Industrial capacitive touchscreen design made simpler

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Introduction

Capacitive touchscreen design must take into account several internal and external factors. Properly considering those factors is critical in order to mitigate challenges such as interference, touch response loss, ghost touches, screen delamination etc. If any one of these challenges is not addressed, it would degrade the user experience and negatively impact customer satisfaction.

This paper discusses common challenges faced when designing capacitive touchscreens for industrial applications, and design choices that need to be carefully considered, such as cover lens thickness, industrial glove use, extreme temperatures, water tolerance, and mechanical and electrical considerations.

Contents

Fundamentals of how a PCAP touchscreen works

Each electrode in a PCAP (Projected Capacitance) touchscreen is part of a system of conductors consisting of neighboring electrodes and/or the nearby ground planes. Together, this system of conductors acts as a capacitor. When a voltage is applied to an electrode, the amount of charge that builds up on it is proportional to both the applied voltage and the associated capacitance of the system of conductors corresponding to that particular electrode. A PCAP touch controller measures this capacitance for each untouched electrode and records it as the baseline capacitance.

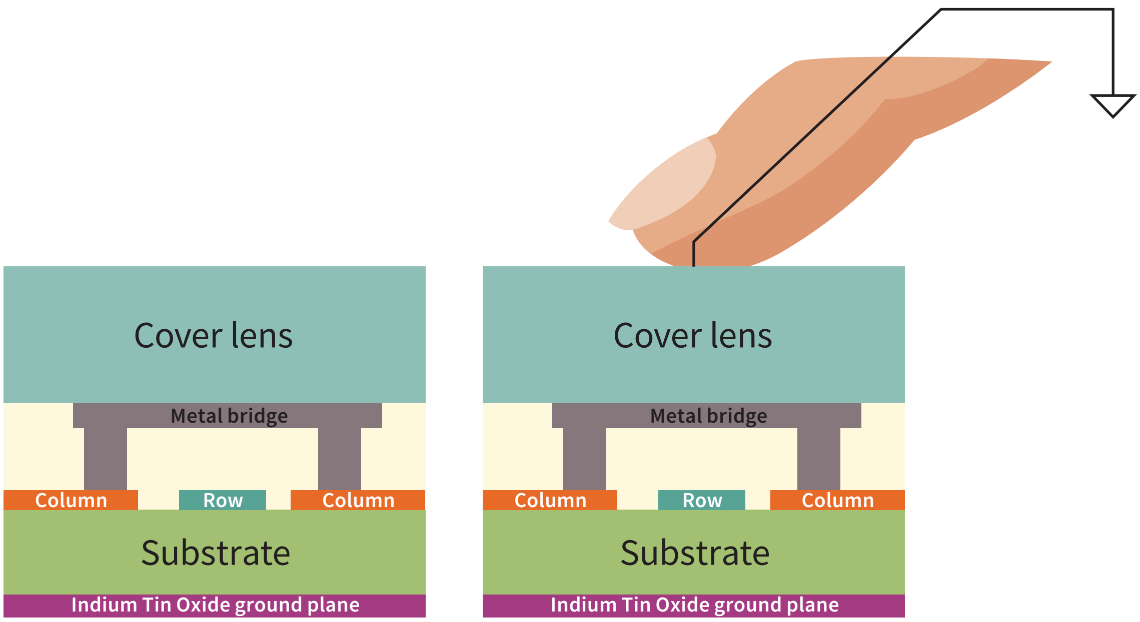


Figure 1: A PCAP Sensor construction

When a finger is close to an electrode, this capacitance value changes as the finger becomes part of the system of conductors that the electrode is part of. The touch controller can calculate the difference between the touched capacitance value and the baseline capacitance value, to establish the “signal” strength of the touch.

Now the capacitance measurement by the touch controller is subject to noise from various sources such as nearby electronic equipment, the display panel, power supplies etc. The proper operation of the touchscreen requires the touch s ignal magnitude to be sufficiently larger than the magnitude of the noise. The design of the touchscreen, as well as the tou ch controller, directly impacts the signal-to-noise ratio in any given application. More detailed guidelines on properly desi gning a capacitive sensing touch solution can be found in Infineon’s CAPSENSE™ Design Guide.

For the touch controller to accurately determine the location of the finger on the surface of the touchscreen both the controller and the panel must be designed such that the signal on an electrode due to a typical finger must drop off gradually as the finger moves away from that electrode, up to a distance of about one electrode pitch, and then drop off quickly beyond that. Allowing a gradual drop off within one electrode pitch will allow the controller to determine the precise location of the finger in between two electrodes. However, if the signal does not drop off quickly beyond that, then it becomes difficult to unambiguously determine the finger location.

An example PCAP touchscreen sensor design

Projected capacitive (PCAP) touchscreen panels typically consist of a rectangular glass substrate sheet that is coated with a thin layer of indium tin oxide (ITO), a material chosen due to it being both optically transparent and electrically conductive. This ITO layer is etched into a pattern to form row and column electrodes. A very common ITO etching pattern is the single-layer diamond pattern shown below.

