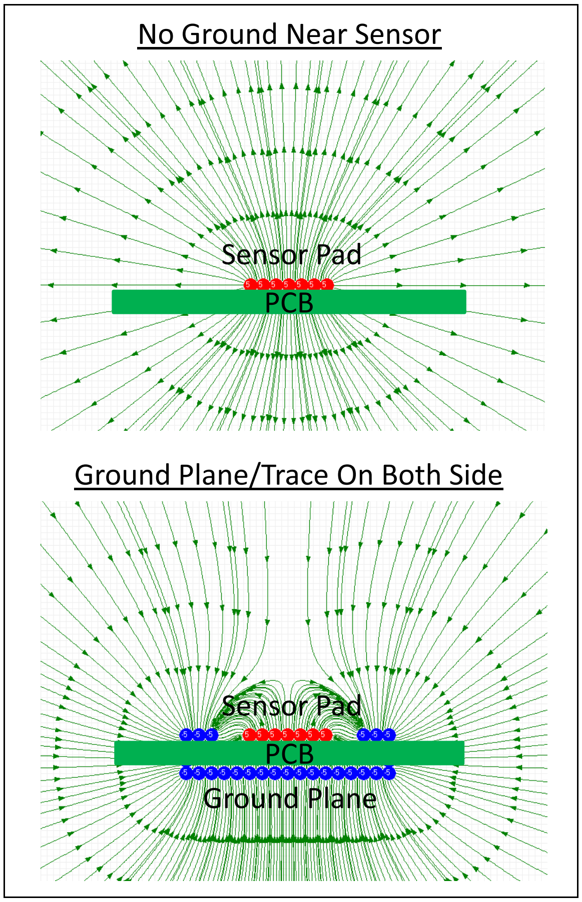
- Maximize the distance of the sensor to a ground plane (all layers of the printed circuit board (PCB) and nearby metallic objects).
- Maximize the size of the sensor.
- Use active guard to shield sensor from the low-impedance trace and ground plane
- Minimize sensor movement in the system to prevent false trigger (double-sided tape, adhesive, clips, etc.)
- For a battery-powered system, maximize the coupling between the system ground and the sensing object.

Ground Plane

Any ground plane or metal surface directly adjacent to the sensor will decrease the range of proximity detection. Ground planes have two effects on the proximity. First, the ground plane will block the proximity sensor from seeing an approaching object if it is placed in its path. This effectively reduces the detection range of the sensing system. In free space, a sensor can emit its electric field freely in all directions with little attenuation. When a ground plane is introduced, the electric field lines emitting from the sensor want to terminate on the ground plane. As the distance between the ground and the sensor decreases, the strength of the field radiating decreases. So, as a ground plane is placed closer and closer to the sensor, the sensing range is effectively reduced.

Second, ground planes will increase the base capacitance when directly below or adjacent to the proximity sensor, which only reduces the detection distance by 70%-90%. In addition to decreasing the range of a proximity sensor, this decreases the percentage of change seen in the signal when an object approaches, which reduces the sensitivity. Figure 2 shows how the ground plane affects the sensing electric field.

FIGURE 2: ELECTRIC FIELD DISTRIBUTION WITH/WITHOUT GROUND PLANE



Sensor Shape and Construction

Every system design is unique with specific aesthetic goals, as well as physical constraints. Microchip recommends loop sensor shapes (large trace with empty center) for large applications (photo frames, keyboards, etc.), and solid pads for smaller button board applications. Loops reduce the overall capacitance that the Microchip device will see and create a larger coverage area. A pad shape is best for small boards where separation from ground is limited, and the pad area is needed to create the desired range.

A loop sensor can have any aspect ratio (i.e., 20cm x 20cm or 5cm x 40cm). The desired function and form factor will guide this decision. Loops as small as 1cm by 1cm create a small degree of proximity. Loops of 30cm x 30cm (30 AWG wire) will create a large proximity envelope. Larger loops or thicker gauge wire may exceed the calibration range of the Microchip device. Microchip recommends keeping the total base capacitance to 45 pF or less to prevent out of range conditions over temperature or other unique user situations such as calibration with debris on the sensor.

