

Proximity Design Guide

1. Introduction

The ability to interact with an electronic device, while not physically making contact with the device, has fascinated designers and users alike for years. There are a variety of ways to implement this type of technology: IR, magnetic, optical, ultrasonic, and capacitive. Each of these technologies comes with its own unique benefits and trade-offs.

Capacitive sensing technologies have the general advantage of achieving very reliable proximity detection with low power, low cost, and relatively easy design. Atmel® has the advantage of being able to do all of these with ranges to over 250 mm.

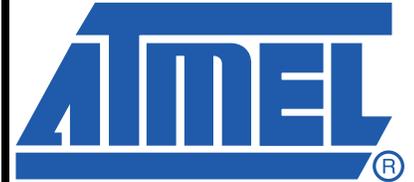
Capacitive sensing generates an electric field, or E-field, as part of the sensing process; this applies to both self-capacitance (QTouch® and QTouchADC®) and mutual-capacitive sensors (QMatrix®). Proximity detection is achieved by adjusting the sensitivity of the standard capacitive sensing circuitry or algorithm.

This can be applied to touch sensor designs using an Atmel application-specific device, or an Atmel microcontroller with the appropriate QTouch Library linked to your application code.

Adding proximity detection to a design provides many benefits:

- A more intuitive user interface
- Power savings – The ability to have an application start/stop based on a user's proximity to a device. The device can stay in sleep mode until a presence is detected, reducing power consumption and extending battery life.
- Make the application interact with human presence:
 - Mobile phone – use proximity sensing to reduce RF power when a mobile phone is placed near a person's head
 - Heating controller – use proximity sensing to activate control panel backlighting when a person approaches

This application note gives advice about the current capacitive touch technologies offered by Atmel, with respect to their usefulness as proximity sensors, and a mechanism to contain and control the E-field generated by the sensors.



Proximity Design Guide

Application Note QTAN0087



2. Sensing Technology

2.1 Introduction

The measurement circuit uses the Atmel patented charge-transfer (QT) technology to measure changes to a sensor as an object approaches. There are three sensing technologies available from Atmel:

- QTouch – Self capacitance, measured using V_{ih} of the sensor input/output (IO) pin
- QTouchADC – Self capacitance, measured using an internal Successive Approximation Register (SAR) analog-to-digital converter (ADC)
- QMatrix – Mutual capacitance, measured using an internal counter and comparator

Figure 2-1. Self Capacitance – QTouch and QTouchADC

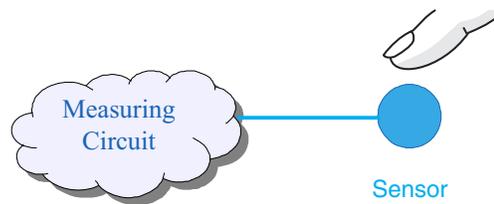
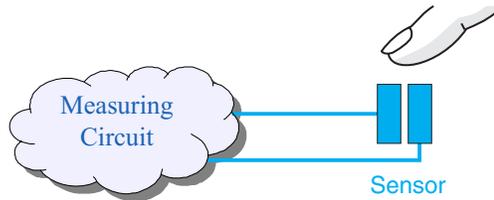


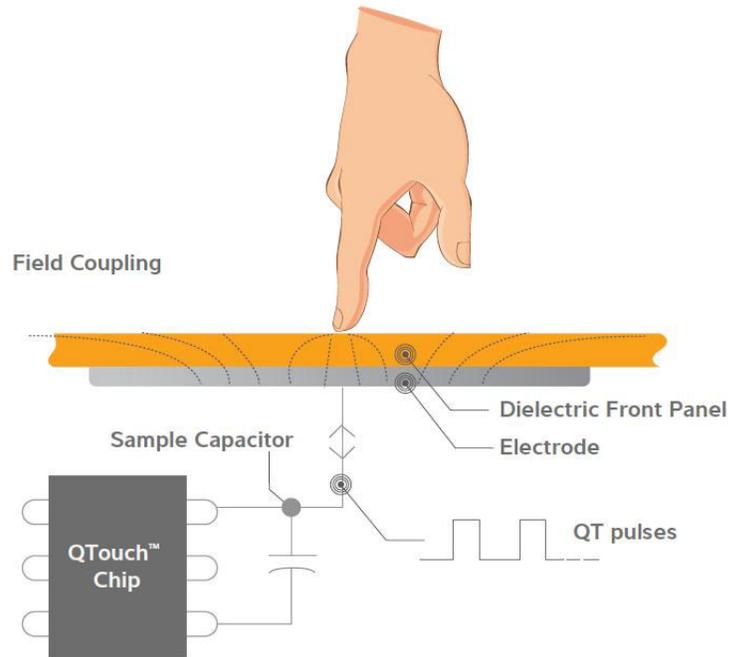
Figure 2-2. Mutual Capacitance – QMatrix



