Applications and considerations of capacitive proximity sensing

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Designing with high-fidelity capacitive proximity sensors requires careful consideration of mechanical design, sensor placement/design, and end-application operating environments. Careful evaluation of a series of design considerations will help to avoid many of the common implementation problems associated with typical capacitive proximity designs. This article presents some common applications of proximity sensing as well as considerations that will greatly maximize design success.

Capacitive proximity sensing brings unique usability benefits to many user-interface systems. As illustrated in Figure 1, proximity sensing can be added to notebook multimedia button arrays to provide a "light-guide" in dark environments when a user finger or hand approaches the notebook. This makes operation in dark environments, such as trying to use a notebook in a darkened aircraft cabin, much less challenging.

Figure 1: Proximity light guide to improve usability in the dark

The light-guide concept can also be adopted by systems requiring reliable operation in dark or dimly lit environments, such as intercom/PA systems, mobile phones, wall switches, and automotive entry systems. Capacitive proximity sensing can also be used to increase the reliability of mobile phones in conjunction with a touchscreen or a capacitive interface: As the user brings the phone toward his or her cheek in preparation to make or receive a call, the touchscreen/capacitive input interface automatically locks its keys and functions so that, for example, the End Call button on the phone is not accidentally selected. Capacitive proximity sensing can also be used to automatically activate key-lock as a user sets down the handset and deactivate the key-lock when a user picks it back up. Such features play an important role in making phones much easier to use.
Proximity sensing can also be exploited to increase the safety of car windows/safety systems. For example, if a hand is present along the window frame as an automatic window is being closed, proximity sensors on the closing window will be able to detect the presence of a hand or arm and stop its advance before causing injury to the passenger. Similarly, industrial equipment can also benefit from the added safety benefit provided by capacitive proximity controls. Bathroom amenities can be made environmentally friendly and efficient with proximity sensing. Faucets can adopt proximity sensing to turn on the water in response to hands held under the faucet. As soon as the hands move away, the faucet will turn off immediately—ensuring that no water is wasted. Hand-soap dispensers can automatically activate when a hand is placed underneath and will not erroneously dispense when other nonconductive objects are placed in proximity to the dispenser. Toilet and wastebasket lids can also implement hands-free operation with the use of capacitive proximity sensors.

Burglary prevention is a potential novel application of proximity sensing. Capacitive proximity sensors can be placed around the house and armed when the occupants have left their homes. If the home is burglarized, strategically placed proximity sensors around the house will indicate the thief’s exact point of entry and his or her path through the house. This type of information will help with post-theft investigation and will lead to faster case resolution. Moving nonconductive objects will not trigger the capacitive proximity sensors (i.e., should a painting fall from the wall while the occupants are out), avoiding incorrect tracking.

The use of capacitive proximity detection in peripheral devices such as digital-photo frames and LCD monitors can enhance device aesthetics while enabling greater ease of use. Traditional digital-photo frames have mechanical control buttons located on the rear or the top of the unit. When users want to adjust the settings of the digital frame or configure the pictures being displayed, it is often quite cumbersome. Using a combination of capacitive controls and proximity sensing on the frame’s bezel allows easy one-finger operation and the keys to be discretely hidden in the bezel when the hand is removed. Figure 2 shows a comparison of analog buttons and the use of proximity sensing and capacitive controls.

Conventional LCD monitors often have unsightly mechanical monitor controls protruding from underneath the bottom bezel or inlaid on the bottom bezel itself. Since monitors are quite light, pushing these mechanical buttons sometimes involves moving the actual monitor out of place. The
use of mechanical buttons becomes an impediment to one-finger operation. As LCD monitors continue to get thinner and thinner, a flat set of controls along the bezel adds elegance and sleekness to the design. The use of proximity sensing complementing an existing array of capacitive controls is a winning combination for LCDs.

Wireless devices using Bluetooth can also benefit from the use of proximity sensing. When a Bluetooth device goes to sleep, there is a perceptible time that is required for the Bluetooth device to wake and be ready for use. The use of proximity sensing allows the sleeping Bluetooth device to wake in advance of the user's imminent touch, thus significantly reducing the perceived delay experienced.