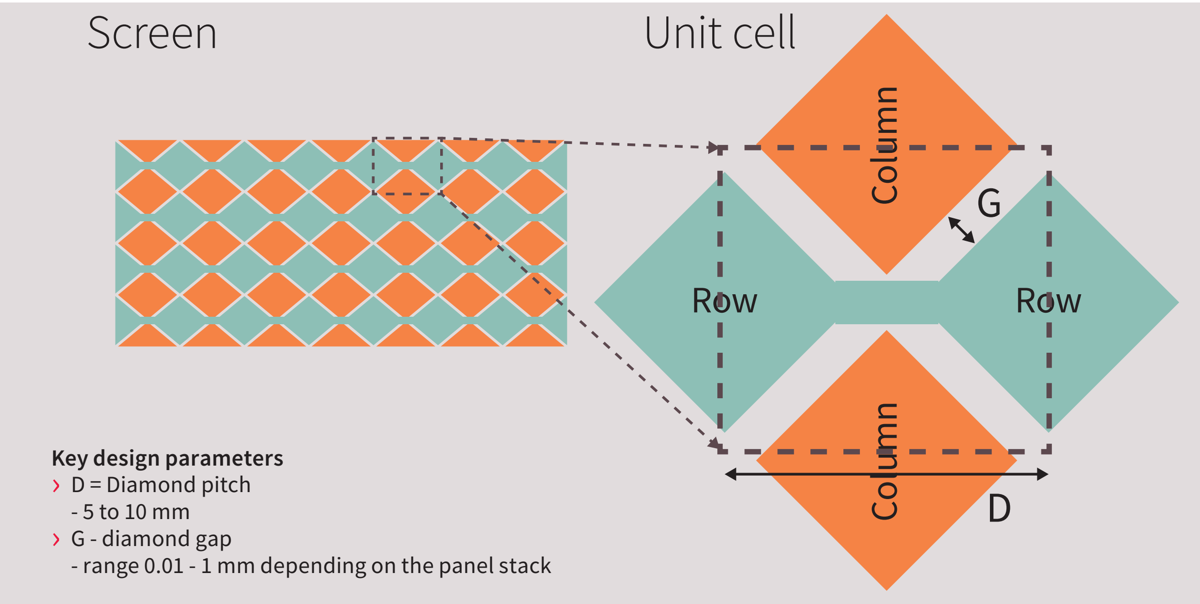


Figure 2: Single layer PCAP sensor construction on touchscreen

As a result of this etching as shown, the row diamonds are connected to form rows, but the column diamonds are isolated. The columns are connected in a subsequent step using metal bridges as shown below. The metal bridges are isolated from the row electrodes. Thus, the touchscreen panel consists of a grid of row and column electrodes.

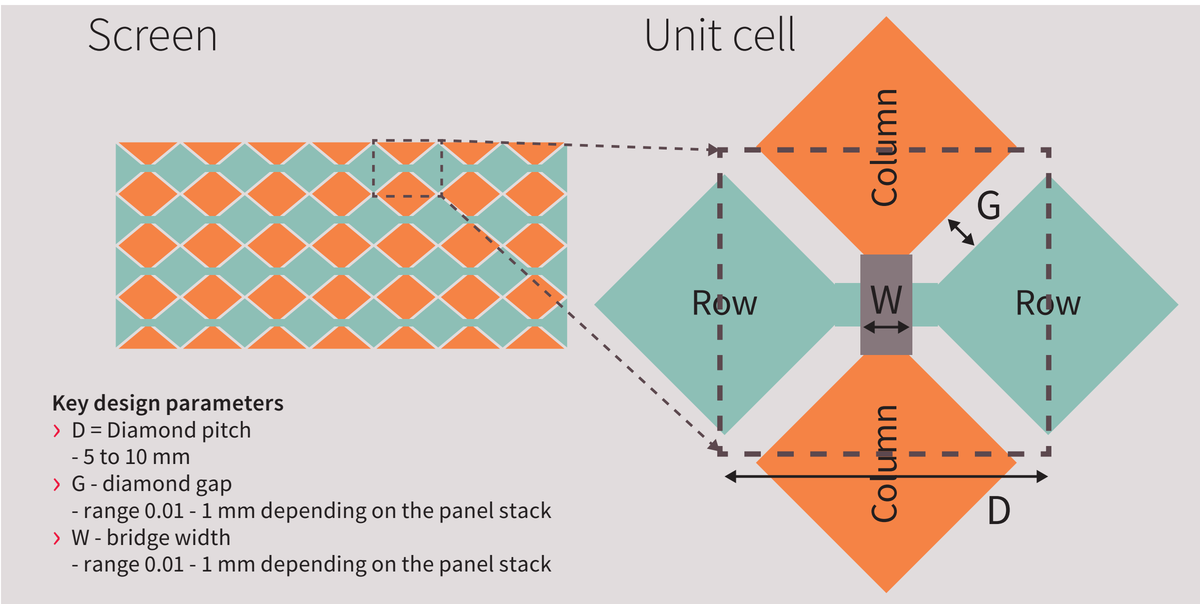


Figure 3: Single layer PCAP touchscreen sensor with metal bridge

A second sheet of glass or plastic, called the cover lens, is used to overlay ITO later. Sometimes the bottom side of the glass substrate is coated with another layer of ITO to act as a ground plane to shield the touchscreen from electromagnetic interference (EMI). The following picture shows a cross-sectional view of the touchscreen panel:

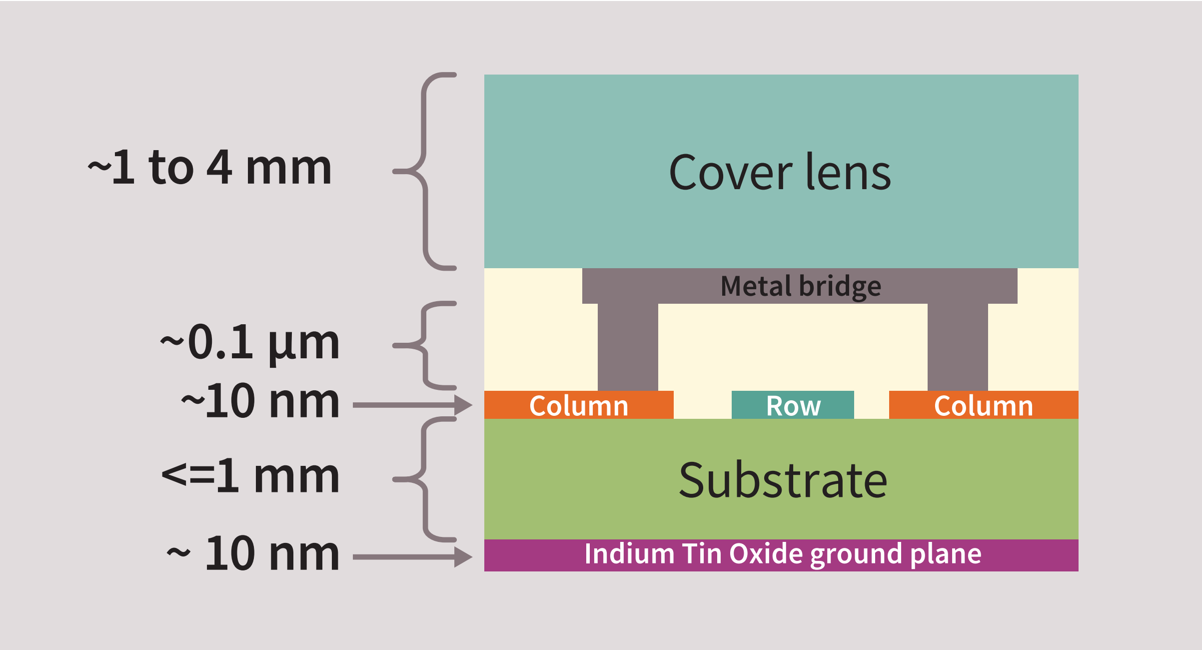
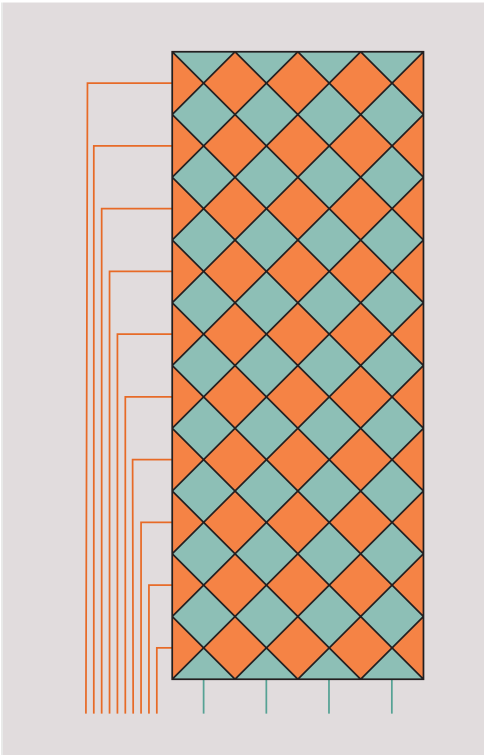