2.2 QTouch and QTouchADC

QTouch and QTouchADC devices charge a sense electrode of unknown capacitance to a known potential. The electrode is typically a copper area on a printed circuit board (PCB). The resulting charge is transferred into a measurement circuit. By measuring the charge after one or more charge-and-transfer cycles, the capacitance of the sense plate can be determined. Placing a finger on or near the touch surface introduces external capacitance that affects the flow of charge at that point. This registers as a touch.

Figure 2-3. QTouch and QTouchADC E-field



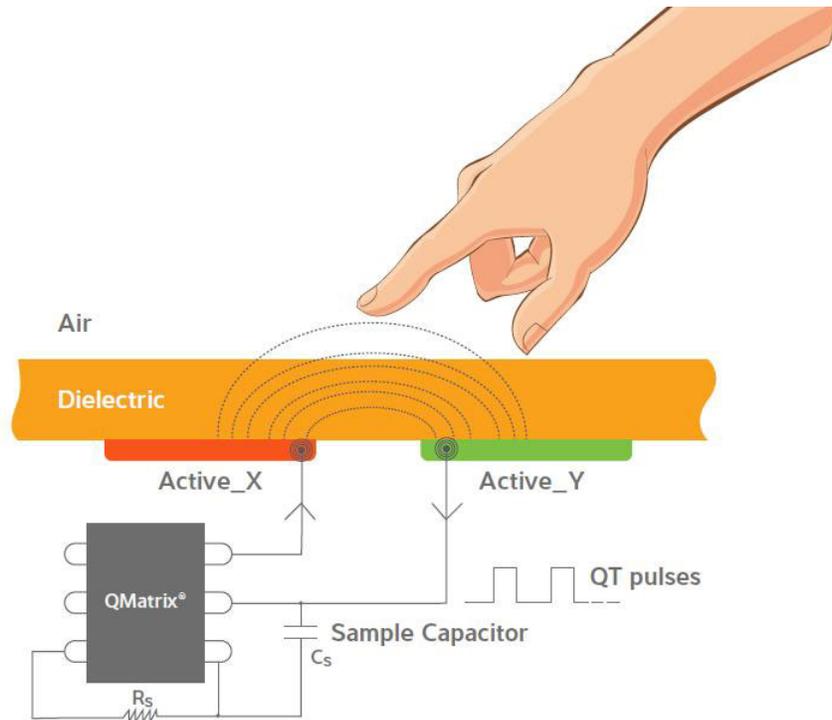
Both QTouch and QTouchADC use the self capacitance of a sensor. The E-field associated with self capacitance is projected away from the sensor into the air. The E-field seeks to couple to ground or an object in close proximity to sensor E-field.

- Electric field lines are projected into the air away from the sensor in an isotropic pattern (a field generated uniformly in all directions)
- Approximately 180 mm of proximity detection is possible with QTouch
- Greater than 250 mm of proximity detection is possible with QTouchADC
- Both parallel and sequential sensor measurements are possible
- QTouch requires two processor pins, one optional series resistor (used to reduce emissions conducted noise) and one capacitor per sensor
- QTouchADC requires one processor pin and one optional resistor (used to reduce emissions and conducted noise) per sensor
- Sensors are single layer and are not shape constrained

2.3 QMatrix

QMatrix uses the mutual capacitance of a sensor. The E-field associated with mutual capacitance is coupled closely to the X and Y portions of the sensors. The E-field couples to an object in close proximity to the sensor's E-field.

