Application Report
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Capacitive Proximity Sensing Using FDC2x1y

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ABSTRACT

Capacitive proximity sensing is a key feature for many smart devices and equipment. In this application note, we review several important advantages of our new capacitive sensing chip FDC2x1y, which is based on an LC resonator. They include its high resolution, immunity to electro-magnetic interference (EMI), and tolerance of high offset capacitance. We also provide some guidelines in sensor design by characterizing the relationship between detection range and sensor size, using a square copper plate as the sensor. The simplicity and flexibility of the sensor allows it to be easily incorporated into various systems that require proximity sensing.

Texas Instruments' family of LC-based capacitive sensors include the FDC2214, FDC2212, FDC2114, and FDC2112. In this application note, we will use the general reference FDC2x1y, where x and y follow the conventions in this table:

x		Y	
1	2	2	4
12-bit with optional 4-bit gain	28-bit max	2-channel	4-channel

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1 Introduction to LC-Based Capacitive Proximity Sensing

Texas Instruments' new capacitance-to-digital converter (FDC) is based on an LC resonator sensor. An inductor and a capacitor are attached to the two inputs of each channel. A conductive sensor plate, e.g. copper, can be attached to either node of the LC tank to serve as the capacitive sensor. In active mode, the device excites a half-sine wave on to the LC tank and measures its oscillation frequency. As a target, e.g. a human hand, approaches the sensor plate, it causes a change in capacitance of the system, which translates to a change in frequency that can be measured. Note that the sensor represents a ground-referenced capacitor.

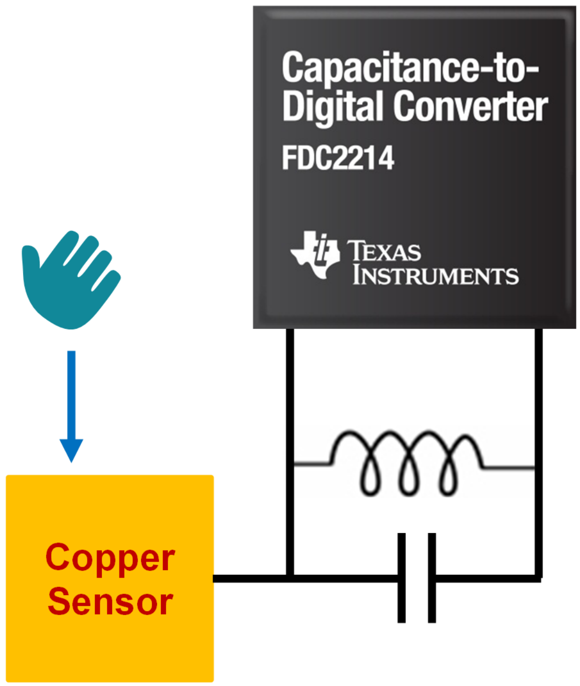

Figure 1. Schematic of Capacitive Proximity Sensing Using FDC2214. Only one channel is shown.

In addition to the capacitive sensor plate, the LC resonator consists of a fixed inductor and fixed capacitor. These components set the baseline oscillation frequency of the sensor. The resonator frequency can be as high as 10MHz, whereas in more traditional capacitive sensing the operating frequency is typically tens of kilo-hertz.

2 Advantages of LC-Based Capacitive Sensing

2.1 High Resolution

The family of FDC chips has a maximum resolution of 28-bit (FDC2214 and FDC2212). The ultra-high resolution makes it possible to perform precise measurement into the deep sub-femto-farad (sub-fF) range, therefore extending the capabilities of many applications. For example, one common application of capacitive sensing is proximity detection, where the detection range is limited by the minimum capacitance that can be measured. With deep sub-fF measurement capability, this new device can achieve longer detection range than earlier generation capacitive sensing devices. This sensitivity is unmatched by other, conventional capacitive sensor products. It can be achieved using either surface mount chip inductors, or inductors constructed from a PCB coil, giving the engineer flexibility in circuit design.

