Capacitive Sensing: Ins and Outs of Active Shielding

David Wang

ABSTRACT

Capacitive sensing has become a popular alternative to optical sensing due to the advantages it possesses in proximity/gesture detection, material analysis, liquid-level sensing, and more. Although capacitive sensing has benefits including very low power consumption, sensing different types of materials, and sensing range, there are certain aspects of using the technology that require attention. For example, parasitic capacitance, external interference, and temperature/humidity changes should be addressed in system design. Fortunately, there are ways to help mitigate these factors so it does not affect the capacitance measurement readings. One of those ways is through active shielding. The FDC1004 features active shield drivers which can reduce EMI interference and help focus the sensing field of a capacitive sensor.

This application note introduces the concept of active shielding, use cases for how shielding can help mitigate parasitic and environmental interference factors, and how to implement it with the FDC1004 in a capacitive sensing design.

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1 Active Shielding Overview

One source of interference in capacitive sensing is parasitic capacitance to ground along the signal path between the sensing device pins and the electrode sensor. This interfering capacitance can be represented by any part of the circuit, or a physical object, that causes an unintended alteration in the electric field. A simple way to mitigate this problem is an active shield. The shield driver is an active signal output that is *driven at the same voltage potential of the sensor input* so there is no potential difference between the shield and sensor input. Any external interference will couple to the shield electrode with minimal interaction with the sensor electrode.

There are several benefits to using a shield in capacitive sensing applications. Using a shield:

- Directs and focuses the sensing zone to a particular area
- Reduces environmental interferers
- Reduces and eliminates parasitic capacitances
- Eliminates temperature variation effects on the ground plane.

The following sections address these benefits in more detail.

2 Benefits of Active Shielding in Capacitive Sensing Solutions

2.1 Simulating Directivity with a Shield

Figure 1 displays the electric field lines between a channel electrode (CH) and a ground electrode (GND) in a parallel fingers topology. CH is excited with a voltage waveform while the GND is a fixed ground reference. The electric field lines (red lines) start from the higher voltage potential electrode (CH) and end at the lower voltage potential electrode (GND), and are symmetric above and below the sensor plane. With no shield, the sensor CH detects objects above and below the sensor and depending on the application, detection above and below may not be acceptable and can misrepresent the capacitance measurements relative to a target. By using a shield sensor underneath the CH and GND electrodes, the field lines below are essentially blocked and only the top field lines have a defined path. This example is somewhat simplified and does not include fringing effects .

No Shield
Sensor detects objects above and below sensor

Shielded
Sensor detects objects only above
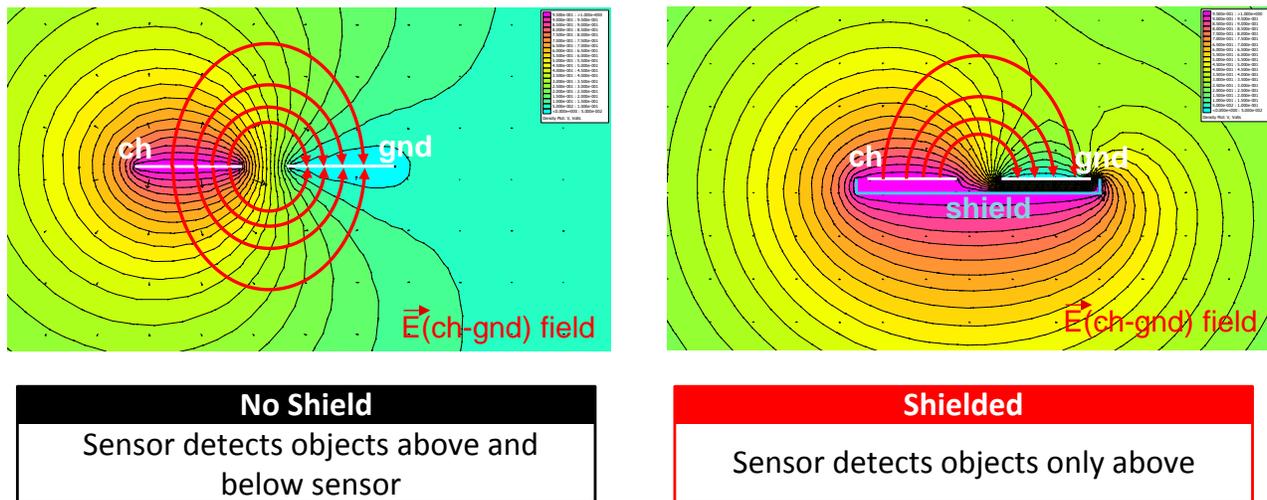
Figure 1. Electric Field Lines Between CH and GND - no Shield