Figure 2-4. QMatrix E-field



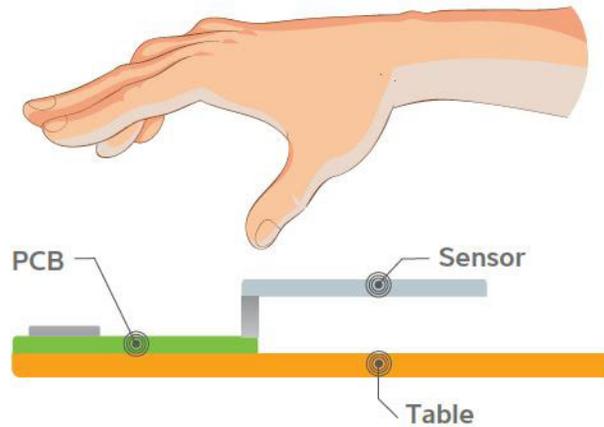
QMatrix uses a pair of sensing electrodes for each channel. One is an emitting electrode into which a charge consisting of logic pulses is driven in burst mode. The other is a receive electrode that couples to the emitter via the overlying panel dielectric. When a finger touches the panel the field coupling is reduced, and touch is detected.

- Field lines are tightly coupled inside the dielectric (XY sensor pattern). Not much of the field is projected into free space
- Approximately 50 mm of proximity detection is possible
- Useful in high humidity or damp environments where water droplets and moisture may collect over the sensors
- Sensors are arranged in a X by Y format, lowering pin count for applications that require a large number of sensors
- Sensors are dual layer and not shape constrained. However, the gap between X and Y layers is dependent upon the dielectric material and its thickness

3. Proximity Sensing

3.1 QTouch

Figure 3-1. QTouch Proximity Sensing

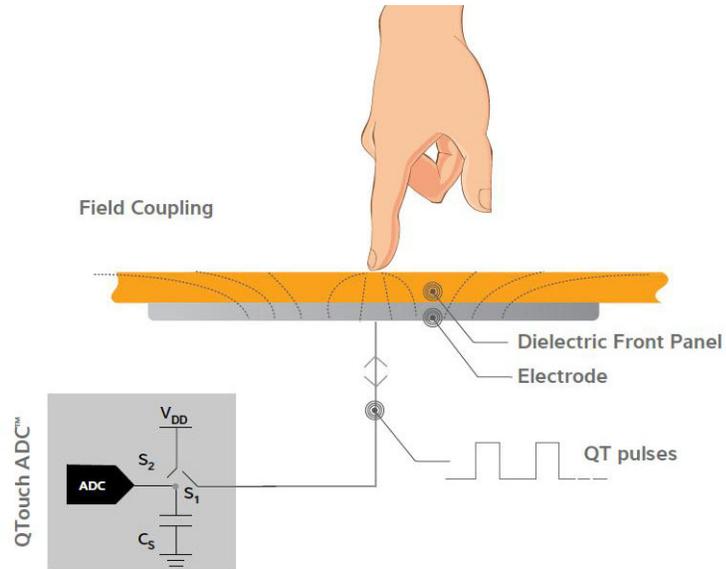


QTouch proximity sensors are touch keys deliberately made over-sensitive. This can be accomplished using a combination of the following:

- Make the sensing electrode larger
- Increase the value of the sampling capacitor C_s
- Decrease the touch detection threshold
- Reduce ground loading effects

3.2 QTouchADC

Figure 3-2. QTouchADC Proximity Sensing



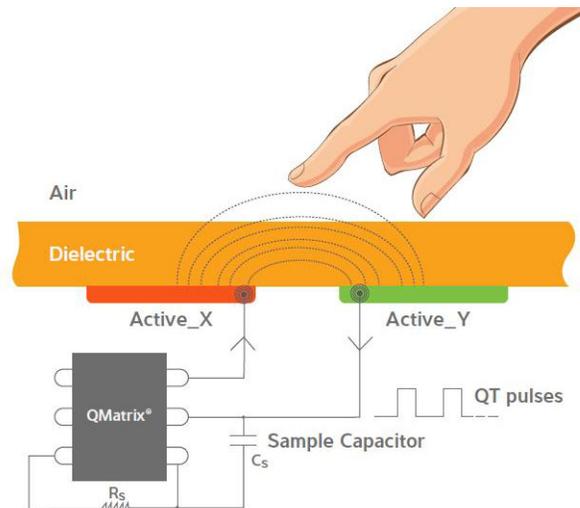
Similar to QTouch, QTouchADC proximity sensors are touch keys made over-sensitive. This can be accomplished using a combination of the following:

- Make the sensing electrode larger
- Increase sampling resolution or over-sampling rate
- Decrease the touch detection threshold
- Reduce ground loading effects

QTouchADC is the better than QTouch for proximity sensing due to its digital oversampling feature.