Figure 4: Complete PCAP sensor construction with metal bridge

In most applications, this touchscreen panel is then bonded on top of a display panel. The EMI from the display panel can sometimes impair the performance of the touchscreen if the ITO ground plane is not included as part of the design.



Touchscreen panel bonded on top of display panel

Metal traces are used to connect all the row and column electrodes to a touch controller integrated circuit (IC) that is typically populated on flexible printed circuit (FPC) along with all the necessary electronic components and connectors.

The touch controller can electrically drive the electrodes and can measure the electrical charge on those electrodes. The firmware programmed on the touch control can make use of these measurements on all the electrodes to determine both whether the touchscreen has been touched, as well as where it has been touched.

This information is then relayed to a host system that is connected to the touch controller, typically via I2C or USB communication protocols.

Challenges:

The display

Mainstream displays in today's products are active-matrix organic light-emitting diode (OLED) and liquid crystal (LCD) designs. The OLED displays provides superior viewing quality and produces less noise for touchscreen sensors. However, they are relatively expensive and commonly found in consumer products where viewing quality is critical for the product. LCD displays are less expensive, more popular, and a common choice for industrial products with touchscreen interfaces.

Inevitably, the display is a significant source of noise for PCAP capacitive sensing touchscreen systems. Display noise is the switching noise capacitively coupled from the surface of the LCD display to the conductive touchscreen sensors. The noise injected from display to touchscreen sensors, through capacitive coupling due to its close proximity to displays, causes jitter in user touch positions (variable touch coordinates being reported for a stationary finger), false touches (report touches even when no finger is on the screen) or non-recognition of a finger when the user actually touches the screen. Display noise is the most common sources of noise affecting touchscreens that is produced within the system. The quality of user experience of touch interfaces is dependent on how well a touchscreen combats noise interference. Poor touchscreen operation due to display noise can make a product difficult to operate, and make customers unhappy, therefore a touchscreen design must be able to detect, differentiate and combat noise.

The figure below shows typical stack-up of an LCD.

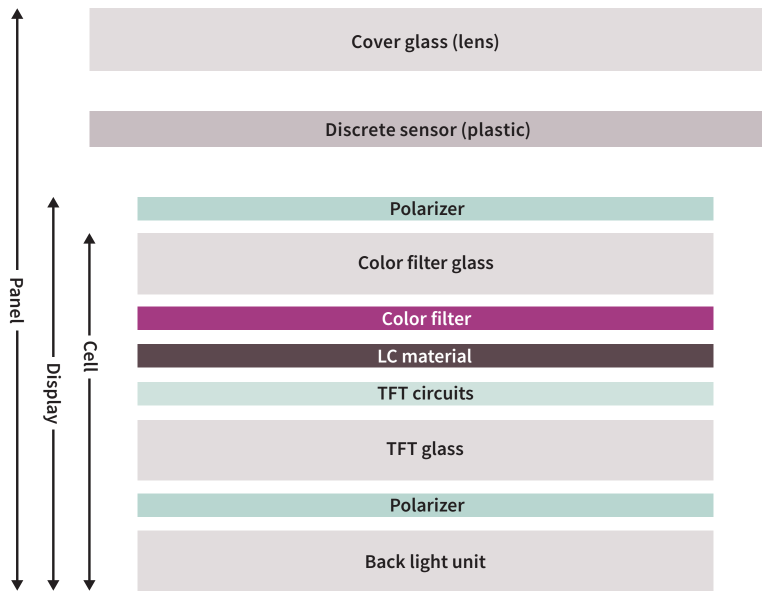


Figure 5: Stack-up of touchscreen enabled with LCD display

LCD displays designed for single-user viewing are normally implemented using vertically-aligned LCD technologies. A key element in these VA LCDs is a VCOM layer which is part of the color filter substrate. In these VA LCDs, the VCOM layer couples switching noise from the lower TFT layer as the various pixels in the display are updated. These pixel updates are the primary source of display noise coupled to the touch screen controller. The expectation on larger displays is that they will be viewed by more than one person, thus requires a wider viewing angle. Many of the larger displays are IPS or AMOLED displays, which have wider viewing angle and no pressure/touch distortion. The selection of display technology for your products should be based on several factors, but with respective touch sensing, the key benefit of both of these is lower display noise compared to VA LCDs.

Touch sensors are analog sensors with high input impedance, and they act as antenna arrays, bringing in strong levels of capacitively coupled noise from the display. It is very important to provide an adequate gap between the touch sensor and thin-film transistor (TFT) polarizer to minimize capacitive coupling. This gap may be an airgap or it could be an adhesive material. A larger gap between the display and touch sensor panel reduces noise coupling, however it also makes the LCD thicker. The critical gap required to minimize noise influence and reliably operate touchscreen is different for every display, and also dependent on the touchscreen controller. Determining the right gap and combination of the display and touchscreen controller is more art than science. You will need to conduct trial-and-error testing, and this can be particularly challenging for larger displays without a well-integrated solution.

