Welcome to Microchip’s Webinar on Techniques for Robust mTouch Touch Sensing Design. My name is Burke Davison and today we’ll be discussing some hardware design guidelines for developing mTouch applications.
We’ll begin with a quick refresher on the basics of capacitive sensing to make sure we’re all familiar with the general idea of the technology as well as the basic physics of how we are detecting the presence of a finger near our sensor.

With that out of the way, we’ll then get into the details of designing the hardware to maximize our signal and minimize the amount of noise. Essentially, we’ll be focusing on increasing the signal to noise ratio of the sensor.
Capacitive Sensing Basics

The Capacitance Equation

So let’s get started.

The most important concept in capacitive touch sensing is the idea that we’re creating a capacitor. By looking at the equation for a capacitor, we can gain a strong understanding of how our hardware design decisions are going to impact quality of the final system.
So here is the equation many of you will be familiar with. Let’s focus on the picture for a second and we’ll come back to the equation.

The capacitance between two surfaces is going to be dependant on three variables:
- The overlapping area of the surfaces
- The distance between them
- And the material that separates them

\[ C = \varepsilon_r \varepsilon_0 \frac{A}{d} \]
If we wanted to increase the capacitance between the two surfaces (which we’ll find is essentially increasing the sensitivity of our sensor) we can either:

- Increase the permittivity, in other words change the material between the surfaces to something that allows charge to flow more easily.
- Increase the overlapping area of the two surfaces
- Or decrease the distance between them

So what does this mean for a capacitive touch application?
This image shows the basic construction of a capacitive touch sensor. A copper plate on the PCB acts as one side of the capacitor and our finger acts as the other plate. Although not shown in this diagram, capacitive touch systems also have a covering material on top of the sensor to protect it from the environment. This material will determine our permittivity and the thickness of the material will determine the distance between our two plates.
When the finger approaches the sensor, it introduces a capacitance that we’ll call $C_F$.

Additionally, we have some amount of parasitic capacitance (or $C_P$) that is naturally present on the system. This capacitance is due to the sensor coupling with nearby ground planes and other traces.

As a sidenote – notice how the parasitic capacitance is based on the board’s ground reference (drawn as a triangle) and how the finger’s capacitance is based off earth ground. This will have important implications for conducted noise which will be discussed in another webinar.
Basics

Capacitive Touch Application

\[ C = \varepsilon_r \varepsilon_0 \frac{A}{d} \]

\[ C_P + C_F = C_{TOT} \]

So if we look at all of the capacitances affecting our capacitor, we can calculate the total capacitance of the sensor. The total capacitance is important because this is what we’ll be measuring when we scan the sensor.

Notice that the finger’s capacitance is going to change while the parasitic capacitance is going to remain fixed. If we imagine that the parasitic capacitance is very small, the finger’s capacitance is going to cause the total capacitance to change by a large amount. However, now imagine that the parasitic capacitance is very large. Now when we add the finger’s capacitance we see a much smaller change in the total capacitance.

Since we’re only able to measure the total capacitance this means that we will want to keep that parasitic capacitance as small as possible so we can see a large change when the finger is added.
So now that we have a basic idea of the physics behind what is happening in our system when we press with a finger, we’ll apply this knowledge to the design of our hardware.
A common question that gets asked is, “How large should I make the sensor”. On this graph, I am showing on the X axis the side length of a square sensor measured in mm, and the Y axis shows the expected sensitivity of the sensor.

The two lines on the graph represent two possible ways that a user might press on the sensor.
The most common method for pressing is by using the full pad of your finger which is demonstrated on the left. There is also the second method which is using just the tip of your finger.

Now the blue line on the graph corresponds to the full press method. Notice how increasing the size of the sensor will gain increased sensitivity until around 15mm. After this point, the sensor becomes larger than the pad of your finger. Likewise, when you press with the tip of your finger, the sensor’s size doesn’t add any significant sensitivity after 9-10mm.

Remember that in the capacitance equation, it is the overlapping area of the two plates that determines capacitance. Once the sensor becomes larger than the area of the finger you begin to see diminishing returns.