3.3 QMatrix

Figure 3-3. QMatrix Proximity Sensing



Proximity sensing with QMatrix can be accomplished using a combination of the following:

- Make the sensing electrode larger
- Increase the spacing (gap) between the X and Y portions of the sensor
- Increase the value of the sampling resistor R_s
- Decrease the touch detection threshold
- Increase the sensor burst length
- Reduce ground loading effects

Self capacitance sensors provide better proximity ranges than mutual capacitance sensors due to their projected E-Field.

4. Proximity Sensors

Sensors for proximity sensing are not as critical as is generally assumed. Sensors can be as simple as a single piece of wire hanging from the sensor or a simple trace running along a horizontal or vertical section of a PCB.

When designing a proximity sensor the following points should be kept in mind:

- The larger the sensor the greater the range (but there is a point of diminishing return)
- System ground-loading should be minimized in the vicinity of the proximity sensor and its trace back to the controller
- Loop sensors are favorable to a flooded fill or plane. Loop sensors yield results that are equivalent but leave space on the board that can be used for component placement
- Sensors can be covered but the proximity detection distance may be decreased, depending on the material used to cover the sensor

For detailed information on proper sensor design, refer to QTAN0080 –*Touchscreen Sensor Design Guide*.

Experiments have been conducted on various types of PCB-based sensors:

- Bar
- Patch
- Loop
- Vertical or horizontal PCB trace
- Self-capacitance sensor
- Mutual-capacitance sensor

Figure 4-1. Examples of a Bar and Patch Sensor Implemented on a PCB



Figure 4-2. Loop Sensor, Made Using 12.7 mm Copper Foil Tape

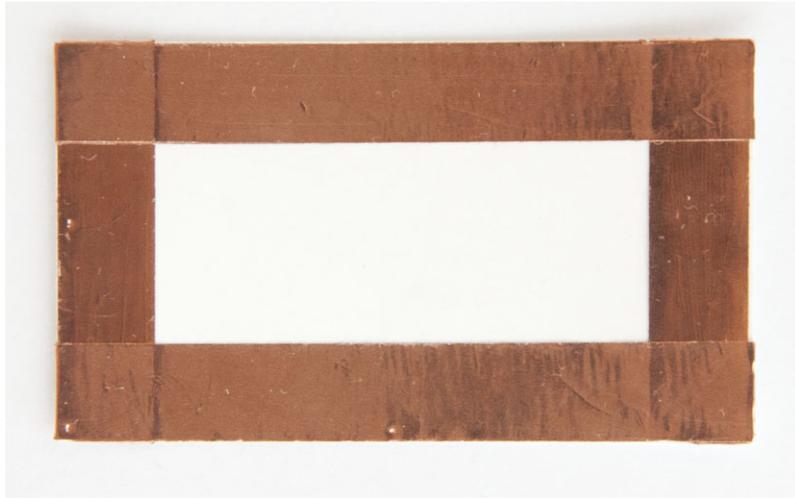
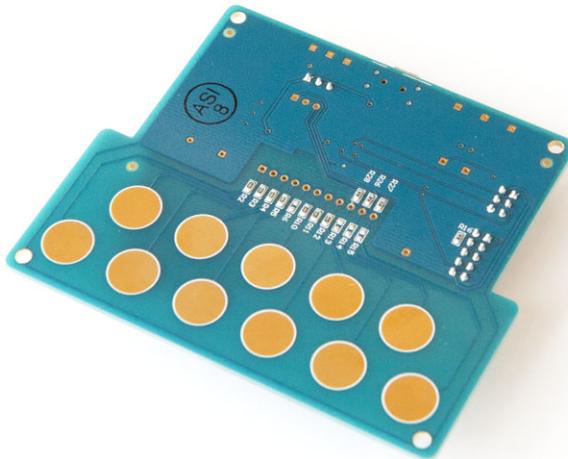


Figure 4-3. Eleven-key Self-capacitance Layout



In [Figure 4-3](#) any of the keys can be made to act as a proximity sensor.

5. Grounding

Proximity sensors are highly sensitive to ground loading as it adds directly to the natural capacitance of the sensor, resulting in a decrease of the sensitivity (gain) of the sensor. Ground, in this case, is anything that looks like an AC ground from the sensor view. It is recommended to keep grounding as far away from the proximity sensor and the connecting trace of the sensor - this connecting trace is essentially an extension of the proximity sensor.

