AZD080 – A guide to prolonged detection using capacitive proximity sensors

Azoteq offers a unique combination of solutions that may be used for prolonged proximity detection. This guide is intended to aid in the selection and design process.

The following guide will review types of proximity sensors for prolonged detection, followed by a focus on capacitive sensing design specifically for such occupancy-type solutions. Various algorithms will be evaluated in order to choose the most effective response for a specific application.

1 Contents:

2 Brief overview of sensor types

2.1 Infrared sensing

Infrared sensors are based on the reflection of infrared light and the absence thereof.

Advantages:

- Directed sensing with narrow field of influence
- Robust against environmental drift effects

Disadvantages:

- The inclusion of an aperture for light transmission and reception
- Relatively expensive hardware
- Relatively high power consumption
- Less effective against materials that absorb light

2.2 Accelerometer monitoring

Accelerometers are multi-purpose sensors that may be used to detect human interaction. Generally, these have the ability to sense acceleration in three dimensions, as well as orientation in relation to the gravitational pull.

Advantages:

- A device that is generally already included in many multi-purpose digital devices
- Can be placed anywhere on a device

Disadvantages:

- Non-directional, only movement based
- Area-specific sensing not possible

2.3 Capacitive sensing

Capacitive sensing proximity solutions are based on human or object interference with electrostatic fields. Most capacitive sensors compensate for larger, static system capacitance and focus on accurately measuring small capacitive differences. The ability to measure small differences is the key element of non-touch proximity detection.

Advantages:

- Ultra low-power options available
- Area-specific sensing (slightly directional with electrode design)
- Environmental shifts may cause favorable triggers
- Low cost

Disadvantages:

- Temperature-dependent internal capacitors
- Environment-specific calibration at power-on

3 Capacitive sensing sensitivity

3.1 Self- vs. mutual capacitance

There are two types of capacitive sensing technologies: mutual capacitance and self-capacitance. Although mutual capacitance is less dependent on a common reference (signal ground), the effects of a varying reference cannot be ignored. Some effects of this technology deem self-capacitance a safer option, especially with reference to area-restricted custom electrode designs.

A follow-up article will discuss the implementation of mutual capacitance technology in mobile devices for proximity sensing and prolonged detection with SAR sensors in mind. This article will focus on self-capacitance solutions in discussions on sensitivity.

3.2 Obtaining sensitivity

Capacitive sensing uses either of the following:

1. Charge transfer method
2. A relaxation oscillator circuit in which variance in capacitance is translated into variance in frequency
3. A fixed frequency AC signal, where the variance in capacitance is translated into voltage differences using a fixed known capacitor and an unknown capacitor

The first method is by far the more popular for proximity sensing because of the leverage obtained from multiple charge transfers (into a "reservoir" capacitor) becoming an integrated average of the instantaneous capacitance. Various other techniques in this architecture seamlessly enable charge multiplication (higher SNR) and parasitic charge subtraction, thereby enabling the detection of extremely small capacitive changes.

3.3 Understanding sensitivity in a mobile device

Capacitive proximity sensors include the measurement of human interference. Humans generally have a fixed coupling to earth. The device has a variable coupling to earth (in hand versus on table).

Shown in Figure 1 is a simplified diagram of the loop that is formed with capacitive sensing. When the GND reference between the body and the device is tightly coupled ($\mathrm{C}_2 \gg \mathrm{C}_1$ & $\mathrm{C}_3 \gg \mathrm{C}_1$), the sensing is optimal, with the sensor charge current only bridging a single unknown and dominating capacitor (C_1). This enables optimal sensitivity. With a lightly coupled GND reference, the charge current will be affected by a second unknown capacitance ($C_x = \mathrm{C}_2 + \mathrm{C}_3$), limiting the charge transfer current with the smaller capacitance. The smaller capacitance dominates the measurement by being in series with the capacitance of interest.

$$\mathrm{C}_{\text{electrode}} = \frac{\mathrm{C}_1 \mathrm{C}_x}{\mathrm{C}_1 + \mathrm{C}_x} \simeq \mathrm{C}_1 \left\{ \text{when } \mathrm{C}_x \gg \mathrm{C}_1 \right\}$$