To illustrate the resolution of the FDC221y, the following table represents a comparison of the measurement results using two types of inductor. The first is a two-layer PCB coil. The second is a chip inductor in a 1210 package. The PCB coil has better performance in terms of resolution. However, the chip inductor has a much smaller footprint and provides enough resolution for most applications. This chip inductor is the default inductor used on the evaluation module (EVM), which is available for purchase at http://www.ti.com/tool/FDC2214EVM.

Table 1. Comparison of Resolutions of PCB Coil and Chip Inductor

Inductor	PCB coil [18.5uH]		CMH322522 [18uH]	
Capacitor [pF]	20	330	20	330
1σ resolution [fF]	0.08005	0.21663	0.21825	0.45886
3σ resolution [fF]	0.24014	0.64989	0.65474	1.37658
6σ resolution [fF]	0.48028	1.29979	1.30948	2.75317

The table shows that using a PCB coil, the 1σ resolution of the FDC221y can be as low as 0.08fF, and even a more conservative 3σ threshold still results in 0.24fF resolution.

2.2 EMI Immunity

A very common concern for capacitive sensing is EMI from surrounding noise sources. For example, a typical fluorescent lamp generates broadband EMI noise that can be picked up by a metal plate. In traditional capacitive sensing, the change in capacitance is obtained by measuring the amount of charge transfer. EMI adds charge noise and therefore would be counted erroneously. An LC based FDC is more immune to EMI noise because the LC tank is an inherent band-pass filter that rejects broadband EMI noise, so most of the broadband signal will be filtered out. Figure 2 shows a comparison between the FDC2214 and a traditional capacitive sensing chip that uses charge-transfer. In this case the noise source is a fluorescent light.