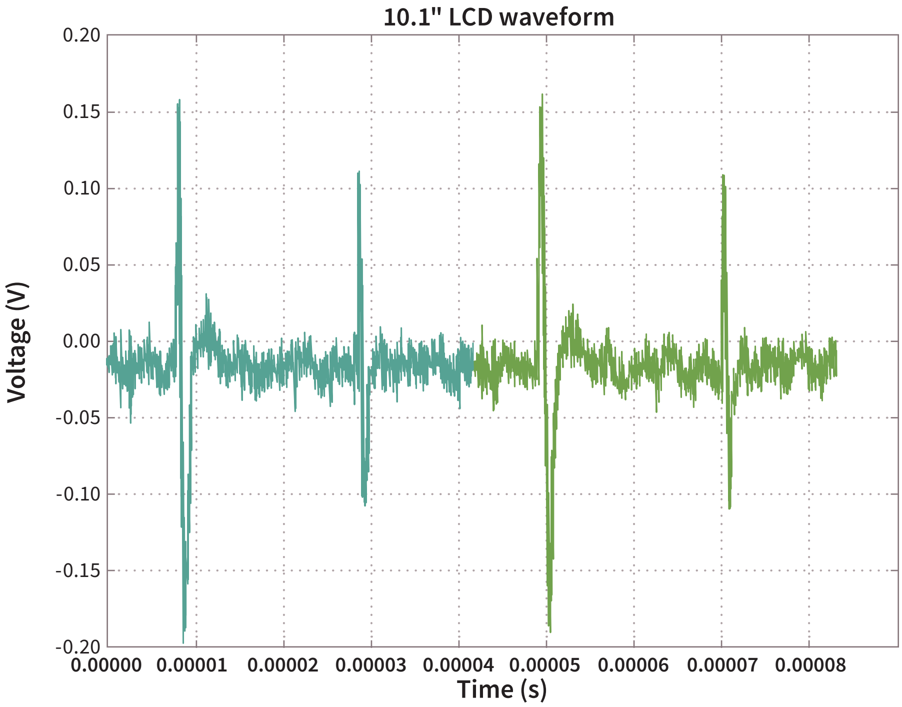


Figure 6: LCD Noise

Fortunately, LCD noise is an inherent, fairly predictable characteristic of a given display. Although LCD noise changes with the image displayed, it can be quite similar (common) anywhere across the display, as it couples fairly uniformly into the sensor and does not significantly change after product design is finalized, thus it can be dealt with during the development phase. The high correlation of LCD noise signals across all sensor signals can be utilized for effectively removing LCD noise from the touch signals using software filtering algorithms, or in some cases, synchronizing display drive with touch controller operation can be highly effective to combat the LCD noise.

Higher frequencies carry more energy than lower frequencies, thus the noise influence on the touchscreen increases with an increase in display pixel clock frequency. This means that a well designed display circuit is important for high resolutio n or larger displays. Design of a high-quality TFT display must include a proper ground plane, with the inner surface preferably connected to ground as a shield, especially if the device needs to satisfy industrial requirements.

Selecting a programmable MCU based touch controller, such as a PSoC™ 4 MCU, provides added advantages and flexibility for system designers to address unique integration challenges.

Cover lens thickness

A touchscreen for industrial application must work with a thick cover glass above the touchscreen. In outdoor applications where vandal-proofing is important, a temper “safety” glass up to 5 mm or more thickness may be required. Indoor applications such as industrial kitchens also may need such thick cover glasses for durability.

A thicker cover lens can potentially degrade touch detection performance and usability of the touchscreen interface, but may be essential for durability of the panel. Therefore, designing a touchscreen system with a thick cover lens to ensure durability in tough conditions, while maintaining an optimal touch detection performance for seamless user experience is a challenge faced by many designers.

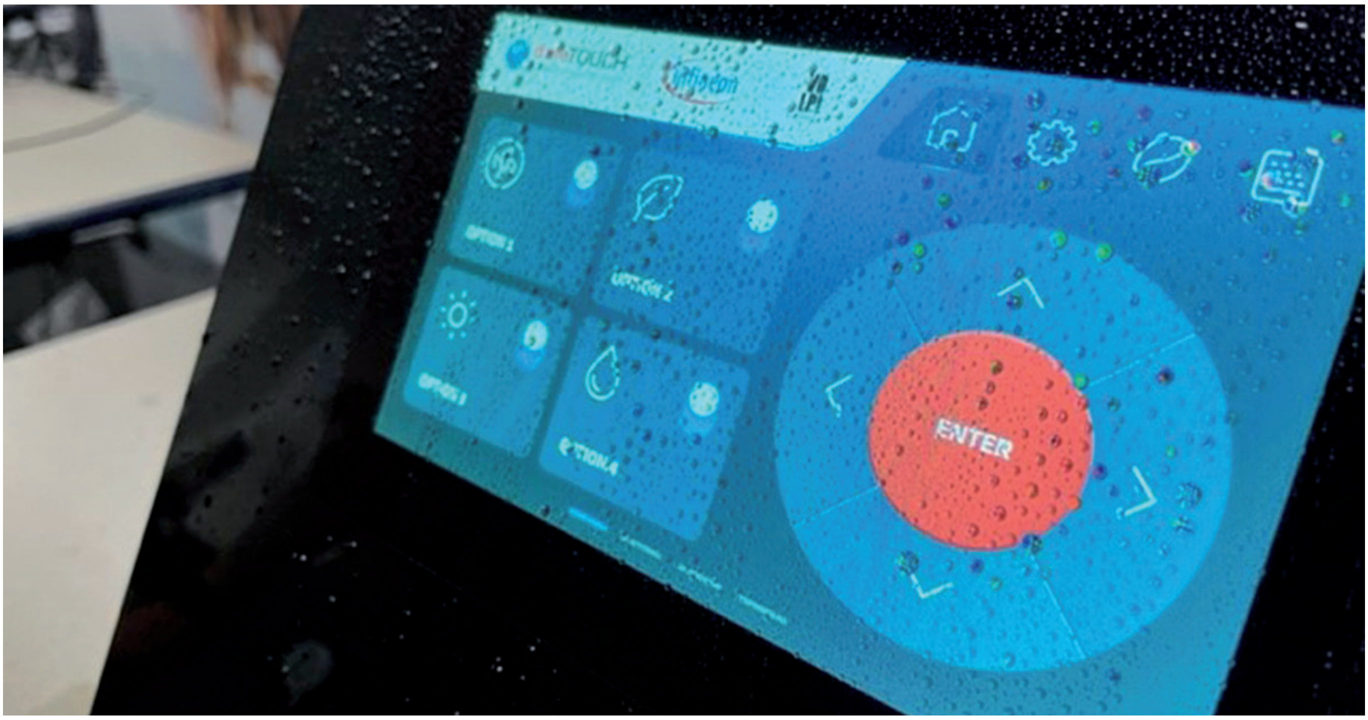


Figure 7: Touchscreen works rugged operating conditions

PCAP touchscreens work by detecting the change in capacitance associated with each electrode, as a finger approaches the panel. The touch signal is the amount of change in the capacitance that can be detected by a touch controller.

