Application Report
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Capacitive Sensing: Direct vs Remote Liquid-Level Sensing Performance Analysis

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ABSTRACT

Capacitive-based liquid level sensing is making its way into the consumer, industrial, and automotive markets due to its system sensitivity, flexibility, and low cost. With using TI's capacitive sensing technology, the system flexibility allows designers to have the choice of placing the sensors directly on the container (direct sensing) or in close proximity to the container (remote sensing). Each configuration has its own advantages and disadvantages. This application note highlights the system differences and performance of direct and remote sensing to provide guidance in how capacitive-based liquid-level sensing is affected.

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1 Direct and Remote Sensing

Direct and remote sensing in liquid-level sensing applications refers to the location of the sensors in relations to the container and target liquid. As shown in Figure 1, the sensors directly on the container is called direct sensing while the sensors located in close proximity to the container is called remote sensing. Designers can select between direct- or remote-sensing configurations, depending on the mechanical and manufacturing constraints of their application.

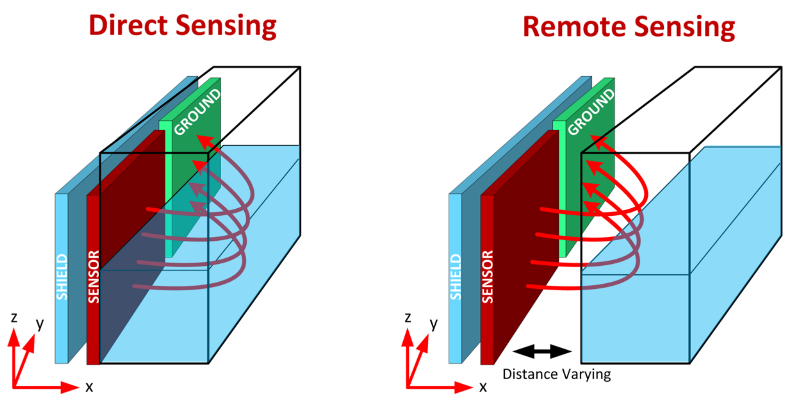

Figure 1. Direct and Remote Sensing

Table 1 shows a comparison of the system differences between the two sensing configurations. Direct sensing has the benefit of being higher sensitivity with minimizing sensor solution size, but the sensors have to be located directly on the container, which may not be feasible in some cases. Remote sensing allows the designer more flexibility in their mechanical constraints and end-product aesthetics. This flexibility comes at a cost of performance and sensitivity compared to direct sensing. Designers will need to compare performance versus mechanical constraints to determine the optimal configuration.

Table 1. Advantages and Disadvantages for Direct and Remote Sensing

	Direct Sensing	Remote Sensing
Advantages	• Higher sensitivity with minimized sensor solution size • Minimizes distance between sensors and target liquid	• Designer flexibility with container and system constraints • Sensors and electronics can be integrated on one board
Disadvantages	• Sensors on the container • Electrical contacts needed if container is detachable • Manufacturing and quality assurance with sensors embedded on the container • Sensors and electronics are separated	• Lower sensitivity • Sensor widths need to be scaled exponentially to keep same performance compared to direct sensing. • Allows only up to a few centimeters remote sensing

2 Direct/Remote Sensitivity Comparison

A sensitivity comparison was performed to determine the relationship between sensitivity and sensor distance from the container. Typically for remote sensing, a main housing cover with a detachable container would be in close proximity to each other. The sensors would be located on the inner or outer side of the main housing.

Figure 2 shows an acrylic housing with the sensors located on the outer side (closest to the container). Liquid-level measurements were taken at 1-cm liquid-level heights (approximately 29 mL, based on container size) up to 8 cm with the container at a fixed distance away from the sensors. Complete measurements were taken with the container 0 mm to 10 mm away from the housing/sensors. The container and sensor size parameters are shown in Table 2. Water was the primary target liquid but an experiment with water mixed with dish soap was also conducted to determine if conductivity of the liquid affects performance. All measurements were taken with the FDC2214 EVM, but since the samples are captured while the liquid height was at a steady state, the relationship between sensitivity and sensor distance from the container is applicable to the FDC1004. One thing to note is that the FDC1004 cannot detect a change in capacitance for high-conductive liquids.