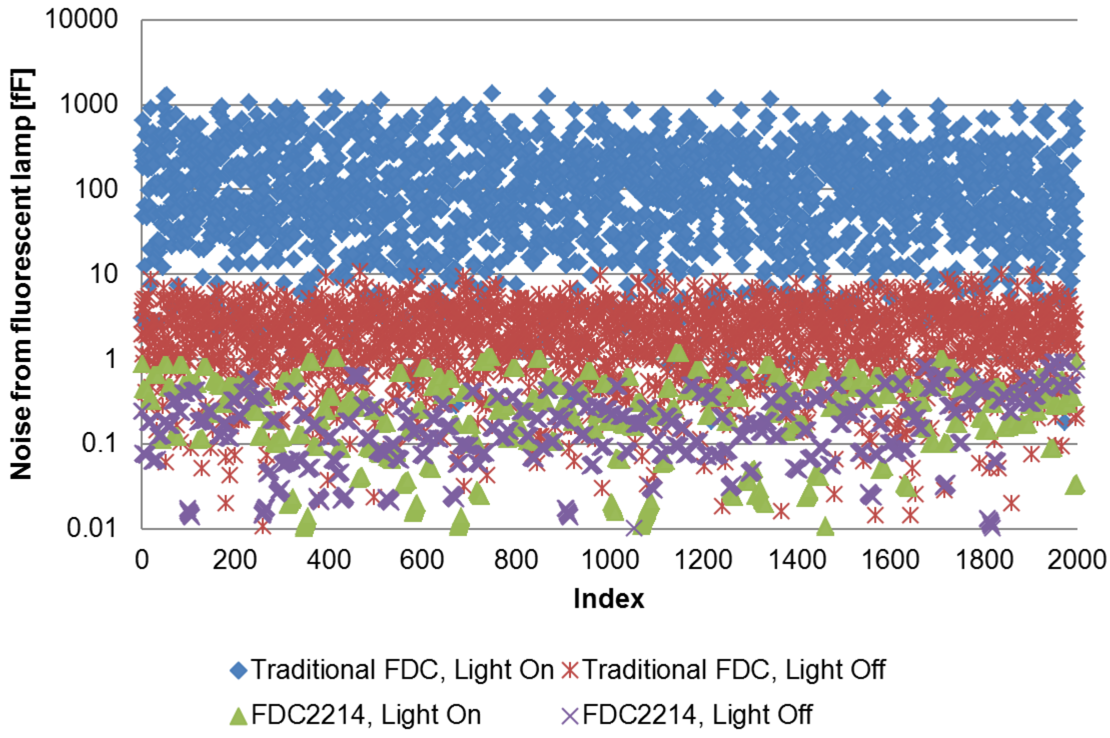

Figure 2. Comparison of EMI Immunity of FDC2214 and a Traditional FDC

2.3 Tolerance of Large Offset Capacitance

In traditional capacitive sensing, there is usually a very stringent limit on the amount of offset capacitance that the chip can handle. For example, traditional capacitive sensors may have a limit of 10 to 150 pF. Not only does this limit the dynamic range of capacitance to be measured, it also significantly restricts the flexibility of sensor configurations.

In the FDC2x1y, the base frequency is set by the LC tank. The sensing plate is not part of the LC tank. Although some parasitic capacitance does couple into the tank and affect the frequency somewhat, it will not cause significant deviation from the base frequency. As a result, a much larger offset capacitance can be tolerated.

3 Sensor Characterization

In this application note, square copper plate sensors are used to characterize the relationship between detection range and sensor area. In addition, in various systems it is quite common to have some kind of ground close to the sensor. Therefore the effect of a piece of grounded metal in the vicinity of the sensor plate is also studied.

To characterize the relationship between sensitivity and sensor size, a proximity test was performed with the FDC2214 for various sensors with a human hand acting as the target. The hand starts from far away and gradually approaches the sensor. When the output signal changes by more than the peak-to-peak noise, it is considered a positive detection. The distance between the hand and sensor is recorded in Figure 3. As expected, the detection range increases as sensor size increases.

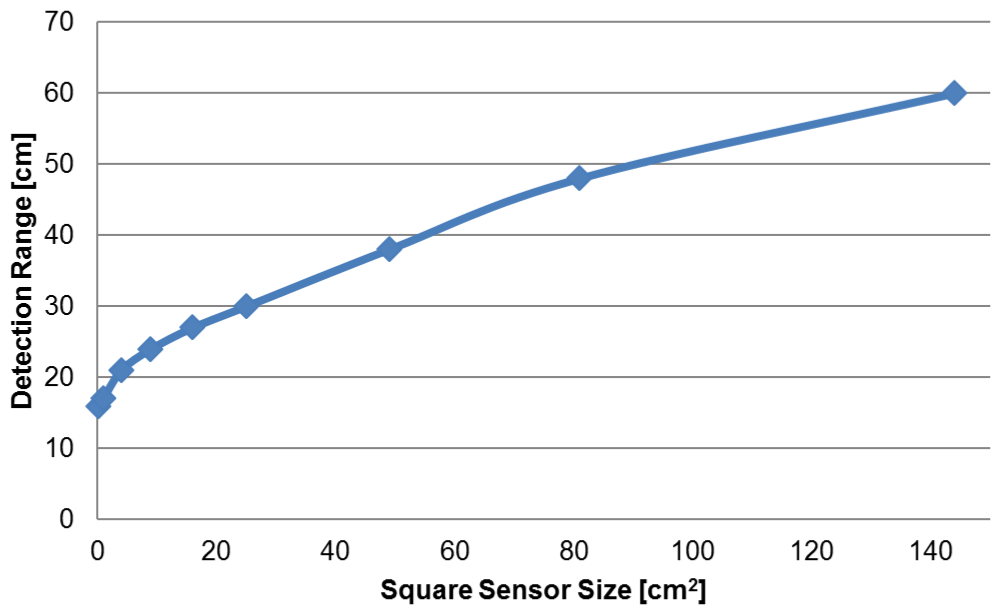

Figure 3. Detection Range vs. Square Sensor Size Using FDC2214

Figure 4 shows the detection range as a function of the separation between a 7x7cm copper sensor and a ground plane, which is directly underneath the sensor and has the same area as the sensor. The gap is filled with acrylic blocks (ε_r = 2.7 to 4.5). When the separation between the sensor and ground plane is small, sensitivity is significantly reduced, because the electric field line distribution in space is significantly disturbed by the presence of ground. Also, the capacitance between the sensor and ground plane is large. As a result, the ratio of the change in capacitance to the total capacitance is small. As the gap increases, both these effects diminish, and sensitivity increases, eventually approaching the limit that can be achieved without the ground plane.