The shape and position of the shield relative to the sensor is an important factor when designing sensors. The sensing angle without a shield picks up any stray interference within the field-line vicinity. The sensing angle with a shield is dependent on how large the shield is compared to the sensor and how close the shield is to the sensor. Figure 2 illustrates how the sensor is focused by the use of a shield. An experiment was performed with 4 different shield configurations and observations can be found in the Shielding Configuration Experiment section.
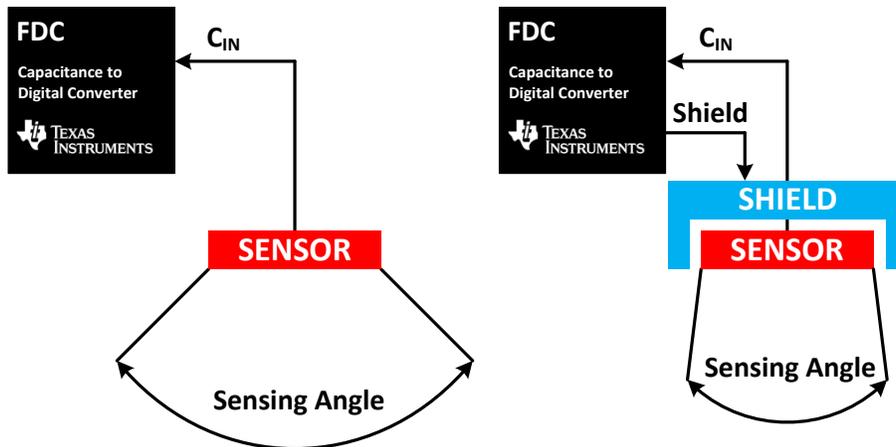
Figure 2. Direct/Focusing the Sensing Area

2.2 Environmental Interferers

The shield wrapped around the signal path between the sensor and the input pin to the device (FDC1004) blocks environmental interferers from affecting the capacitance measurements. Environmental interferers include the human hand, radiated electromagnetic signals, and noise from other electronic devices. Since the shield has the same drive signal as the sensor, any interference is picked up along the shield line, while the sensor line is unaffected. Figure 3 visually demonstrates how a sensor line without shielding could register corrupted data from interferers.
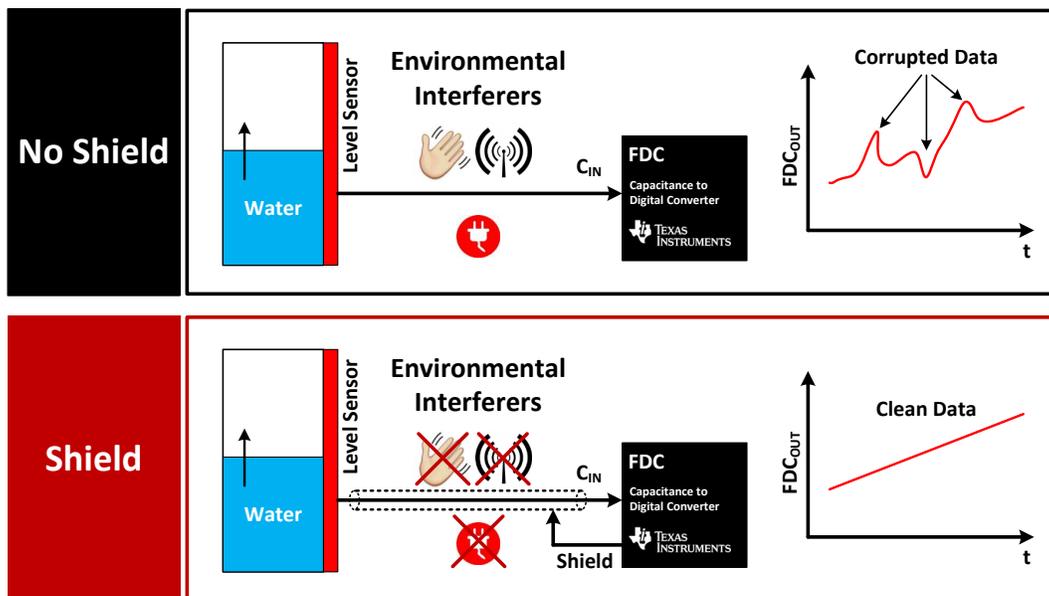
Figure 3. Shielding to Mitigate Environmental Interferers