When a ground plane is absolutely necessary, a hatched pattern is recommended which is common practice for most standard QTouch layouts. When implementing proximity there are some minor variations that have been proved to be best practices for achieving further proximity ranges:

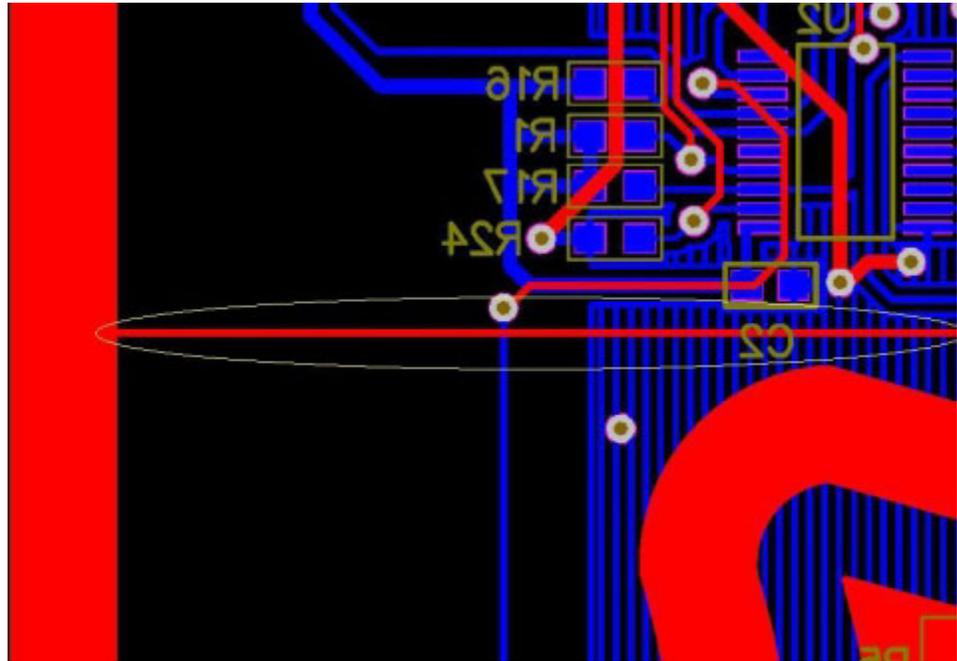
1. Avoid ground planes if possible. If necessary, for the sensitivity of the buttons, sliders, or wheels, they are acceptable – just keep them away from the proximity sensor or at a minimum separate the proximity sensor and its trace with a driven shield (See “[Driven Shield \(E-field Directivity\)](#)” on page 12.).
2. Use a 33% mesh fill.
3. Use 45° angles in the mesh.

If a ground plane is used, the ground should be connected directly to the controller VSS pin to provide a clean ground having no relative voltage spikes on it. Also, the proximity sensor and its connection back to the processor should be separated by the maximum distance of air or thickness of insulation as possible.

When designing with proximity sensors, or any QTouch product, remember that ground areas near the sensor increases the capacitive loading resulting in a loss of sensitivity. Although this capacitive loading effect can be compensated for by increasing CS when using QTouch, increasing the oversampling rate when using QTouchADC, or increasing Rs when designing with QMatrix, an overall decrease in signal-to-noise ratio (SNR) and an increase of power consumption will occur.

A proximity sensor is located along the left side of the figure below. As you can see there is no ground plane near the proximity sensor – good practice. However a portion of the sensor trace runs directly over the meshed ground plane. Even though there is separation between the trace and the meshed ground plane (each on separate PCB layers) the proximity detector's range will be reduced some degree due to signal absorption by the ground plane. In addition the ground plane is meshed on a vertical instead of the recommended 45°. In this portion of the PCB design the proximity sensors trace is at a right angle to the ground plane traces - standard practice for reducing signal cross coupling, however there is enough coverage by the ground plane to cause signal absorption.

Figure 5-1. Example of Poor Routing 1



If we continue to follow the proximity sensor trace back to the controller, it takes a left turn and runs directly on top of a ground plane trace and parallel to another signal trace. Both the ground plane and signal trace running parallel to the proximity sensor trace will absorb some of the sensor signal resulting in a slight loss of detection range.