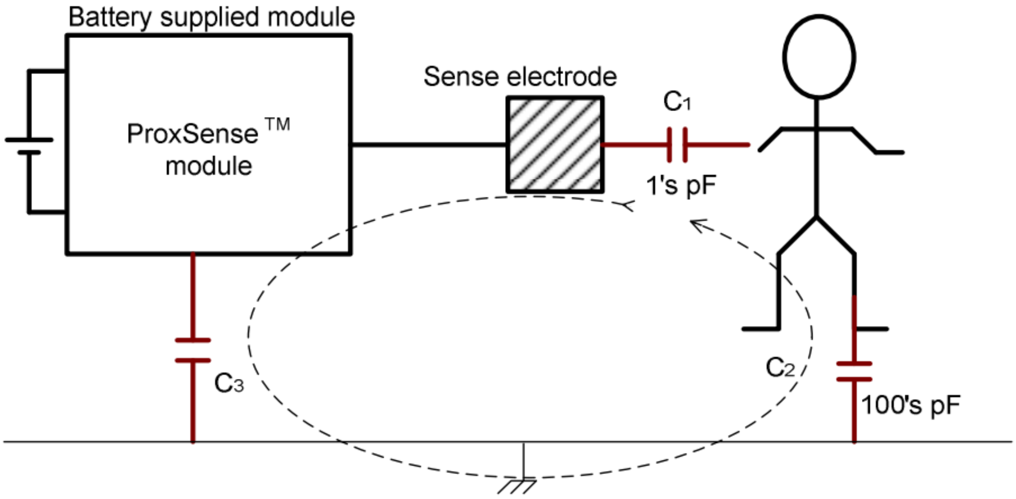

Figure 1: A simplified diagram of the main capacitive elements that influence sensitivity

$$C_{electrode} = \frac{C_1 C_x}{C_1 + C_x} \simeq C_x \; \{\text{when } C_1 \gg C_x \}$$

Therefore, a hand-held device will sense a hand from the same body much better than a hand from a different body. As a practical example, the sensor will be much more sensitive:

- in-hand, approaching with the other hand (Figure 3), than
- on a table or carpet, approaching with one hand (Figure 2).

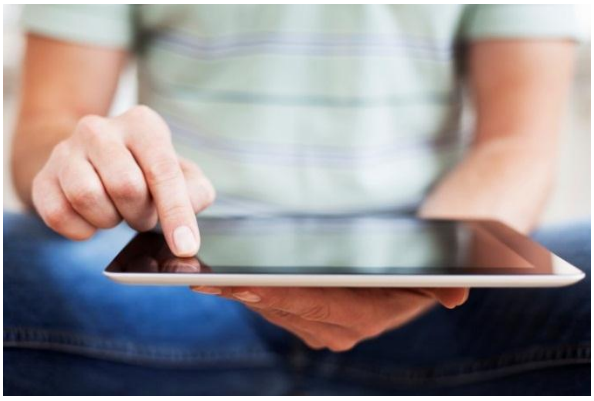

Figure 3: An example of a tablet in hand

3.4 Dislocated sensitivity

A capacitive sensor solution consists mainly of two parts:

1. The integrated circuit (sensor IC) with supporting components

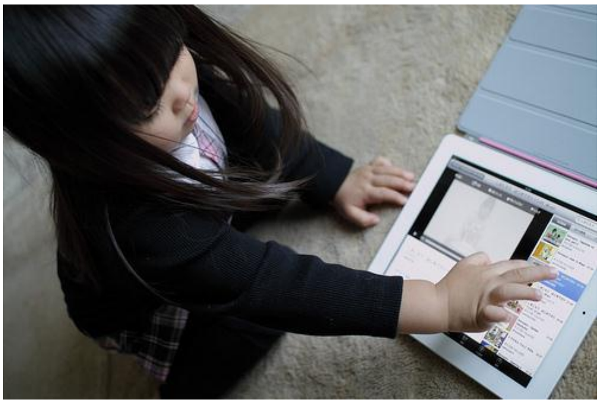

Figure 2: An example of a tablet on carpet

2. The electrode structure connected to the sensor IC

The success of the solution is largely dependent on the design of both of these elements. The first is generally fixed by the IC vendor with a reference design, leaving the designer with a few options for configuring the device. The second is an aspect that is placed in the hands of the designer, emphasizing the need to understand electrode design.

A common reason for proximity sensor failure is mismanaged electrode designs. An example of this would be an electrode with excessive copper covering a large conductive structure such as a metal frame or battery. This may become a problem in three areas:

1. Capacitive sensors have a limit in the driving capability of the load capacitance to their reference signal GND. Reaching peak driving capability will limit sensitivity.
2. By creating the peak load capacitance in an area that is mechanically variable, even by a few um's, the smallest mechanical changes could cause the sensor to trip falsely.
3. By creating load capacitance in areas that are not the main sensor areas. Sensitivity should be maximized in the main areas.