2.3   Parasitics

A capacitive sensing design will most likely be implemented on a rigid printed-circuit board (PCB). Good system-level design principles require a ground plane to help reduce noise and increase signal integrity. For capacitive sensing applications, a ground plane becomes an issue because it creates a termination source for electric field lines even though the ground plane is not where the intended sensing area should be. If the sensor is on the top layer and the ground plane is on the bottom layer of a PCB (as shown in Figure 4), fringing effects occur and cause the capacitance measurements to include the capacitance path from the sensor to the ground plane. This large ground parasitic capacitance can be reduced significantly with a shield plane between the sensor and ground plane. In the ideal case, the shield eliminates all influence from the ground plane but because of fringing effects, a small parasitic ground capacitance amount is seen in the measurements. The shield size would have to be much greater than the size of the sensor and ground plane so the field lines on the edges are much weaker compared to the overall capacitance measurement.
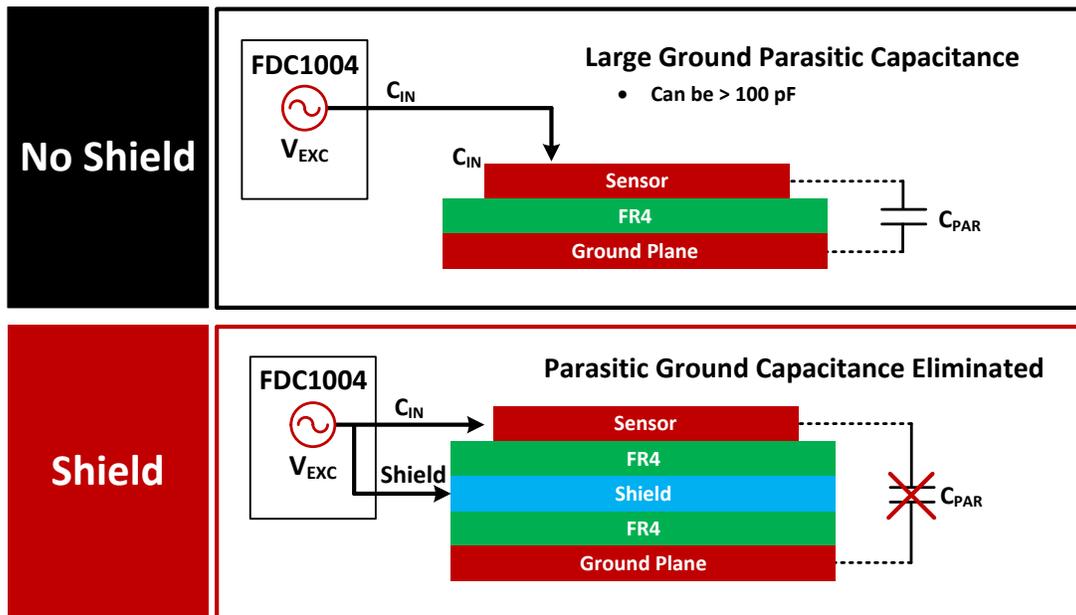
Figure 4. Ground Plane Effects With and Without Shielding