In most cases you won’t know how a user will decide to make their press – will they do a full-pad press or a tip-only press? For this reason, its best to always design for the full press option. So sensors should generally be around 15mm x 15mm.
There are a couple quick exceptions to this rule. First – if you are implementing a proximity sensor, this is not going to apply. In this case, you want a large sensor that will be able to detect large objects such as hands and bodies moving nearby.
Exceptions - Consideration #1

Ideal sensor size = area of finger press
(15 x 15 mm or 0.6 x 0.6 inch)

1. Proximity sensors
2. Thick Covers

Second, if your system is going to have a thick covering material, the diminishing returns of increasing area that we saw previously isn’t going to happen until the sensor gets a little larger.

We will see soon, however, that there are better options to consider if a thick cover is required.
The next topic we’re going to talk about is how far apart adjacent sensors should be separated. In this case, we give the general guideline that the separation should be around 2-3 times the cover’s thickness – and there are two reasons for this.

First, when a finger is pressed above a sensor it is going to affect the sensors nearby. This is called crosstalk. Remember how the capacitance between the finger and the sensor is inversely related to distance.

So in the example shown, the capacitance between the finger and the sensor it is directly above would have a distance value of 1. The capacitance of the neighboring sensor, however, will have a distance value of 2.7. So the amount of capacitance change you will see on the right sensor will be around 2.7 times the amount of change you’ll see on the left sensor.
Consideration #2
Separate sensors as much as possible.
Ideal minimum is 2-3x the cover's thickness.

Now if we don’t follow this guideline and, instead, separate the sensors by the cover’s thickness, the amount of crosstalk seen on the sensor on the left is going to be greatly increased because the distance is now only 1.4 compared to the right sensor’s distance of 1.
So – the first reason to separate sensors is to minimize the amount of coupling between the user’s finger and nearby sensors.
Now for the second reason to separate sensors by this amount, we need to look at the field lines coming off our sensor. This is an extremely simplified drawing, but it will help illustrate the point.

If we take two sensors and place them next to each other…
The field lines of one sensor will begin coupling with the neighboring sensor.
Consideration #2

Separate sensors as much as possible. Ideal minimum is 2-3x the cover's thickness.

When these field lines are able to reach the other sensor by travelling only through the covering material, the amount of coupling is going to be very strong. This is because the permittivity of the covering material is going to be several times higher than the permittivity of air.
So, as you might expect, the field lines that have to travel through the cover, out through the air, and back through the covering material are going to be much weaker and are going to result in a much smaller amount of coupling.

Now, in this example, the amount of separation between the sensors is a little less than the cover’s thickness. If we decrease the cover’s thickness so that we are following the guideline, we will see a change in the amount of coupling.
Consideration #2

Separate sensors as much as possible. Ideal minimum is 2-3x the cover’s thickness.

Notice how the field lines that were previously able to travel only through the cover are now required to travel through air before reaching the neighboring sensor. In this example, we achieved this by decreasing the cover’s thickness but this could just as easily have been done by separating the sensors instead.
Consideration #2
Separate sensors as much as possible.
Ideal minimum is 2-3x the cover’s thickness.

In some applications, this design consideration cannot be followed due to other system requirements. If this is the case, one of the things we can do is add an air gap in the covering material.

By doing this, don’t change the intended capacitance shift in any significant way…
Consideration #2

Separate sensors as much as possible.
Ideal minimum is 2-3x the cover’s thickness.

But the capacitance between the finger and the neighboring sensor must now be considered as three capacitors in series.
Consideration #2

Separate sensors as much as possible. Ideal minimum is 2-3x the cover’s thickness.

And we know that the smallest capacitance in a series will dominate. So by adding the air gap, we effectively shield the neighboring sensors from crosstalk.

Likewise, if you think back to the field lines we showed earlier, the strong coupling lines that were previously able to travel only through the cover before reaching the neighboring sensor are now required to travel through the same air gap.

So we recommend separating sensors by 2-3 times the cover’s thickness for two reasons, first – it limits the amount of finger-to-sensor coupling on neighboring sensors. Second, it lowers the amount of sensor-to-sensor coupling through the field lines.
The next topic we’ll discuss is the thickness of the covering material that is placed over the sensors. In this graph, I am showing the expected sensitivity (or capacitance of the finger) in relation to the thickness of the covering material. Notice how the sensitivity decreases rapidly until around 3mm when it begins to level off. For this reason, we recommend trying to keep the covering material less than 3mm so you can benefit from this increased sensitivity region.