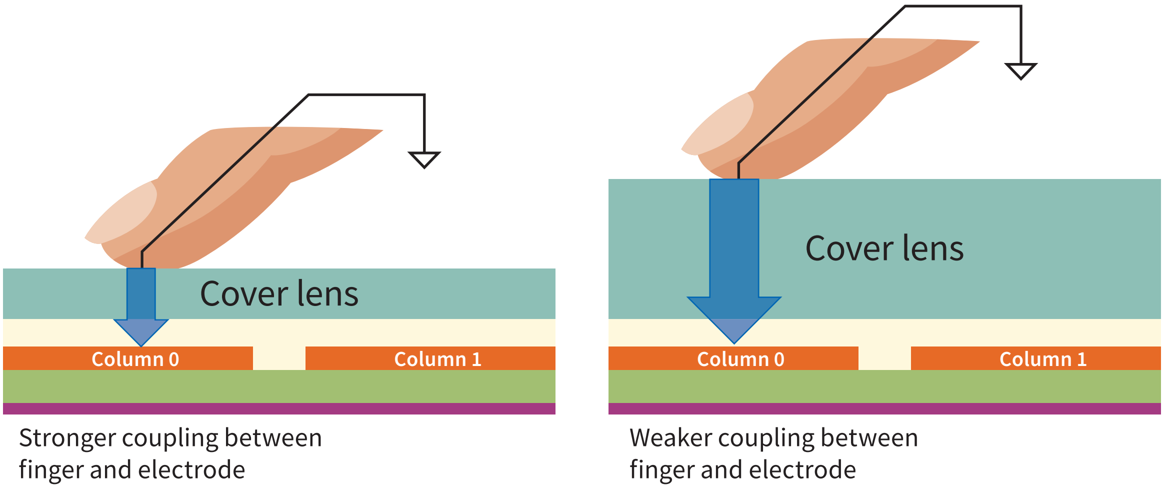
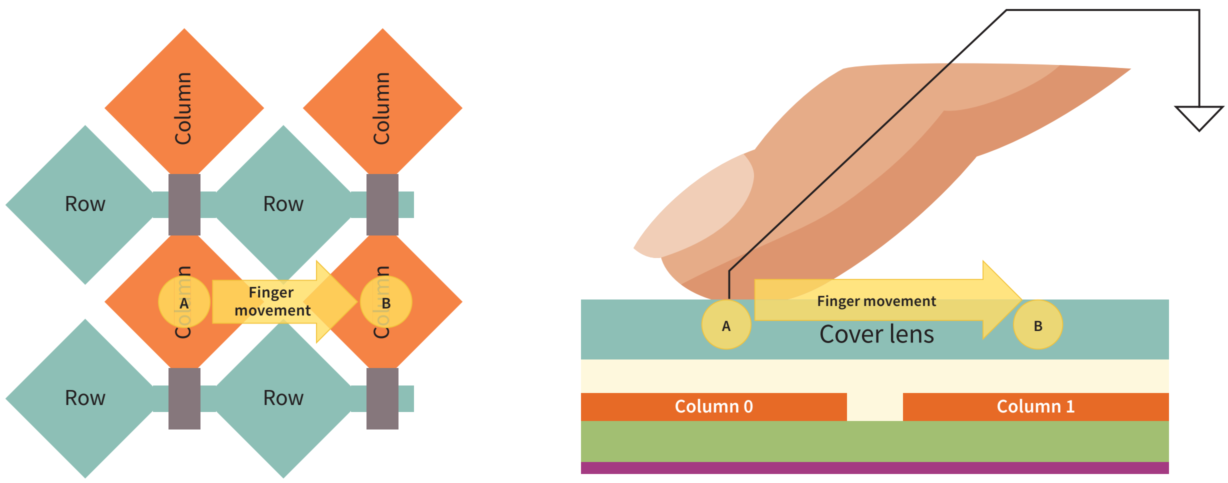


Figure 8: Effect of cover lens on touchscreen

In general, the thicker the cover lens leads to the smaller amount of capacitive coupling, although other factors can influence this coupling, especially the sensor electrode pitch (center-to-center distance between two adjacent electrodes).

The diagram below shows an overhead view of a portion of a touch panel, with part of the electrode diamond pattern of a couple of rows and columns shown. Suppose a finger is touching position A (the center of one of the Column 0 diamonds)



and slides horizontally to position B (the center of the nearest Column 1 diamond).

Figure 9: User finger movement on touchscreen – Overhead and cross-section view.

The following graph shows capacitive coupling on two sensor electrodes when moving the finger from electrode 0 to electrode 1, with different cover glass thickness on the sensors.

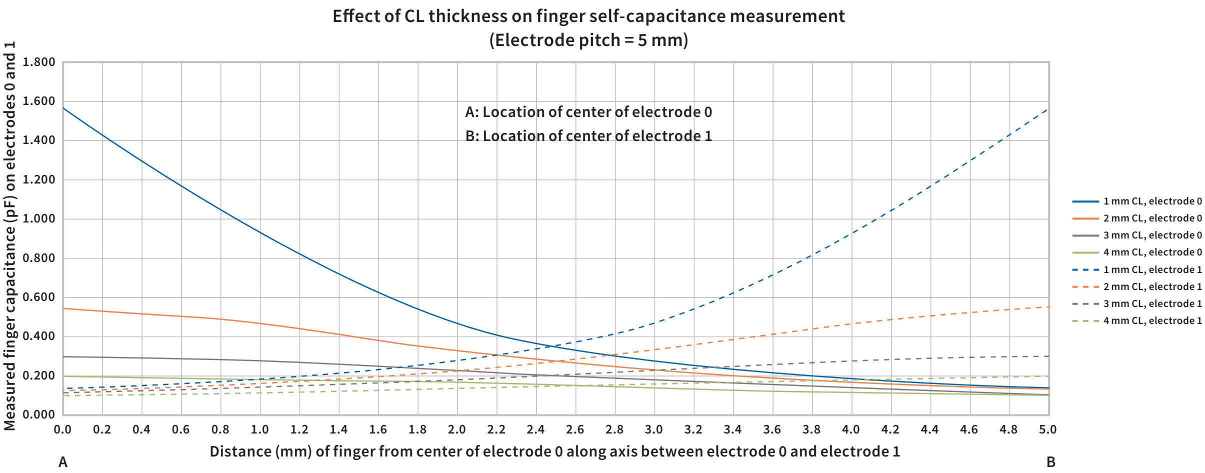


Figure 10: Effect of thickness of cover lens on signal from a moving user finger

There are two challenges in supporting a thick cover lens: (a) the thicker the cover lens, the capacitive coupling (touch signal) signal significantly reduces in general. (b) Capacitive coupling is most affected by the thicker cover lens when the finger is in between two adjacent electrodes.

A larger sensor pitch helps to improve the amount of capacitive coupling (provided the pitch is not larger than the width of the finger contact area). The following graph shows the effect of cover lens thickness on the capacitive coupling, for a sensor with an electrode pitch of 10 mm.