2.4   Temperature Effects on Ground Planes

Temperature is a factor that causes the parasitic ground plane capacitance to vary in addition to the initial parasitic capacitance offset it introduces into the measurements. These variations are seen as drift in the conversion result and may significantly compromise the system accuracy. Inserting a shield plane between the sensor and ground plane will help mitigate the influence of the parasitic ground plane capacitance from the measurements.
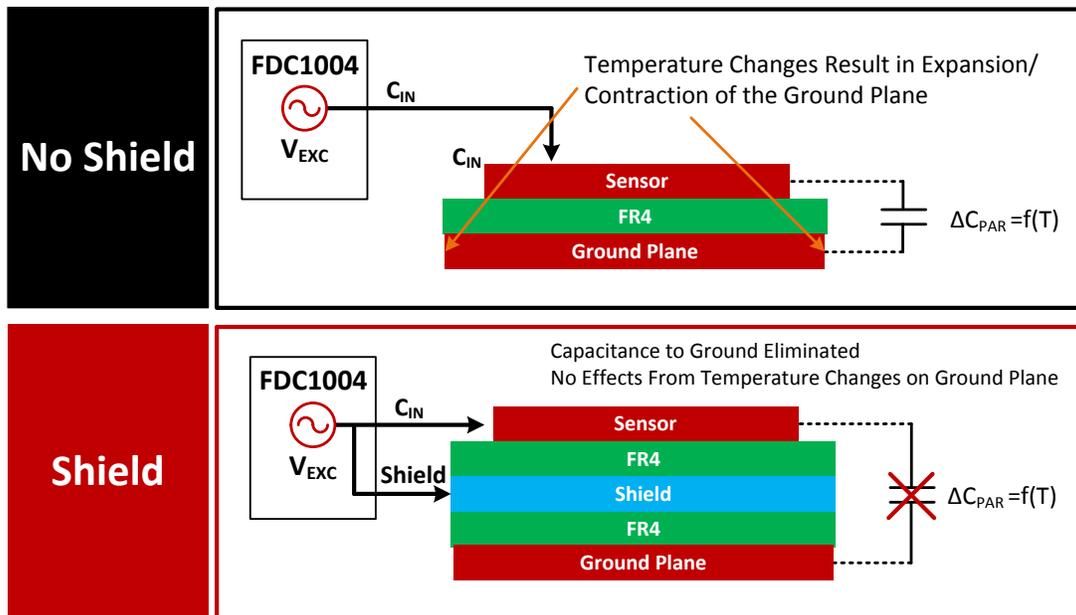
Figure 5. Temperature Effects on Ground Planes

3   Typical Implementation With the FDC1004

3.1   Single-Ended Measurement

The FDC1004 has four channel sensor inputs (CIN1–4) and two shield driver outputs (SHLD1–2). For single-ended measurements, SHLD1 and SHLD2 are internally shorted (if CAPDAC is disabled) and can be paired with any of the four channel sensor inputs shown in Figure 6. If the CAPDAC is used with single-ended measurements, then SHLD2 is floating, as shown in Figure 7.
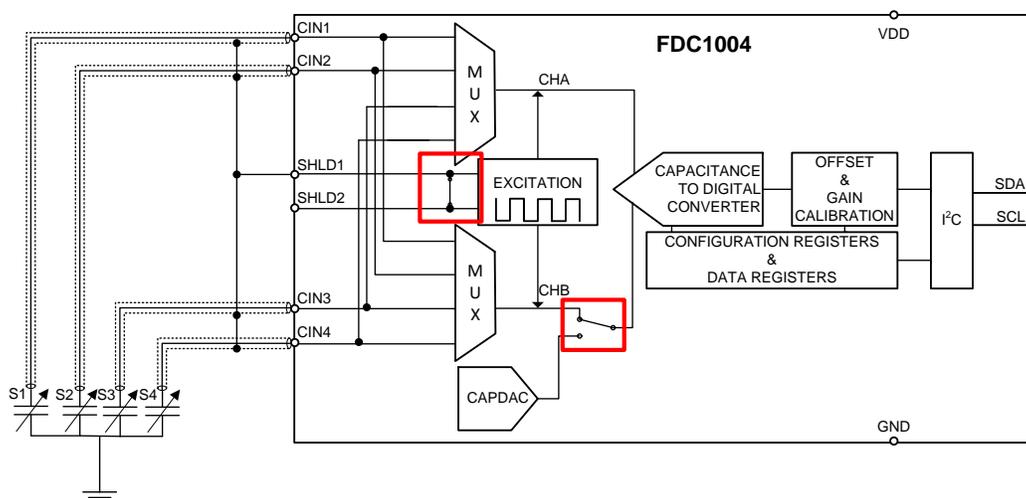
Figure 6. Shielding in Single-Ended Configuration With CAPDAC Disabled
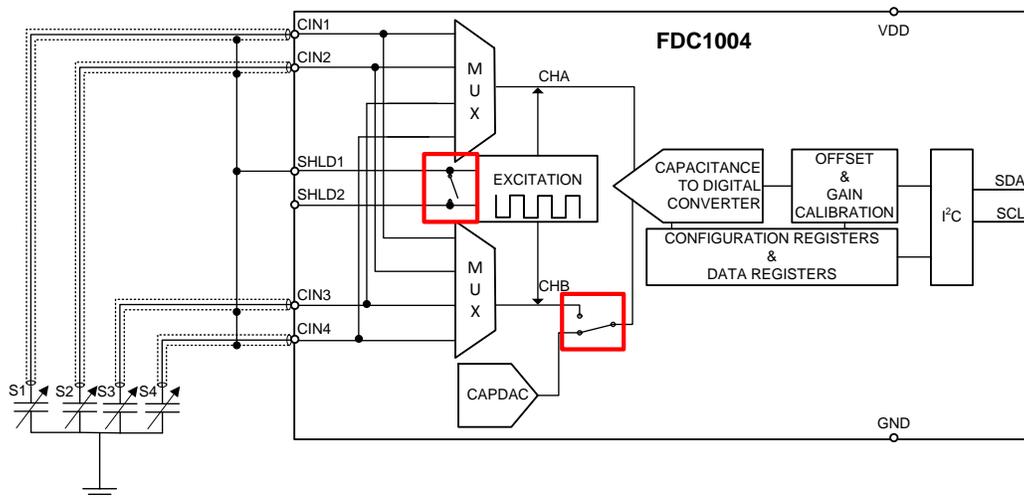
Figure 7. Shielding in Single-Ended Configuration With CAPDAC Enabled