Also notice how the sensitivity curve changes based on the material being used. Since glass has a higher relative permittivity than plastic, the amount of sensitivity is going to increase. Likewise, if you increase the size of your sensor you will also see these curves shift up.
Consideration #3

Keep the cover as thin as possible.

For thicker covers…

1. Increase sensor size

Recommended

Thickness < 3 mm
Sensor Size = 15x15 mm

A 3mm cover is not feasible for all systems, however. Sometimes design constraints require something thicker. As we mentioned before, one of the adjustments you can make in this case is to increase the size of the sensor.
Consideration #3
Keep the cover as thin as possible.

For thicker covers...
1. Increase sensor size
2. Create a slot for the PCB

Another option would be to cut a slot in the covering material that your PCB could fit into. The overall thickness of the covering material would remain the same, but the thickness seen by the sensors will be reduced.
Consideration #3

Keep the cover as thin as possible.

For thicker covers…

1. Increase sensor size
2. Create a slot for the PCB
3. Create a slot for a spring or EMI gasket material

Recommended
Thickness < 3 mm
Sensor Size = 15x15 mm

A similar third alternative is to cut a slot in the covering material and then bridge the air gap with either a metal spring or with a conducted EMI gasket material.

There are a couple things to keep in mind if you decide to go this route:

First – make sure there are no air gaps between the bottom of the cover and the top of the spring or EMI gasket material.

And second – make sure that a via is placed inside the air gap to allow air pressure to equalize. Otherwise, if the system has to be transported by airplane, the air pressure difference could pop the cover off the PCB.
As one final sidenote about covers – if you want to have a curved surface, make sure you do not leave an air gap between the PCB and the cover.

Just as before, you can either cut a notch in the material for the board to fit in, or you can bridge the gap using a spring or EMI gasket material.
Knowing how to effectively use ground planes to your advantage is an important tool to have when designing a capacitive sensing application.

For our purposes, we can essentially split grounds into two types: the front ground plane and the back ground plane.

Front ground planes are going to slightly reduce the amount of conducted noise seen by the system. This is because the user’s hand is going to begin coupling to the top ground plane as the finger comes in to press on the sensor. Conducted noise isn’t covered in this webinar, but the essential thing to remember is that ground planes on the front will help increase the system’s stability.

Ground planes on the opposite side of the board will mainly be protecting the sensors from radiated noise coming from behind the system. If your system is going to be placed near a significant noise source, this could be a way to help shield from the effects of that noise. Be careful, though! The PCB material that is separating the sensor and the bottom ground plane has about the same permittivity as glass. So a ground plane directly behind a sensor is going to have a large parasitic capacitance associated with it.

Remember that we are only able to measure the total capacitance of a sensor, so increased parasitic capacitance is going to decrease the sensitivity.
We can use this knowledge in many different ways – and I’ve shown three possibilities here. On the top system, we have heavy grounding on both the top and the bottom which is going to lower our sensitivity significantly, but we’re going to gain a high amount of noise immunity in the process.

The middle example shows that we could decide to use a cross-hatched pattern for the back-side ground plane which will increase our sensitivity slightly while still providing a moderate level of radiated shielding.

Alternatively, we could opt for a high amount of sensitivity and little immunity from noise by removing the ground from the sensor areas.

Ultimately, how you use ground planes is going to depend on the individual requirements of your system.
Consideration #5
Keep sensor traces thin and short.

Larger trace lengths mean...

Increased $C_P$
(Decreased Sensitivity)

Antenna Behavior
(Increased Noise)

Sensor placement and trace design are also important when designing your system. As a general rule, keep the traces thin and as short as possible. This is going to minimize the parasitic capacitance and will reduce the antenna behavior of the sensors.

You will also want to keep any high current and communications lines away from the sensor traces. If you have to cross them as some point, make sure they run in a perpendicular direction and never in parallel. This will minimize the amount of possible crosstalk.
You will always want to use an adhesive to connect the cover with the PCB. Air gaps will significantly decrease your system’s sensitivity.
When choosing an adhesive, there are a few things to keep in mind.

First, keeping it thin is best. 2-3 mils is typical.

Second, always read the bonding instructions. Many of them require that a certain amount of pressure be maintained for a certain amount of time before the glue will be secure. You want to follow those suggestions.