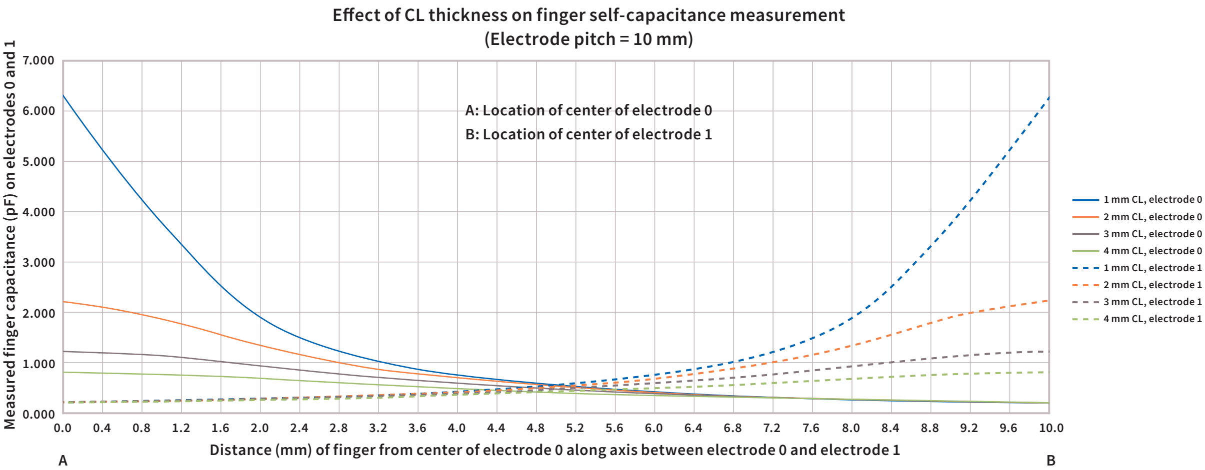


Figure 11: Effect of thickness of cover lens and sensor pitch size on signal from a moving user finger

As can be seen from the vertical scale on this graph, a larger electrode pitch helps to improve the capacitive coupling, even when the finger is in between two adjacent electrodes. While the larger pitch helps to improve the touch signal, the touch signal change with respect to finger position shows higher non-linearity, which can cause non-linear response for finger touch on touchscreen. A seamless user experience and uniform touch response from the touchscreen, while supporting cover glass thickness, requires striking the right balance between the cover glass thickness and sensor pitch for the design.

Impact of gloves on touch performance

Figure 12: Touchscreen with Gloves for Industrial applications

Thick gloves can also cause the touch signal to become small and make it difficult to detect touches. Unlike in the case of thick cover glass, there is additional variability in this signal depending on the type of glove material (or dielectric constant of the material), the thickness of the glove used, the fit of the glove, and the pressure exerted by the user. These factors make the glove use-case much more challenging to solve than thick cover lenses

The following graph shows the effect of thickness of the glove on the measured capacitance on two adjacent electrodes.

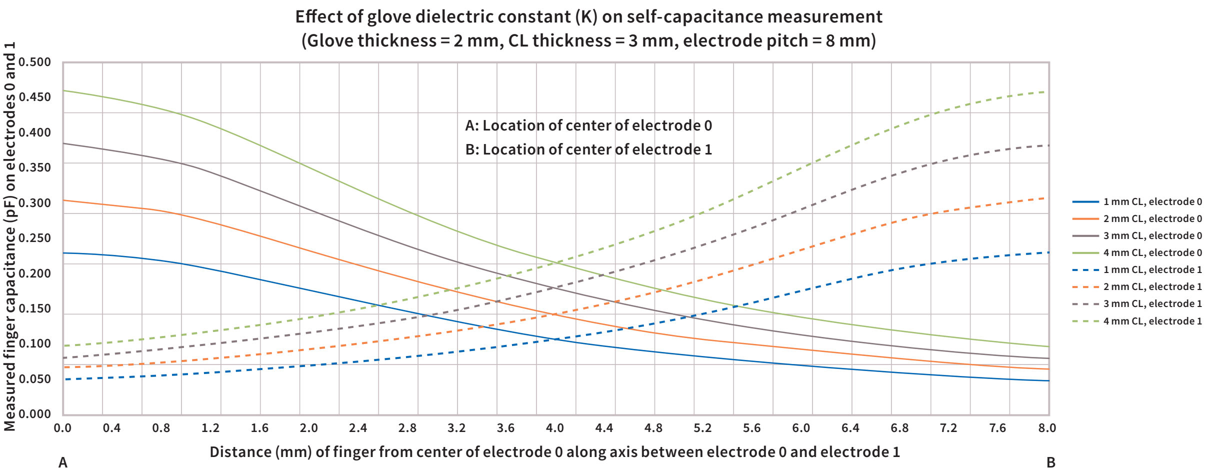


Figure 13: Effect of different gloves on touch signal

The effective dielectric constant of a glove is dependent on various factors, such as the percentage of material that is filled with air (which in turn depends on the amount of compression), ambient relative humidity, moisture content in the glove, etc.

In order to support operation with gloves, the cover lens thickness and sensor pitch should be further optimized to support glove touches, and a touch controller which can very effectively differentiate tiny capacitance changes due to user touches from noise is a critical piece of the design. Additionally, a sophisticated touch signal processing algorithm is often required to handle and effectively detect glove touches, and several trial phases and fine tuning of algorithm and sensor and system design is often expected due to additional variability in the touch signal in glove touch use cases.

Figure 14: Touchscreen operation with Gloves

Impact of temperature

Many manufacturers provide touchscreens for temperature ranges from 0 degrees up to +35 degrees Celsius, sufficient for consumer interior applications. An extended operating temperature range of -40°C to +85°C are typically required for industrial applications. Supporting such a high temperature range is challenging for designers as temperature fluctuations can potentially interfere with the touchscreen operation.

With temperature changes, the differential contraction can break the adhesive layers that hold the touchscreen stack-up together. The problem is worse in outdoor applications where cold ambient temperatures cause contraction, and the operating touchscreen's higher internal temperatures cause expansion, which together lead lead the sensor stack-up to break apart.

It is very important to select appropriate adhesives and make the stack resilient to the temperature range required by the application. These adhesives are used to bond the cover lens to the touch screen, and to bond the touchscreen to the display.

Capacitive touch screens make use of conductive layers as sensors to detect changes in capacitance when a conductive object, like a finger coming close to the screen. The touchscreen relies on consistent and uniform change in sensor capacitance upon user touches to detect user touches on the screen. The changes in temperature around the touchscreen sensor affects the value of the capacitance because of changes in the dielectric properties. If the air or surrounding temperature becomes too hot or too cold, the capacitance value of the sensor may change so much that it leads to inconsistent touch signals. Further, sensor stack up deformation due to the thermal expansion or contraction can have an influence on the sensor and its operation.