3.2 Differential Measurement

For differential measurements, SHLD1 is assigned to CINn and SHLD2 is assigned to CINm, where n < m. For example, in the measurement CIN2–CIN1, where CHA = CIN2 and CHB = CIN1, SHLD1 is assigned to CH1 and SHLD2 is assigned to CIN2. In this configuration, the CAPDAC is disabled.
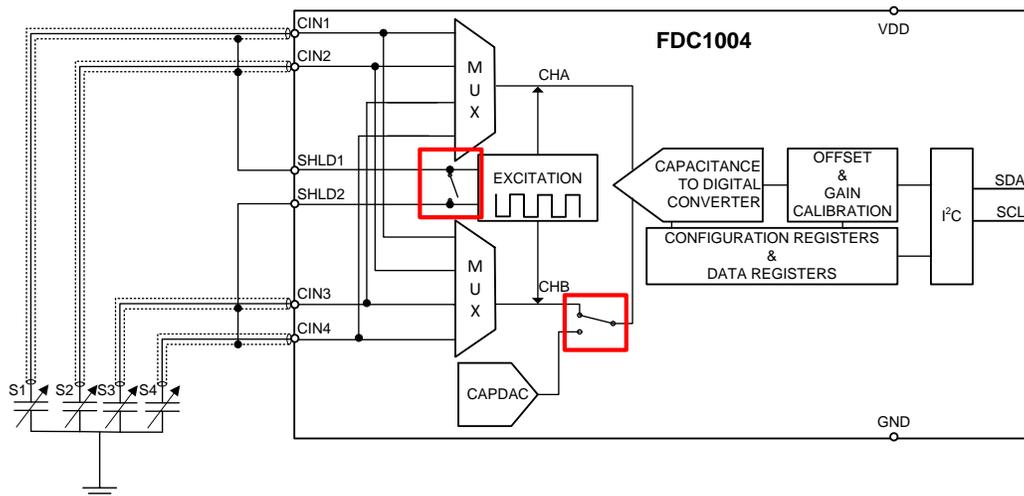
Figure 8. Shielding in Differential Configuration, CAPDAC Disabled

4   Shielding Configuration Experiment

An experiment with four different shielding configurations was performed to determine what kind of relationship shielding has with directivity, sensitivity, and mitigating interference. The sensor topology employed here is mainly used for proximity and gesture recognition applications (grounded targets). The four configurations, shown in Figure 9 and Figure 10, were as follows:

1. CIN1 electrode only
2. Shield1 the same size as CIN1 and directly underneath
3. Shield1 larger (200% larger) than CIN and directly underneath
4. Shield1 Ring added on the same plane as CIN1 with Shield1 underneath (same as configuration 3).
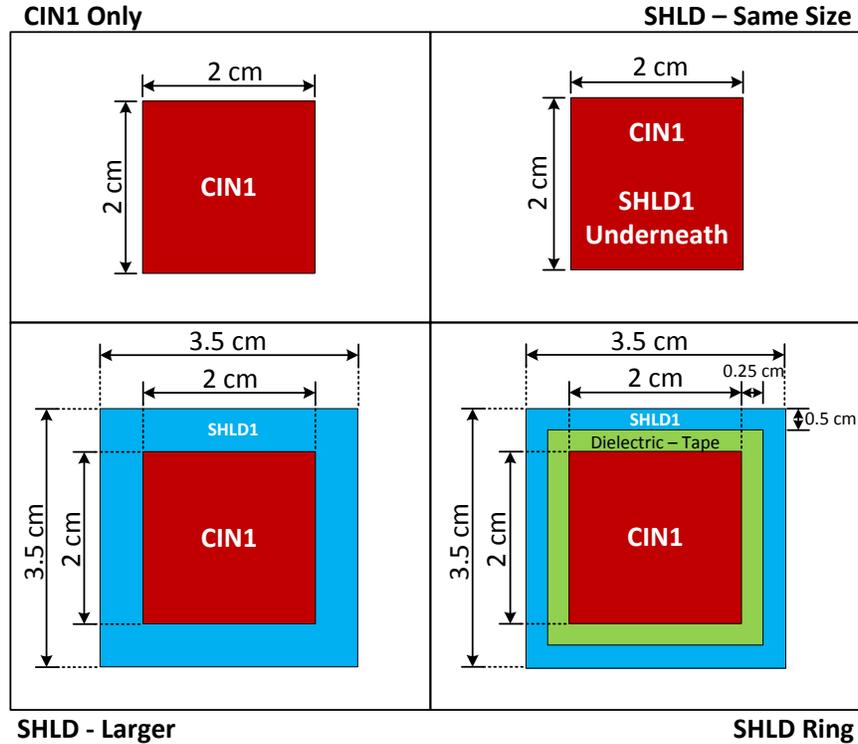
Figure 9. Sensor Layouts - Top View
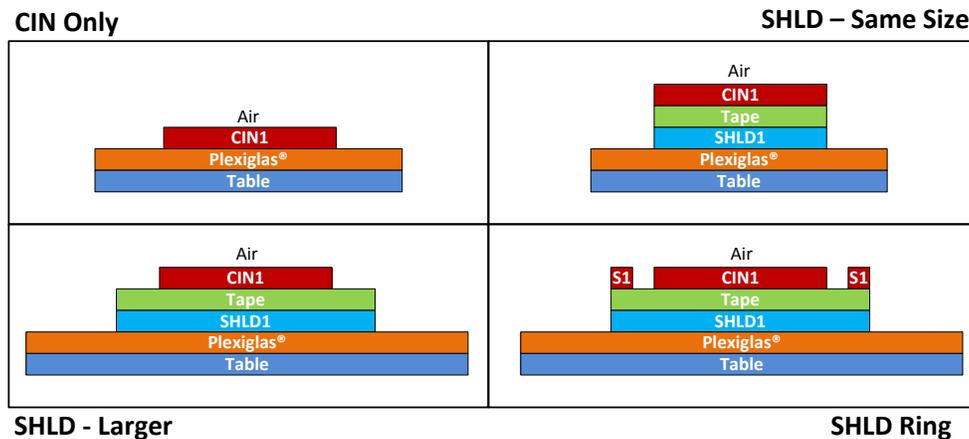
Figure 10. Sensor Layouts - Side View

Figure 10 shows the side profile of the sensor layout stackup. The Plexiglas® and table are part of the experimental test setup in Figure 13 and had a thickness of 0.6 mm and 3 cm, respectively. The plexiglas only served as a way to house the sensors with written distance intervals to determine proximity distance.

The actual sensor configurations 3 and 4 prototypes are shown in Figure 11 and Figure 12 with the entire test setup in Figure 13.
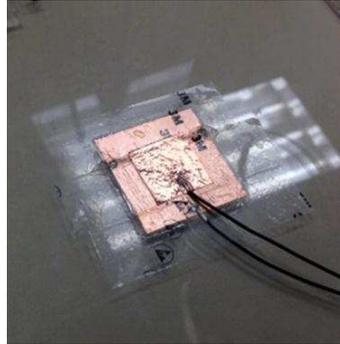
Figure 11. Actual Sensor - Larger SHLD1 Underneath CIN1
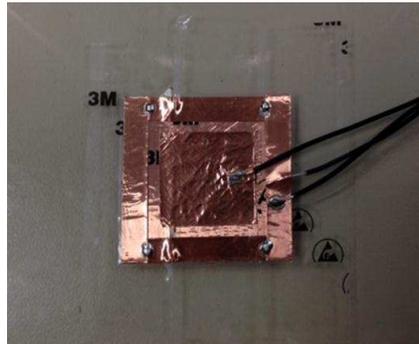
Figure 12. Actual Sensor - SHLD1 Ring around CIN1 with SHLD1 Underneath
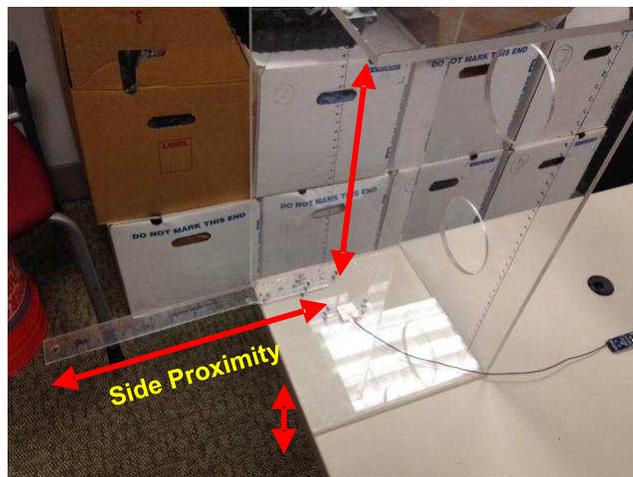
Figure 13. Shielding Configuration Test Setup