If a pad is determined to be the best fit, any shape can be used. A long and thin pad of 1cm x 25cm (25cm^2) would be well suited for the bottom or side of an LCD monitor. If space is available, a large 5cm x 5cm (25cm^2) pad will create a large dome of proximity detection. A circular pad with r = 2.83cm (~25cm^2) would provide a similar dome of proximity. If the capacitance is too large, the shape could be converted to a loop by removing the center area of the square or circle.

Physical shapes are unlimited. Sensor shapes can include circles, ovals, squares, rectangles, or even serpentine around boards. The overall effectiveness of the sensor is not determined by the shape, but rather the area of the conductor relative to the user or object entering the proximity zone. Proximity range is directly proportional to the sensor's size. Larger sensors provide greater proximity detection ranges.

Loop sensors can be created with solid copper wire (with/without insulation), flex circuits, or on a PCB. In the case of a wire, solid core or stranded will perform similarly, however, solid core is easier to assemble in the manufacturing process. Larger gauge wire will provide increased range due to the increased surface area. The physical design will limit how large of a wire can be used. Designs can start with 30 AWG and increase until the desired range is achieved, aesthetic design limits are reached, or calibration limits are reached.

In the case of a PCB loop sensor, the larger the trace width, the larger the range. A minimum trace width of 7 mils (0.18 mm) will function as a sensor, but larger traces will produce greater range.

Solid PCB pad shapes need to follow the same guidelines, maximize area and keep nearby ground to a minimum.

Figure 3 shows the relationship between detection distance and sensor size. Higher VDD voltage also extends the distance, because with higher VDD the sensor will generate stronger electric field for sensing.

Table 1 shows the signal shift for different size of sensors when the hand is at a different distance for a particular design; the shift percentage is also shown in Figure 4.

Note: The shift percentage is not directly related to the maximum reliable detection distance. The detection distance is determined by the Signal-to-Noise Ratio. And the maximum detection distance requires a minimum SNR of 3.5 for a reliable system.