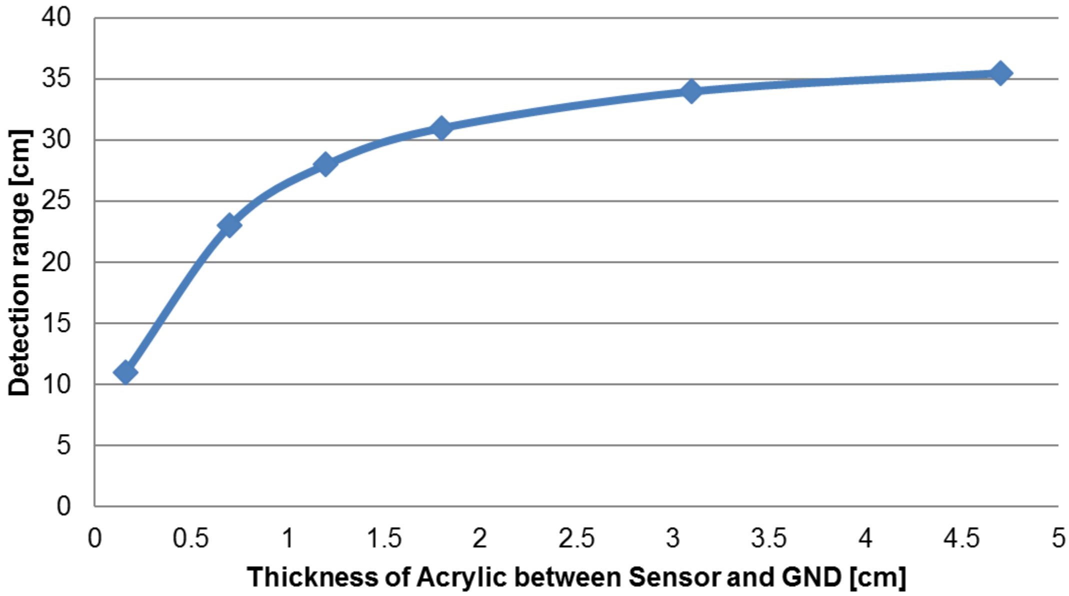

Figure 4. Detection Range vs Thickness of Acrylic Between Sensor and Ground Plane

4 Common Applications

Depending on the nature of the target, capacitive proximity sensing applications can be classified into two main categories.

Table 2. Sample Applications

Detection Target	Sample Applications
Human	System wakeup
	Door activation
	Simple gesture sensing
Other objects (e.g. wood, plastic, etc.)	Collision warning and emergency stop for doors, robots, or other movable equipment.

Comparing these two categories of targets, sensitivity of human is certainly higher than that of non-conductive materials such as wood and plastic. Future application notes will address use scenarios that involve a variety of materials and sensor configurations.

5 Summary

In this application note, we reviewed the important advantages of Texas Instruments' FDC2x1y and presented data that shows the relationship between detection range and sensor size using a simple square copper sensor. It should be noted, however, that the sensitivity data is specific to the sensor configurations used in the measurements. It should serve as a general guideline, but may not be exactly the same in another system. The detection range will depend on the system configuration. For example, grounded metal objects in the vicinity of the sensor and other sources of parasitic capacitance will affect sensitivity. In addition, the surrounding environment parameters, such as humidity, also affect the capacitance between the target and sensor. Last but not least, there is human-to-human variation. Thus, for any capacitive proximity sensing application, one must take these variables into consideration in designing the sensor and system.

Please visit http://www.ti.com/lsds/ti/analog/sensors/overview.page for more information on Texas Instruments' sensing solutions.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Original (October 2015) to A Revision	Page
• Added epsilon symbol	4

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