4.1   Experiment Results

As explained in the previous sections, shielding the sensor electrode helps block any external interference and noise. The experimental results show that even though shielding does not totally eliminate all of the interference, it does significantly reduce it. Figure 14 displays the change in capacitance versus the distance of the hand to the sensor from the top side, considered the target zone for the sensor. This case is the most common direction of proximity detection whereas the proximity from the side (shown in Figure 15) is treated as the unwanted interference, requiring a shield. As the shield size increases, so does the change in capacitance from side proximity. It is important to note that increasing the area of the shield decreases sensitivity and dynamic range to some extent in the target zone. Various applications require a certain proximity range and margin for interference and the shield needs to be sized appropriately for each case, since it does not have a linear relationship to range and interference. See Appendix A: Liquid Level Approach for all data collected from this experiment.
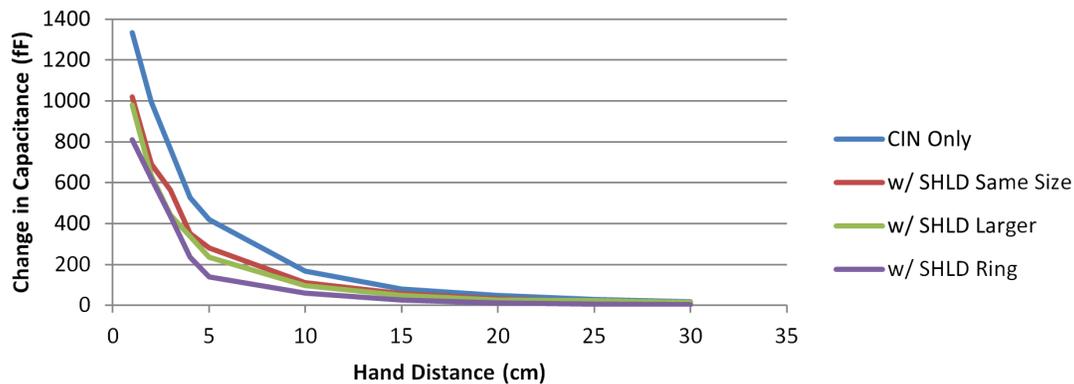
Figure 14. Experimental Results of Proximity From the Top Side
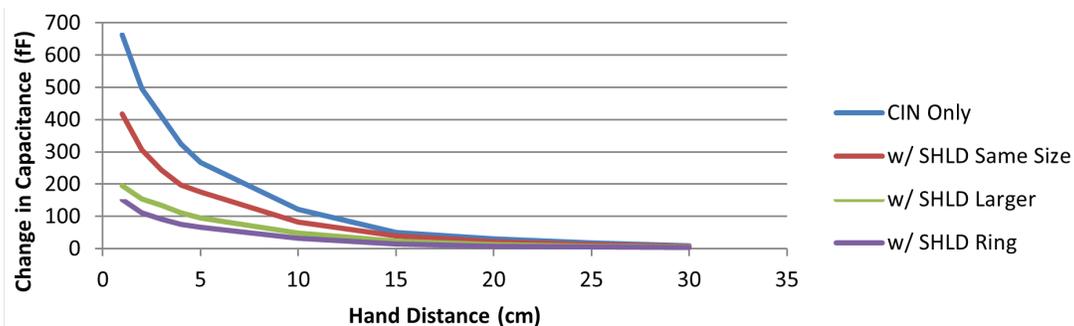
Figure 15. Experimental Results of Proximity From the Side

The capacitance measurements of proximity from the bottom side show that at a fixed distance away from the sensor, there is a significant reduction capacitance change. All of the interference cannot be eliminated unless the shield is much larger (an order of magnitude) than the sensor.