FIGURE 3: DETECTION DISTANCE VS. SENSOR SIZE

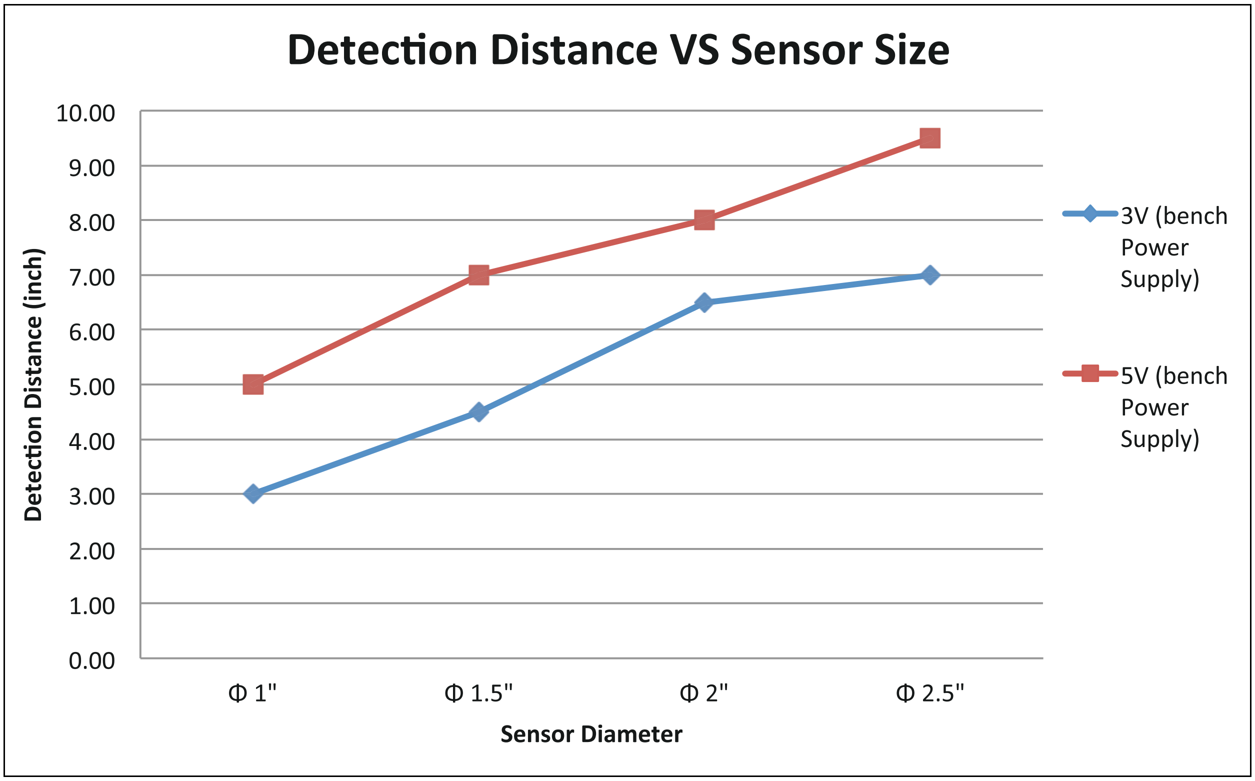
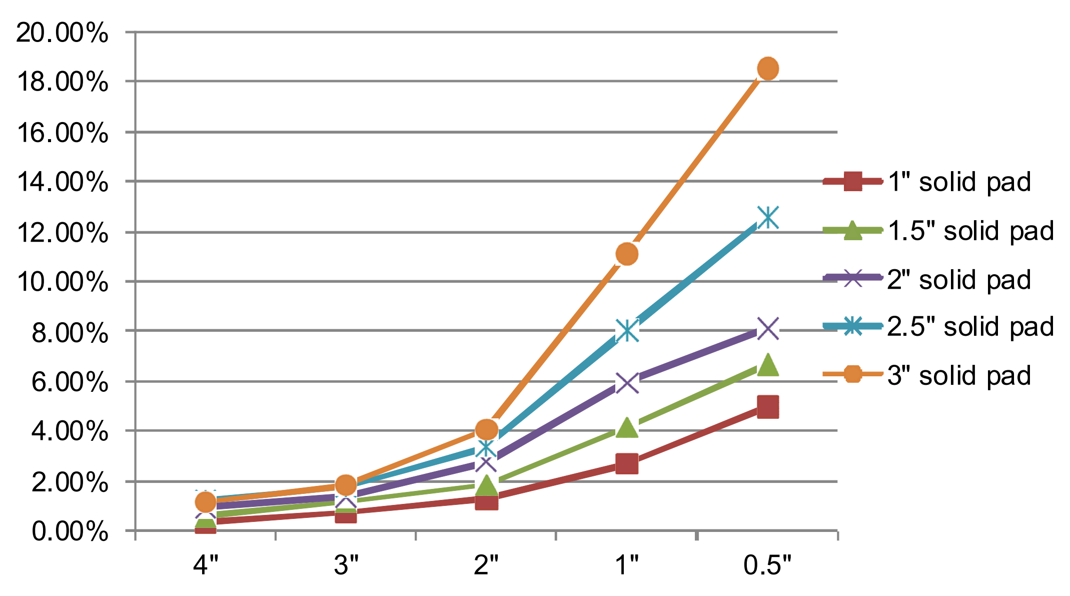


TABLE 1: SIGNAL SHIFT vs. DISTANCE FOR FIVE DIFFERENT SENSORS

Hand Distance from Sensor						
	baseline	4"	3"	2"	1"	0.5"
1" solid pad	12317	12365	12410	12480	12650	12930
1.5" solid pad	12345	12420	12490	12576	12860	13170
2" solid pad	13038	13163	13220	13400	13820	14100
2.5" solid pad	13235	13400	13470	13682	14300	14900
3" solid pad	13500	13660	13750	14050	15000	16000
Detection Difference from Baseline						
1" solid pad	0	48	93	163	333	613
1.5" solid pad	0	75	145	231	515	825
2" solid pad	0	125	182	362	782	1062
2.5" solid pad	0	165	235	447	1065	1665
3" solid pad	0	160	250	550	1500	2500
Signal Shift Percentage from Baseline						
1" solid pad	0.00%	0.39%	0.76%	1.32%	2.70%	4.98%
1.5" solid pad	0.00%	0.61%	1.17%	1.87%	4.17%	6.68%
2" solid pad	0.00%	0.96%	1.40%	2.78%	6.00%	8.15%
2.5" solid pad	0.00%	1.25%	1.78%	3.38%	8.05%	12.58%
3" solid pad	0.00%	1.19%	1.85%	4.07%	11.11%	18.52%