The display and display controller can have different operating temperature specs and must be selected appropriately for the application.

A capacitive touch sensor is essentially an analog-to-digital convertor, and the electronic components in it can be affected by temperature. The following graph shows the effect of temperature on a typical capacitive sensor electrode. Note that in this example, as the temperature ranges from --40°C to +85°C, the baseline capacitance variance is within +/-4% of the nominal value at room temperature (25°C).

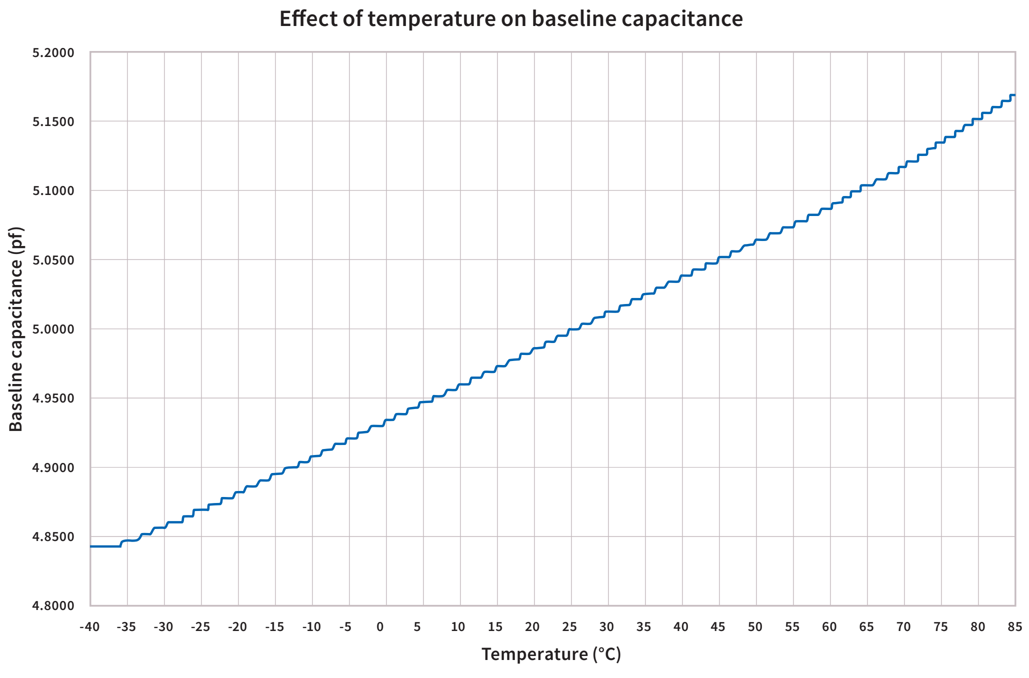


Figure 15: Effect of temperature on PCAP sensor

The above discussed issues cannot be completely eliminated in most cases. A well-designed touchscreen for extended temperature range in industrial application requires these unwanted variations to be minimized and compensated in hardware and software.

Water tolerance

A waterproof touchscreen implies touch performance that is totally immune to the effects of water. For a water tolerant touchscreen, water levels encountered in normal operation do not interfere with sensor operation. Splatters and spills on the touch surface are tolerated, but total immersion is not. Water tolerance is a reasonable and cost-effective solution for operation in a wet environment. In a water tolerant touchscreen, only the touch of a finger produces a signal large enough to register as a "touch". However, a unit submerged cannot operate normally.

A sensor's touchscreen produces a signal by detecting the changes in the electric field and capacitance of the sensors. Unfortunately, this operating principle makes a capacitive touch sensor influenced not only by human finger touch, but also other electrically conductive objects which can influence capacitance of the sensor. Water or other electrically conductive liquids on the surface of a touchscreen can also drastically change the measured capacitance on those electrodes that are in close proximity to those liquids.

There is enough of a difference between the two signals to make possible techniques for discriminating between a touch and a liquid spill. Liquid tolerance needs to be considered for applications where liquids or moisture can come in contact with the user interface of the product, such as in outdoor applications and power sports vehicles which may be subjected to rain and snow.

Selecting a touch controller such as the PSoC 4100S Max, which has driven shield electrodes to nullify the effects of liquid s and also has ability to sense both self and mutual capacitance, provides advantages in designing robust water proof to uch screen solutions.

Figure 16: Outdoor touchscreen application needs to withstand sunlight explore and high heat

Mechanical and electrical considerations

Touch performance can be affected by its mechanical construction and integration into the host system. This section provides an overview of the typical mechanical challenges that must be considered.

A variety of screen coatings or etching can be used to help reduce glare, improve sunlight readability, and improve water touch performance.

While PCAP touchscreens can operate even in the presence of water, the touch cannot function if the touchscreen is submerged under water. The mechanical construction must prevent water from accumulating and allow for any water to quickly and easily flow off the touchscreen. This can be achieved through the use of appropriate hydrophobic coatings, careful selection of the mounting angle, and minimizing any bezel heights, as well as distance of the bezel from the edge of the touchscreen. It is also important to prevent water from accumulating above the metal traces on the edge of the touchscreen that connects to the touch controller board (FPC). The design should be such that any water flows away from the traces.