Figure 5-2. Example of Poor Routing 2



Even though there are a few design rule violations in the above example layout, the resulting proximity detection range was found acceptable for the intended application.

6. Driven Shield (E-field Directivity)

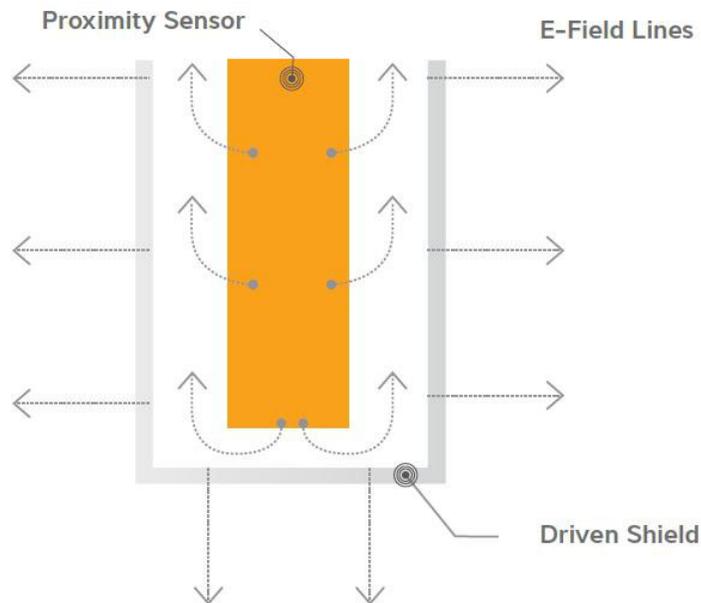
A standard self-capacitance proximity sensor, based on QTouch or QTouchADC, generates an isotropic E-field resulting in 360° of detection. In addition, design requirements might place the proximity sensor directly over, or in close proximity to, ground or a metal object. The E-field generated, regardless of the type and shape of sensor used, tends to be isotropic, therefore proximity will be detected around 360° of the device.

Basic physics states that electric fields of the same polarity repel each other. This is also true with the Atmel capacitive-sensing technologies. The trick is how to control this E-field.

As seen in [Figure 6-1](#), the center copper plate is the proximity sensor, and the outer loop (driven shield) generates an electric field of the same polarity as the proximity sensor. The proximity sensor E-field is repelled by the driven shield E-field when they are of equal polarity, phase and amplitude (magnitude).

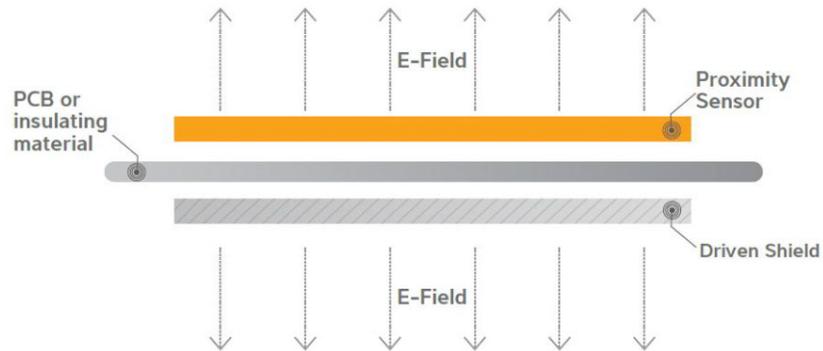
In some applications, such as when the proximity sensor is near metal or ground, the driven shield should be driven with a signal of the same polarity and phase as the proximity sensor, but with greater amplitude or magnitude. This is easily accomplished with a non-inverting amplifier.

Figure 6-1. E-field Directivity – Isotropic



In an application where it is desired to have the proximity sensor E-field project from the front (component) side of the device, the proximity sensor E-field can be blocked from the rear of the device by placing a driven shield below the proximity sensor. This is shown in [Figure 6-2 on page 13](#).