In summary, Figure 14 and Figure 15 show that either using a shield that is the same size as the sensor, or one that is 200% larger in area, have about the same impact on target zone sensitivity, but using a larger shield can reduce the vulnerability to interference from the side.

5   Conclusion

The presence of a shield paired with primary sensor electrode provides a barrier against an external interference in the surrounding environment. This barrier becomes more effective as the area of the shield increases, but as the shield area increases, the sensitivity and dynamic range in measurements decreases. The experimental results quantify a trend between shield size, sensitivity, and interference even though the relationship is non-linear. It is important to minimize the trace length for both shield and primary sensor and to route them close to each other (depending on where the interference is present). Overall, shielding is beneficial to capacitive sensing systems. The use of 2D and 3D finite element analysis simulations, in conjunction with empirical data, provides more accurate estimates of how the shield placement and size correlate to sensitivity and less interference in the system.

Appendix A: Liquid Level Approach

Table 1 lists all the data from the different experiments.

Table 1. Experiment Results

	Hand Distance (cm)	CIN Electrode Only		CIN and SHLD Electrode (Same Size)			CIN and SHLD Electrode (SHLD Larger)			SHLD Ring Around CIN, SHDL on Bottom		
		Capacitance (pF)	Change in Capacitance (fF)	Capacitance (pF)	Change in Capacitance (fF)	Error Decrease	Capacitance (pF)	Change in Capacitance (fF)	Error Decrease	Capacitance (pF)	Change in Capacitance (fF)	Error Decrease
Proximity From TOP	Baseline	5.4619		3.4155			3.0703			1.4542		
	30	5.48	18.1	3.4262	10.7	40.88	3.0844	14.1	22.10	1.4589	4.7	74.03
	25	5.4896	27.7	3.4345	19	31.41	3.0924	22.1	20.22	1.4617	7.5	72.92
	20	5.5104	48.5	3.4474	31.9	34.23	3.0979	27.6	43.09	1.4676	13.4	72.37
	15	5.5415	79.6	3.4718	56.3	29.27	3.1181	47.8	39.95	1.4801	25.9	67.46
	10	5.6292	167.3	3.5272	111.7	33.23	3.1687	98.4	41.18	1.5142	60	64.14
	5	5.8813	419.4	3.6965	281	33.00	3.3053	235	43.97	1.5939	139.7	66.69
	4	5.9887	526.8	3.7677	352.2	33.14	3.4069	336.6	36.10	1.6909	236.7	50.07
	3	6.2274	765.5	3.9802	564.7	26.23	3.5114	441.1	42.38	1.8918	437.6	42.83
	2	6.4558	993.9	4.1081	692.6	30.31	3.7063	636	36.01	2.0745	620.3	37.59
	1	6.7952	1333.3	4.4339	1018.4	23.62	4.0503	980	26.50	2.2633	809.1	39.32
Proximity From SIDE	Baseline	5.4619		3.4155			3.076			1.453		
	30	5.4714	9.5	3.4234	7.9	16.84	3.0812	5.2	45.26	1.4561	3.1	67.37
	25	5.4796	17.7	3.4278	12.3	30.51	3.0839	7.9	55.37	1.4583	5.3	70.06
	20	5.4924	30.5	3.4374	21.9	28.20	3.0891	13.1	57.05	1.4602	7.2	76.39
	15	5.5119	50	3.4547	39.2	21.60	3.099	23	54.00	1.4673	14.3	71.40
	10	5.5839	122	3.4978	82.3	32.54	3.1244	48.4	60.33	1.4861	33.1	72.87
	5	5.7287	266.8	3.5911	175.6	34.18	3.1705	94.5	64.58	1.5197	66.7	75.00
	4	5.7856	323.7	3.6131	197.6	38.96	3.1872	111.2	65.65	1.5277	74.7	76.92
	3	5.8723	410.4	3.6593	243.8	40.59	3.2113	135.3	67.03	1.5437	90.7	77.90
	2	5.9587	496.8	3.7223	306.8	38.24	3.2301	154.1	68.98	1.5643	111.3	77.60
	1	6.1255	663.6	3.8323	416.8	37.19	3.2714	195.4	70.55	1.6055	152.5	77.02
Proximity From BOTTOM (dielectric: plexiglass - 0.6 cm table - 3 cm)	Baseline	5.605		3.1559			3.0675			1.4538		
	3.6	6.3066	701.6	3.5004	344.5	50.90	3.3404	272.9	61.10	1.6203	166.5	76.27

Revision History

Changes from Original (February 2015) to A Revision   **Page**

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

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