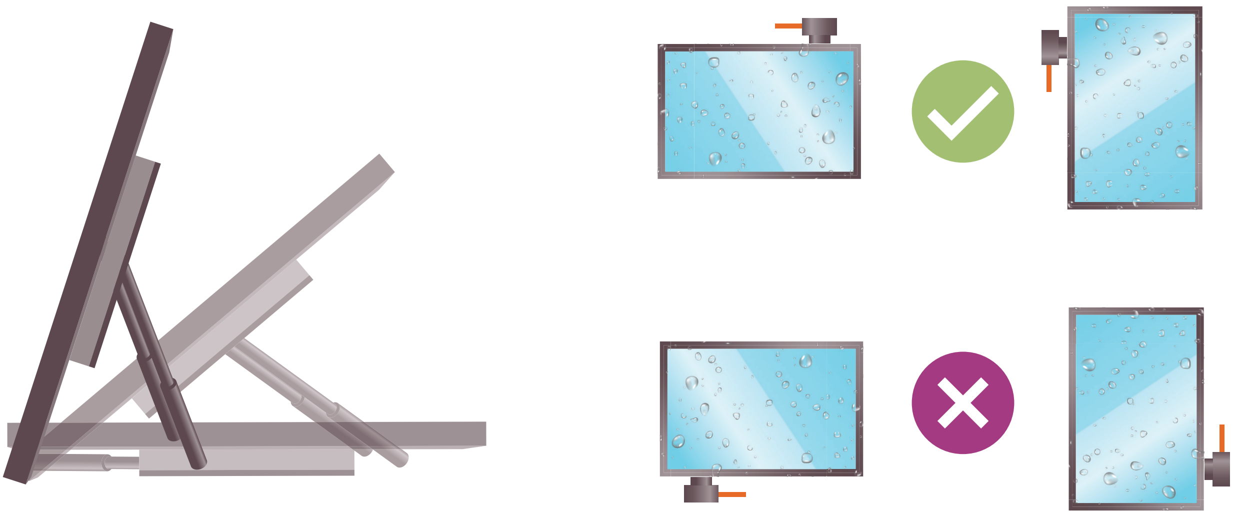


Figure 17: Wiring and mounting recommendation for liquid tolerance

Thermal protection and dissipation options should be carefully considered when using a touchscreen and display in an outdoor enclosure. These include enclosure design, passive or active cooling, and appropriate coatings on the touchscreen itself.

There are several options for bonding an LCD display, touchscreen, and cover lens – including perimeter bonding and full optical bonding. These options must be selected based on the intended application and on cost considerations. Options for mounting the resulting assembly into an enclosure should also be carefully considered with respect to how the weight of the LCD is supported. Glues or adhesives that are used to mechanically support the LCD must be carefully selected to support the weight, shear, and tensile forces over the full temperature range of the assembly. Furthermore, it is important to ensure that the bonding mechanism between the cover lens and the touchscreen, or the one between the touchscreen and the LCD, is not subjected to tensile, compressive or torque forces. Any mechanical stress or strain on the bond may result in bubbles, migration, or delamination.

Electronic or electrical peripherals near the touchscreen or its FPC may cause interference, depending on distance, frequency, and signal strength. The physical placement of those peripherals needs to be carefully considered in order to minimize the interference.

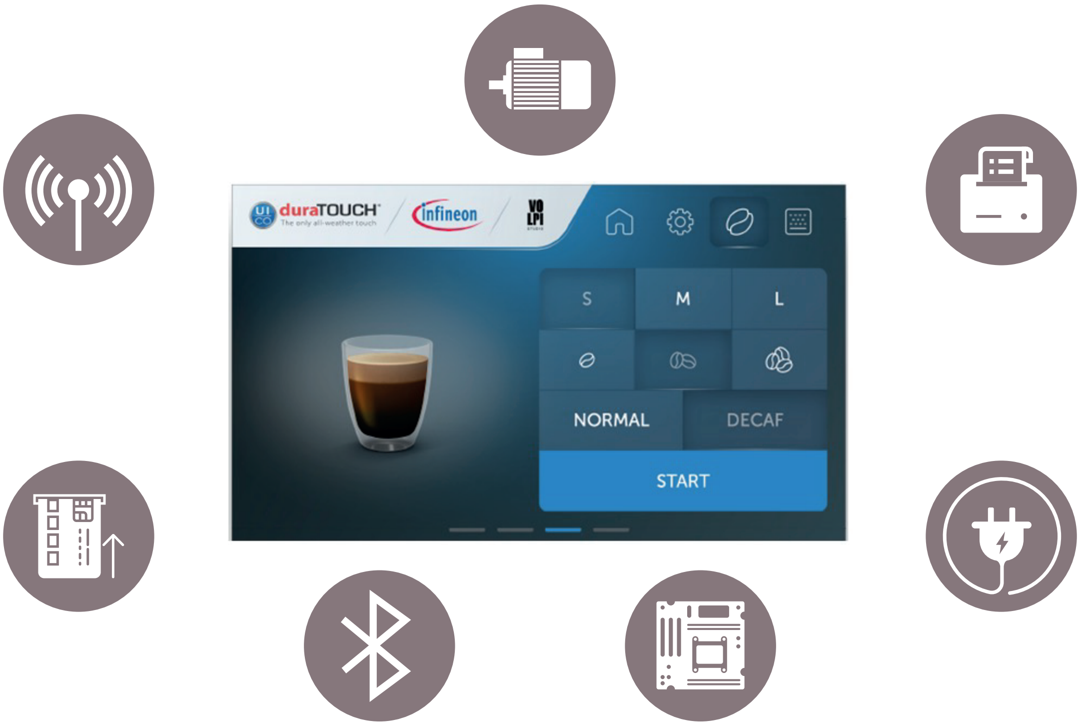


Figure 18: Touchscreen and potential external noise sources

Any power or signaling cables need to be appropriately routed and shielded in order to minimize interference. Cables from other devices and peripherals can cause interference and should be kept at a safe distance from the touchscreen controller and flex circuit. LCD LVDS and LCD backlight cables, power, I2C, USB, and any other communications cables should be routed away from the touch controller and flex circuit. Cables that are near the touch controller or flex should be shielded whenever possible. Grounded foil tape can be used to cover unshielded cables if needed. If cables need to cross, keep them perpendicular. Parallel routed cables are more likely to interfere with each other. The cable routing and any resulting signal interference can affect the touchscreen tuning. Changing the cable routing or shielding may require retuning the touch sensor.

Proper circuit grounding of the touch controller and surrounding metalwork is critical. The touch controller requires a short low impedance ground path to the host circuit and LCD driver circuit. A short impedance ground path is also required between the touch controller and any surrounding metalwork, including the LCD backplate and device chassis. Circuit ground and chassis ground in view of the touch sensor needs to be at the same potential to avoid excessive signal noise. Ground connections that use dissimilar metals must be designed carefully to avoid galvanic corrosion, especially in high humidity applications. If a conductive adhesive such as foil tape is used as a ground connection, ensure that the adhesive is compatible with the thermal and humidity requirements for the application. High vibration applications may require additional grounding reinforcement and design considerations.

The touchscreen requires a clean and stable power source for best performance. A dedicated precision LDO (low dropout) linear regulator is highly recommended. The touch sensor voltage source should remain stable and independent of other load changes from the host, for example from speakers, motors, lighting, printers, or other peripherals.

Conclusion

When designing a projected capacitive touchscreen, the contents of this paper will help you understand design challenges for industrial applications. Nothing will extensive testing; however, development time can be greatly reduced when cover lens thickness, industrial glove use, extreme temperatures, water tolerance, and mechanical and electrical considerations are addressed early in the design process.

Module suppliers, such as UICO, sell touchscreen modules (powered by Infineon touch controllers) that address these challenges in the module design. Industrial customers can rest assured that these challenges are carefully addressed in touchscreen modules designed by UICO.

For help with your design and to answer any questions, please visit the Infineon and UICO partner webpage here.

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