A few pointers to optimize sensitivity:

1. Pass areas with thin signal lines where sensitivity is not required or impractical.
2. Sense in desensitizing areas by using hatched pours instead of solid copper. This drastically reduces the load capacitance, while maintaining the sensor area and sensitivity close to that of the solid structure.
3. Use solid copper only in small areas where distance is to be optimized.

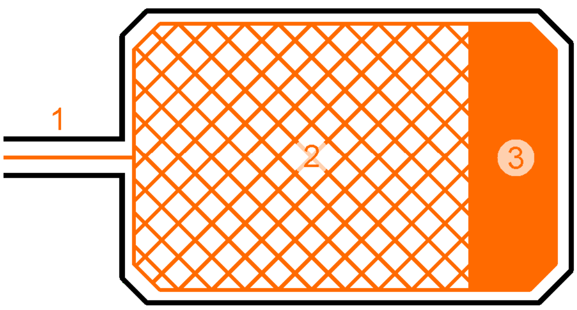

Figure 4: Example electrode with varying areas for specific purposes

4. Do not attempt to sense directly above conductive surfaces. The capacitive load generally is very desensitizing and affects the sensitivity of the whole electrode. It also causes dependence on mechanical stability.
5. Mechanically fix the electrode, especially when running past conductive surfaces that are fixed to or that couple to the reference signal GND.
6. See the Azoteq application note AZD073 on the design guidelines for meeting FCC SAR requirements. This document offers more design guidelines for the electrode.

4 Prolonged proximity sensing algorithms

4.1 Fixed thresholds with no auto-timeout

A simple algorithm may be implemented that enables detection using fixed thresholds (multiple levels are possible, e.g. proximity and touch). A commonly used touch button algorithm uses a timeout release when a “stuck key” is assumed. Prolonged detection sensors, by definition, usually do not limit the time a device may be in use. By disabling a timeout routine, the device is technically suited for long-term sensing. Such an algorithm is best suited for static devices in which the only variables are slow temperature changes and the intended user influence. This is best suited for where a fixed detection distance is crucial. This algorithm may be extended by the designer to allow for mobility. This is done through the implementation of timers in an MCU as shown in Figure 5.

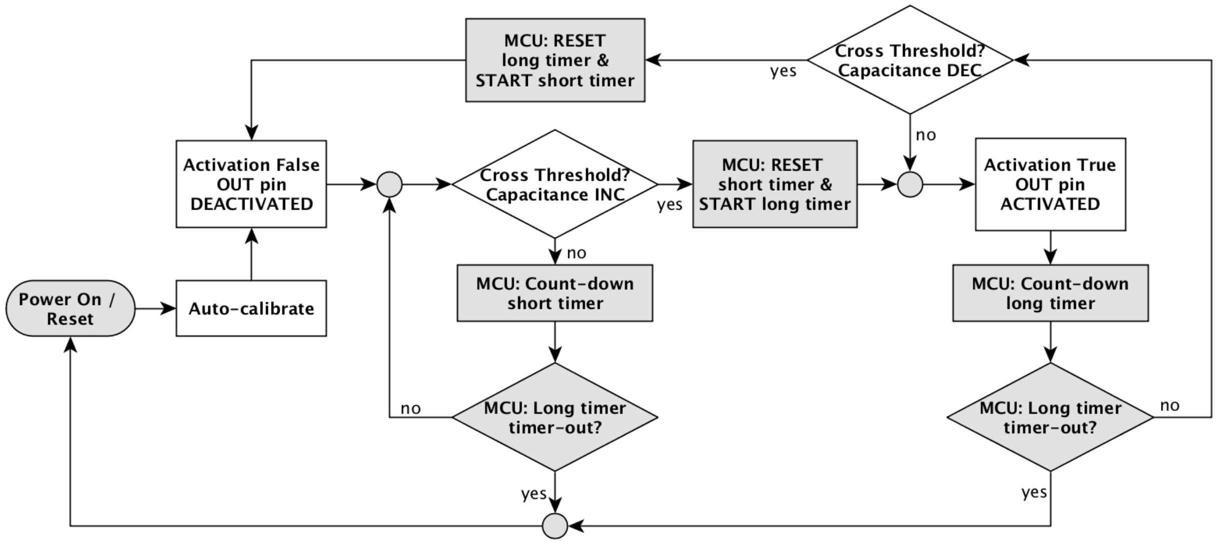

Figure 5: Flow diagram of a design with fixed thresholds, no auto-timeout and aid from an external MCU