FIGURE 4: SIGNAL SHIFT VS. DETECTION DISTANCE

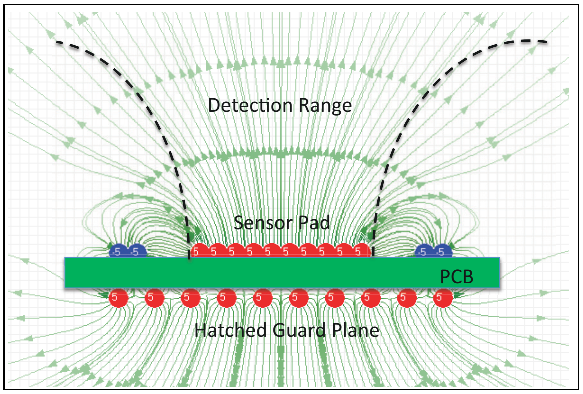


Active Guard

Sometimes, due to the constraints of the application design, the sensor may be very close to a larger ground area, communication line, LED control line, etc. All these will significantly lower the signal SNR, by either increasing the base capacitance or generating an interference signal near the sensor. Active guard is a way of minimizing the base capacitance by reducing the electric potential between the sensor and its surrounding environment, and it also shields the sensor/trace from surrounding low-impedance interferences. Active guard can also be used to shape the electric filed to achieve directional detection without decreasing its sensitivity by using a grounded shield. In Figure 5, putting a hatched guard plane beneath the sensor on the bottom of the PCB makes the detection range only above top side of the PCB.

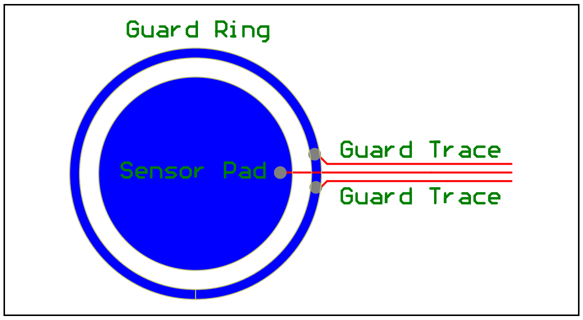
Another way to shape the electric field is using the mutual drive, which drives the trace/electrode out of phase with sensor. The mutual drive will pull the electric field into its direction instead of pushing it out. But this method will increase the base capacitance.

FIGURE 5: SENSOR DESIGN WITH GUARD SHIELD



A layout example is shown in Figure 6. More details on how to layout and drive active guard can be found in the application note AN1478, "*mTouch™ Sensing Solution Acquisition Methods Capacitive Voltage Divider*".

FIGURE 6: SENSOR WITH ACTIVE GUARD LAYOUT EXAMPLE

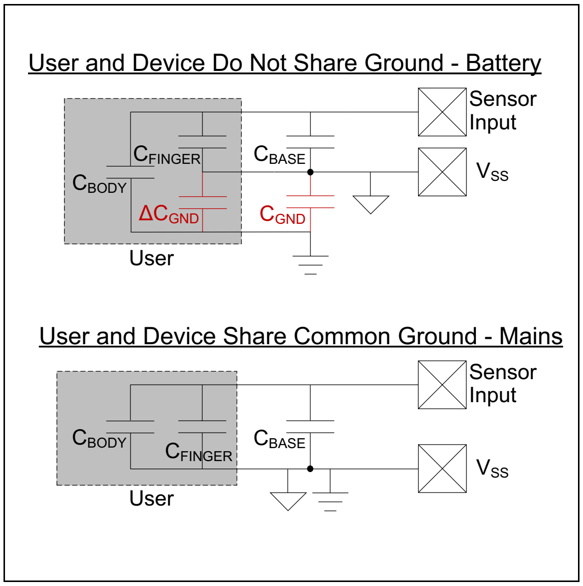


Power Scenarios Analysis

Proximity sensors can be easily integrated into different applications which are powered by mains/wall power or battery, but the powering method has significant impact on the proximity detection distance.