Third, if you’re designing a system that might go above 250 degrees Fahrenheit, make sure it doesn’t exceed the adhesive manufacturer’s limits.

Fourth, be careful of bubbles. Most adhesives that have been developed for touch applications are bubble-resistant, but you should double check just in case.

Finally, if you’re using plastic as the covering material, make sure the adhesive is designed for the specific type of plastic you are using. There are high surface energy plastics, low surface energy plastics, and specific adhesives for each.
Consideration #6

Always use an appropriate adhesive

Suggestions

3M™ Optically Clear Adhesives
ex: 8211, 8212, 8213, 8214, 8215

3M™ Adhesive Transfer Tape
ex: 467MP, 9626, F-9752PC, 9122

For some example adhesive options, I have provided some 3M adhesives we have used in the past that have worked very well. For more information about adhesives, I recommend contacting the glue manufacturer directly. They are experienced with helping customers find the right product for the job.
Series resistors are something you can add to a design that will help increase its reliability. The first thing it does is help stabilize the reading under noisy conditions. As a nice bonus, it will also protect the microcontroller’s pin from electrostatic discharge. Perhaps the most important effect the series resistor will have will be explained on the next few slides.
When deciding what the power supply voltage will be for your application, there is a simple rule of thumb: bigger is better. The higher VDD is, the more immune to noise it will be. The picture on the left shows a normal reading with noise being injected on top of it. The graph on the right shows the readings of a sensor as it is pressed under this noise. I am going to increase the amount of noise on the system and watch what happens to the graph on the right.
Consideration #8

Keep $V_{DD}$ as high as possible to maximize noise immunity.

Notice how the shift decreased. Now if I increase the noise even more…
Consideration #8

Keep $V_{DD}$ as high as possible to maximize noise immunity.

The shift changes directions! And if I increase the noise even higher than that…
Consideration #8
Keep $V_{DD}$ as high as possible to maximize noise immunity.

The positive shift becomes even more pronounced!
Consideration #8
Keep $V_{DD}$ as high as possible to maximize noise immunity.

So what we’re seeing is that the noise, if strong enough, can cause a complete reversal in the direction that we will expect to see a shift. The problem with this is not so much with the case where we have a large negative shift or a large positive shift, but at the point where the noise causes it to cross over from negative to positive. If this specific amount of noise is being injected on our sensor, we will see no shift when a user presses.

The reason this happens is due to the noise causing a rectification of the pin’s input diodes on the microcontroller. Unfortunately, there is no way to completely eliminate this effect, but we can attenuate it by doing two things:

First, by keeping VDD as high as possible
And second, by adding a series resistor to the sensor.

If enough noise is pumped into the system, eventually we will see the shift-reversal occur. But by adding a series resistor and keeping VDD high, the amount of noise required to cause this behavior would be so high that other parts of the design are likely to start failing first.
Summary
Hardware Design

\[ C = \varepsilon_r \varepsilon_0 \frac{A}{d} \]

Hardware Design Considerations:
1. **Ideal sensor size is the area of a finger press (15 x 15 mm)**
2. **Separate sensors as much as possible (2-3 x cover)**
3. **Keep the cover as thin as possible (< 3 mm)**
4. **Use ground planes to your advantage**
   - Front Plane: Conducted
   - Back Plane: Radiated
5. **Keep sensor traces thin and short**
6. **Always use an appropriate adhesive**
7. **Put a series resistor on each sensor line**
8. **Keep V_{DD} high to maximize noise immunity**

So if we put all of these guidelines together, we get a list of suggestions that can help us design our system to maximize sensitivity and minimize the amount of noise on our readings. Remember that most of them come directly from the equation for a capacitor and that the capacitance can be thought of as the sensitivity.

And that concludes this webinar on the hardware design technique for robust mTouch touch sensing design.
For more information about mTouch, visit our website at [www.microchip.com/mTouch](http://www.microchip.com/mTouch).

You can also check out application note 1334 which going into more detail about all that we covered today as well as information on how noise affects capacitive sense.

As always, [www.microchip.com/webinars](http://www.microchip.com/webinars) is a great resource as well for information about mTouch design and a wide range of other topics to help you design a successful product.

Thank you for watching! If you have any questions, please visit the mTouch forum at [www.microchip.com/forum](http://www.microchip.com/forum).