Recommended devices for such a user interface are the Azoteq IQS127 and IQS227AS. For prolonged detection, these devices should be configured with a "filter halt = always" to prevent losing the activation. It is recommended that the device is reset periodically when no activations have been seen for a while (see short timer in Figure 5). Also, to enable long-term stability it is recommended that a long-term timer is implemented for when the sensor is activated for an extended and unrealistic period of time (see long timer in Figure 5). These timers should be implemented apart from the capacitive sensing device in an external MCU (see the elements in Figure 5 that are labelled "MCU")

4.2 Fixed thresholds with movement sensing

Prolonged detection can also rely on human movement for keeping the activation triggered. Such an algorithm makes use of the ability to sense with a high signal-to-noise ratio. The slightest movements sensed within an activation will prevent a timeout from occurring and

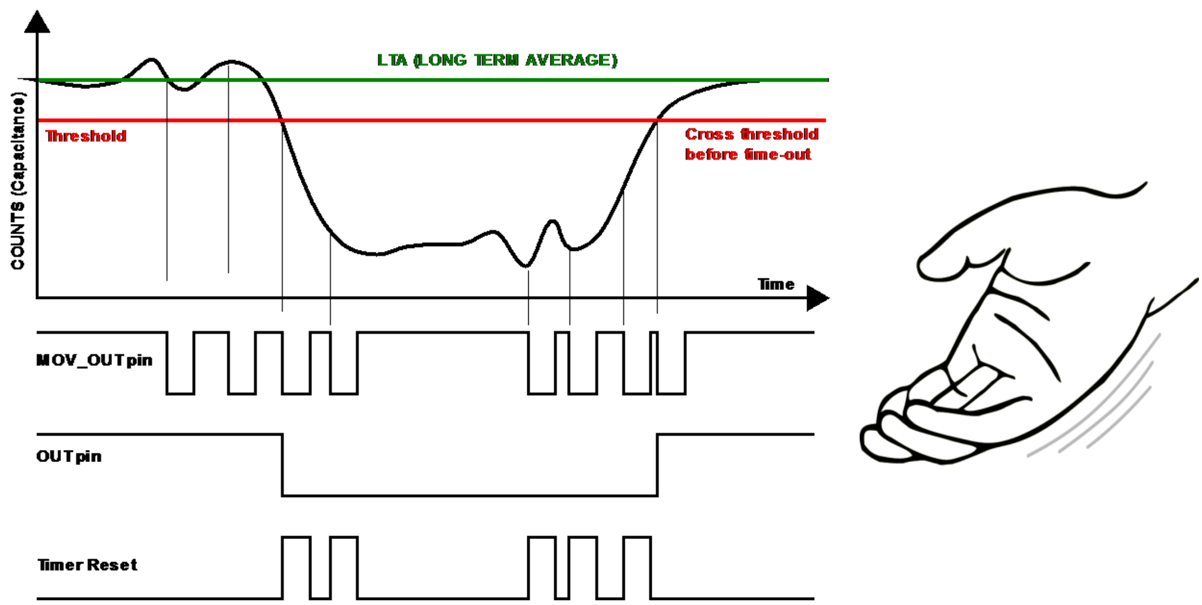

Figure 6: Typical output of a movement based device

preserve the activation. Such a sensor combines the advantage of a very sensitive threshold with the ability to clear activations based on the absence of a typical user characteristic.

The Azoteq IQS229 is an example of a solution with such an algorithm. This solution includes minimal setup complexity and is optimized for SAR qualification in mobile devices such as tablets. The algorithm is summarized in Figure 7.