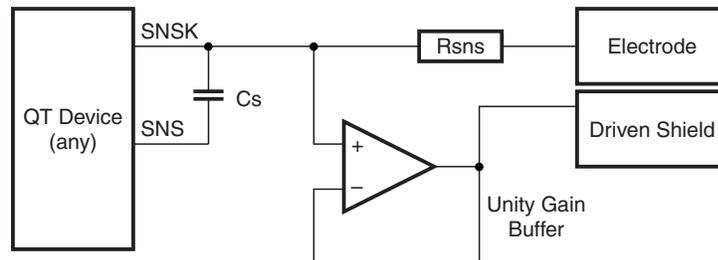
Figure 6-2. E-field Directivity – Front



The driven shield and proximity sensor must be electrically insulated from each other. If the proximity sensor is located on one surface of a PCB, the driven shield must be placed on a surface directly below the proximity sensor. This can be the bottom layer of a double-sided PCB or any of the inner layers of a multi-layer board. In either case, the driven shield must be of a size equal to or greater than the proximity sensor.

Figure 6-3 shows a QTouch-based driven shield. This circuit may also be used for QTouchADC, the only difference in the circuit would be C_s – it is not required when using QTouchADC.

Figure 6-3. QTouch-based driven shield



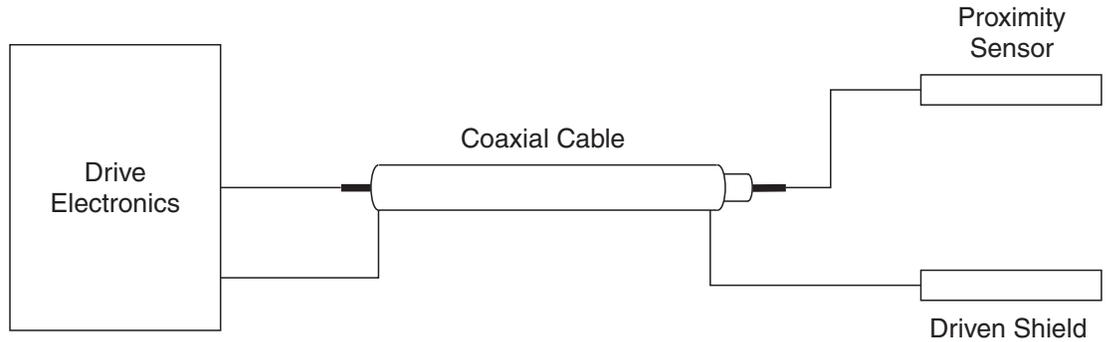
Wires or PCB traces that connect the proximity sensor to the drive electronics are as much a part of the proximity detection circuit as the proximity sensor. Anything that can be detected by the proximity sensor is also detected by the wires or traces connected to the drive electronics. This can be a problem when the drive electronics are remotely located from the proximity sensor. An example of such a situation is where a proximity sensor is located in the steering column of an automobile. Two problems are presented by this scenario:

- Signal absorption by the steering column and other wiring in close proximity to the proximity sensor lead resulting in lower signal deltas
- The steering column acting as an unintended proximity detector

When the proximity sensor is located some distance away from the drive electronics, or the connecting wire must be run within a bundle of wires or a metal enclosure, using a driven shield to isolate the proximity sensor interconnect becomes necessary.

In [Figure 6-4](#), a 1.2 m length of RGS-178 coaxial cable is used to connect the drive electronics to the proximity sensor. The internal conductor is used as the connection between the drive electronics and the proximity sensor. The coaxial cable braided shield is driven with a buffered version (same amplitude, phase, and polarity) as that of the proximity sensor. This effectively constrains the proximity sensor E-field inside the coaxial cable and eliminates false detections based on metal objects or human presence near the proximity detector wiring.

Figure 6-4. E-field Directivity – Within the Coaxial Cable



7. Maximum Proximity Detection Range Considerations

There are a few items to consider when designing for maximum proximity detection range:

- It is important to keep in mind the effects of noise when designing proximity sensing circuits. There will be a trade-off between proximity detection range and overall system stability or immunity to noise.
- Proximity range varies significantly depending upon system design and application.
- Unshielded sensors improve the proximity sensor sensitivity and resultant detection range; however the field will span a full 360°. There is a high probability of unintended triggers within the 360° field. For example, a wall-mounted control panel with a proximity sensor can be triggered by someone approaching from behind the wall. This can easily be prevented by introducing a ground shield (which will reduce sensitivity), or driven shield in to the design.

References

- QTAN0080 – *Touch Sensors Design Guide*

Revision History

Revision No.	History
Revision AX – November 2011	<ul style="list-style-type: none">• Initial release of document.
Revision BX – March 2012	<ul style="list-style-type: none">• Added “Grounding” and “Maximum Proximity Detection Range Considerations” sections.

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