The difference between mains-connected system and battery-powered system is the grounding. Normally, the human body is strongly coupled to the earth ground. For a mains-connected system (Figure 7), the human body shares the same ground with the touch/proximity system. When the finger gets close to the sensor, it increases the pin capacitance in two aspects. First, it helps the coupling between sensor and the surrounding ground plane, C_{FINGER}. Then, the human body has a capacitance in reference to the earth ground, C_{BODY}. Because they share the same ground, C_{BODY}, C_{FINGER} and C_{BASE} are in parallel. The total added capacitance will be simply the sum of C_{BODY} and C_{FINGER} (Figure 8). For a proximity sensor, the C_{FINGER} is usually very small compared to C_{BODY}, as the ground plane is placed far away from the sensor.

FIGURE 7: TWO SYSTEM POWERING SCENARIOS



For a battery-powered system, both the human body and sensing system have a coupling capacitance to earth ground, and the human body could usually add more coupling (ΔCGND) between the system and earth ground. In the simplified physics model (Figure 8), ΔCGND and CGND are combined into a capacitance CGND, which can be considered as the coupling between the human body and system ground. In this case, the C_{FINGER} is still in parallel with C_{BASE}, but the C_{BODY} is now in series with C_{GND}, so the coupling between the human body and the system ground becomes a significant factor to determine the total capacitance adding to the sensor. Therefore, to have a good sensitivity for the proximity sensor, the system and the human body should have a good coupling. Figure 9 shows the sensitivity for the same system having different coupling with the human body. If the system is mounted on a wall or any place near a mains-power, connecting the system ground with the mains-power ground will be the easiest way to create a strong coupling between the human body and the system in order to get the maximum sensitivity.

FIGURE 8: PHYSICS MODEL OF CAPACITIVE SENSING SYSTEM

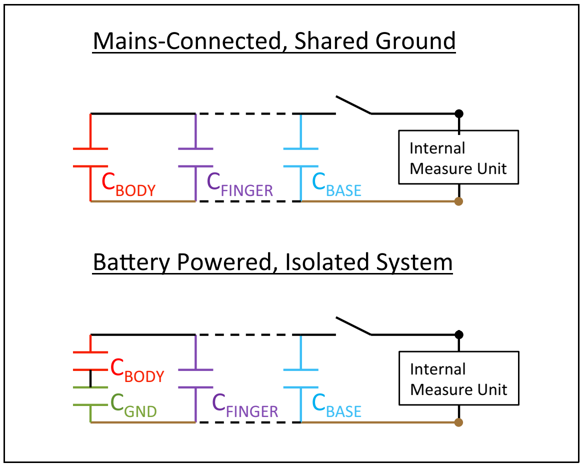
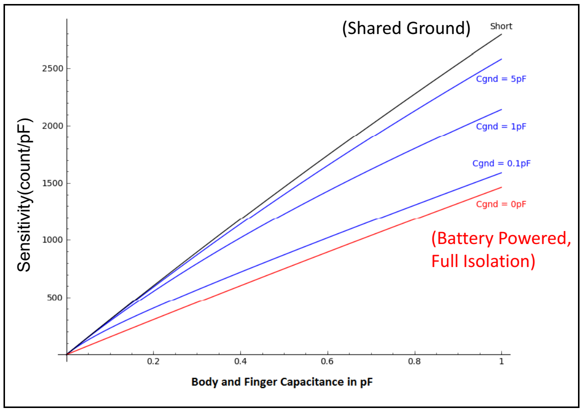


FIGURE 9: PHYSICS MODEL OF CAPACITIVE SENSING SYSTEM



SUMMARY

Microchip provides a low-cost, low-power, high signal-to-noise ratio and flexible capacitive proximity solution. The solution works well for a majority of applications, and requires the fewest components of any solution on the market.

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