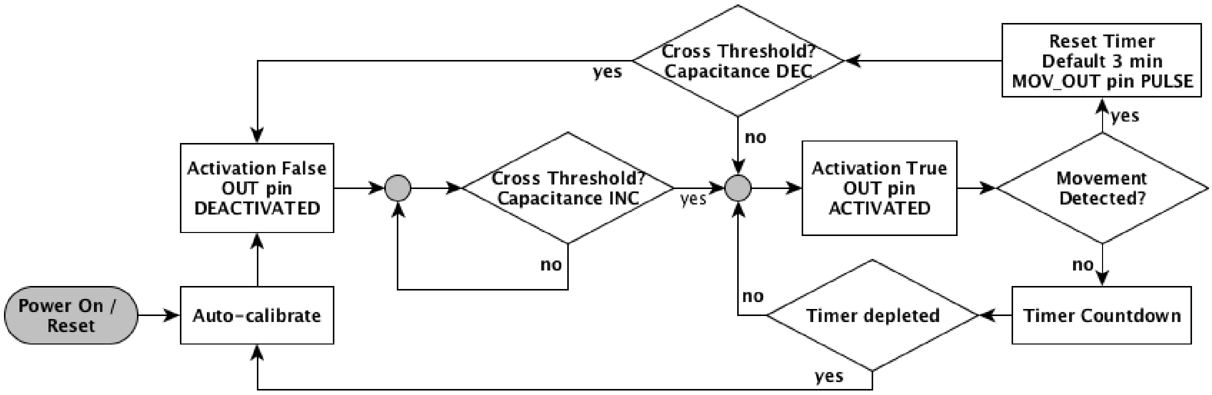

Figure 7: Flow diagram for a movement based algorithm for prolonged detection

4.3 Dynamic thresholds

Another technique assumes that the initial threshold would not be accurate for a release over an extended period of time. Once triggered, the initial threshold is discarded and a release threshold is calculated entirely from the current trigger intensity. This algorithm is designed to give reasonable variance in trigger intensity while offering an effective release. This algorithm effectively compensates for long-term environmental drift within a triggered condition, while offering an optimized release. In order to offer a stable solution, the release threshold is generally much closer to the device body than the activation threshold. In Figure 8 is a simplified flow diagram of the concept.

Such dynamic threshold solutions are available with the Azoteq Dycal™ devices, such as the IQS128 and IQS228AS. The IQS128 is a very popular device for passing the SAR qualification process. Recent advances in the SAR testing methods have caused some minor problems in passing the test because of the time-dependent varying threshold levels of this algorithm. While still being very effective in real-world situations, Azoteq recommends using a movement-based sensor such as the IQS229 for SAR qualification.

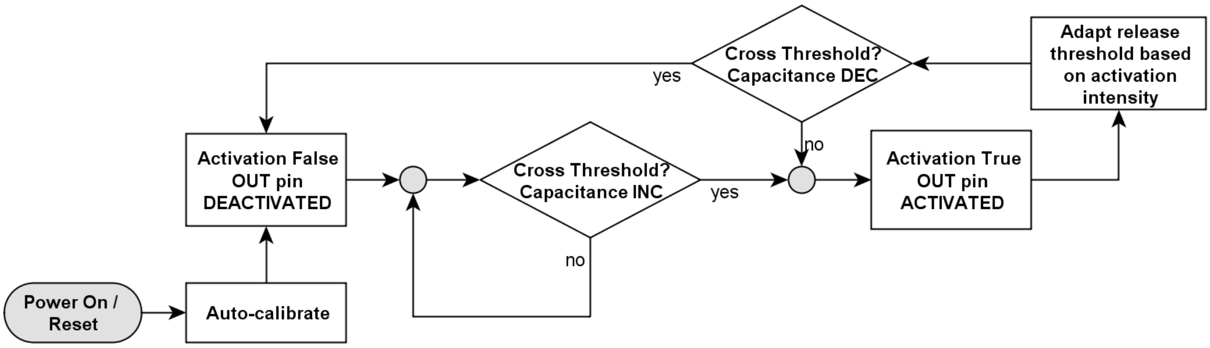

Figure 8: Flow diagram of a dynamic threshold calibration algorithm

4.4 Conclusion

The options discussed above aid the effective implementation of prolonged detection using capacitive proximity sensing solutions. Capacitive sensors are favored for their low cost while offering excellent low-power performance coupled with unobtrusive aesthetics.

1. By using fixed thresholds with no timeout (Azoteq IQS127 & IQS227AS), the designer may implement a long-term sensing solution by adding some intelligent control via timers in an MCU. This option is recommended for designers requiring the most cost-effective solution that also offers dual detection levels (proximity and touch), while already having an MCU in the design for a timer implementation. The recalibration achieved through timers will make this option stable in the long term, keeping the sensing distance optimal and rejecting excessively long activations.
2. Using fixed thresholds with movement sensing (Azoteq IQS229) is ideal as an SAR sensor and for various other applications that may rely on typical human movement. Fixed thresholds ensure passing the SAR qualification tests, while movement sensing is used to ensure prolonged detection stability with the rejection of inanimate objects. The IQS229 offers easy configuration, with threshold and timer settings selectable via external strapping.
3. The use of dynamic thresholds (Azoteq Dycal™ devices such as the IQS128 or IQS228AS) enables solutions with an optimized release. This is ideal for applications such as on-ear detection, where release delays are particularly unwanted. Such a solution is also very well suited for applications for which human movement is not present or difficult to detect.

Capacitive sensing provides a range of effective solutions for prolonged activations. The advantages mentioned make these sensors a very tough contender in the proximity sensor market where prolonged activations are expected.

Appendix A. Contact Information

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