There is also the added advantage of efficient power consumption. As the finger or hand is removed from the device enable with proximity sensing, the device can immediately enter into a sleep or power-conservation mode. This eliminates the need to place timeout intervals in software. Time-out intervals can be cumbersome when they are too close together and turn off devices while they are still in use (e.g., thinking of what you want to write in an email and having the screen go dark). Similarly configuring time-out intervals that are too long causes can cause unnecessary power consumption.

Achieving a high-fidelity capacitive sensing design can be straightforward. Subject to a product’s mechanical design, there are two primary factors to consider in achieving a successful proximity design: the area of the proximity sensor and the coupling of the sensor to ground and other active signal lines. In general, the larger the sensor and the smaller the parasitic capacitive coupling, the better the proximity detection range/performance.

Figure 3 illustrates a typical proximity sensor implementation with a wire proximity antenna and its associated capacitive sensing circuit. The proximity antenna typically forms a loop around the area where proximity detection is required. Looping the sensor accomplishes two objectives: It decreases parasitic capacitance while extending the area of detection. Care should be taken to ensure that the distance between the proximity antenna and the surrounding metal chassis or other metal casing is maximized so that parasitic coupling is minimized.

Figure 4 shows the electric-field distribution of a proximity antenna separated by a distance of 10 cm from a user's finger or hand. The illustration on the left depicts the field distribution when the proximity sensor is not subject to metal coupling; the illustration on the right depicts the effect of coupling.
Figure 4 shows that as the metal coupling increases, the amount of electric field that couples to the finger decreases. As a result, the inter-capacitance between the antenna and the finger decreases, translating into a decreased detection range. Depending on the strength of the metal coupling, this can reduce the proximity signal by as much as 10 times. Attaching the metal object to a driven shield can decrease its coupling with the proximity antenna (i.e., increase inter-capacitance between the finger and antenna). A driven shield is maintained at the same potential as the proximity sensor to minimize parasitic coupling. The use of a shield can improve detection signal by more than five times over a similar design that does not employ a shield. However, it still will not offer the same detection distance as an antenna without the presence of metal coupling.

Instead of having a discrete proximity antenna separate from the main controller PCB, the proximity trace could also be situated directly on the controller PCB. Care should be taken to ensure that the proximity trace is not placed in a region of the PCB without ground-fills or metal traces that could increase parasitic coupling and decrease detection range.

For some applications, using a fixed proximity antenna is not possible because there is a lack of spare I/Os on the controller chip or the end device does not have the necessary space to accommodate a discrete antenna wire. For interface designs that are already using capacitive sensing, the capacitive buttons/sliders can be logically tied together to create a giant proximity sensor, thus saving the need for a separate pin dedicated for the proximity sensor. This can be realized through the use of a dynamically configurable capacitive sensing chip such as PSoC from Cypress Semiconductor. However, because the buttons and sliders have strong coupling to ground-fills and ground layers of the PCB board, tied pins will experience a higher parasitic capacitance and a lower detection range.

The use of shield electrodes has also proven useful in decreasing the parasitic capacitance. If there is no room to fit an external antenna comfortably and securely around the device, fixed proximity still enables good performance without having to worry about antenna assembly.

Proximity performance can be noticeably improved through the capacitive controller firmware. A larger detection range can be achieved by averaging several capacitive signal counts on the proximity trace over a period of time. Obviously, this will affect the response speed of the proximity sensor. Careful experimentation will reveal the optimal averaging time and detection range tradeoff.

LCD noise/EMI emissions can affect the performance of the proximity sensing system. There are generally two approaches to overcoming this problem: careful selection of decision thresholds and the appropriate use of shielding. If the signal-to-noise threshold (the ratio of proximity signal to peak noise) is greater than 5:1 in a system without the LCD present, the noise/finger thresholds can be adjusted higher and/or lower, respectively, to achieve a better noise-filtering effect.
Capacitive proximity sensing offers increased usability, improved industrial design, and increased functionality with many different consumer applications. Additionally, proximity sensing can be part of household and industrial energy-efficient designs. Designing for proximity systems can be made manageable through careful consideration of device mechanical design, proximity sensor size/placement, and minimizing parasitic coupling. Proper adjustment of finger/noise thresholds and the use of averaging can further improve the performance of a capacitive proximity system. Using a firmware reconfigurable capacitive sensing controller IC allows proximity to be implemented without the need for an extra controller I/O.