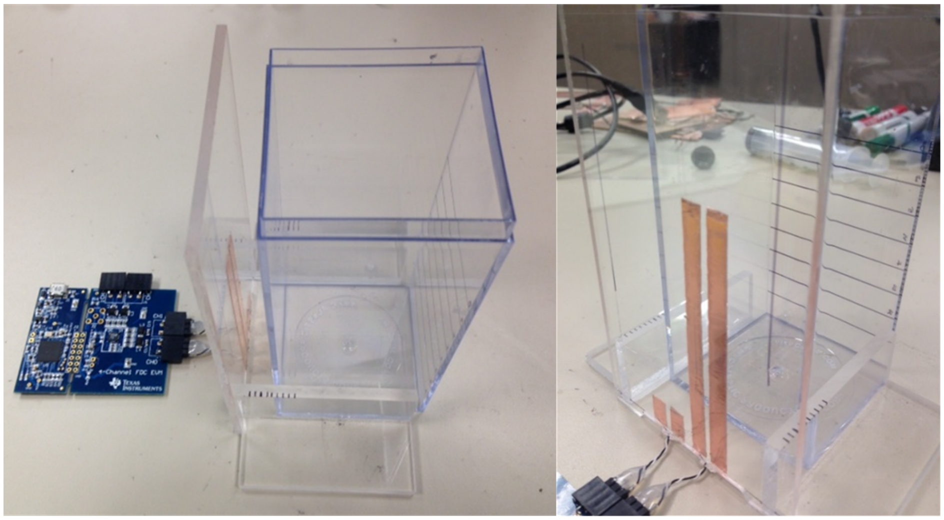

Figure 2. Prototype Setup

Table 2. Container and Sensor Size Parameters

	Container	Level Sensor	Reference Sensor
Length (cm)	5.7		
Width (cm)	5.7	0.6	0.6
Height (cm)	12.6	8	1
Thickness	≈2mm	1 oz (1.4 mils)	1oz (1.4 mils)
Gap between sensors		2 mm	

Figure 3 shows water height versus capacitance of various remote sensing distances. Capacitance increases proportionally as water height increases, as expected, but as the water container moves away from the sensors, sensitivity of the system decreases significantly. Figure 4 shows a decreasing logarithmic relationship between remote sensing distance and capacitance. The majority of the sensitivity is reduced within a remote sensing distance of 2 mm. From direct to 2-mm and 4-mm sensing distances, sensitivity decreases 64% and 80%, respectively (Table 3). As the container moves further away from the sensors, the sensitivity change tapers off.

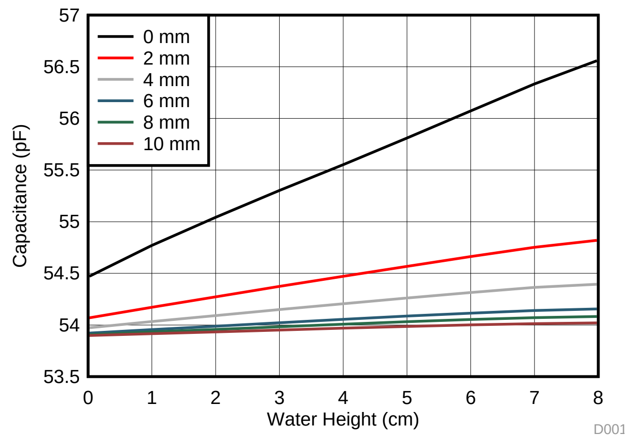

Figure 3. Water Height vs Capacitance

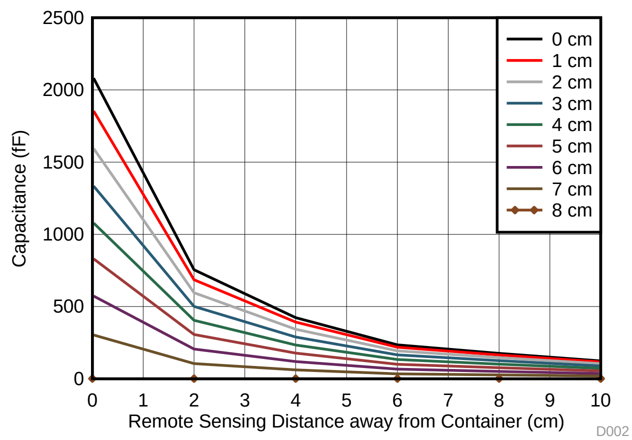

Figure 4. Remote Sensing Distance vs Capacitance for Water

Table 3. Remote Sensing Percentage Change (LEVEL sensor)

Remote Sensing Distance (mm)	Average Sensitivity (fF)	Percentage Change from Direct Sensing (%)
0	262.34	
2	94.35	–64.03
4	52.86	–79.85
6	29.31	–88.83
8	21.98	–91.62
10	15.44	–94.12

For remote sensing to have the same performance and sensitivity compared to direct sensing, the sensor size widths need to be larger. Table 4 compares the cases of direct sensing, 2-mm remote sensing and, 2-mm remote sensing with a larger sensor size. As an experiment, for remote sensing at 2 mm, a sensor size of 1.2 cm (twice the width of the initial experiment) was conducted in the same manner as the initial experiment. An average sensitivity per level height of 207 fF was obtained for this case. By doubling the sensor width, sensitivity of the system increased 120%. Overall, increasing the sensor widths by a factor of 3 should have similar sensitivity performance for this specific prototype.

Table 4. Analysis of Increasing Sensor Width at Remote Sensing Distance 2mm

	Direct Sensing	2-mm Remote Sensing	
Sensor Width (cm)	0.6	0.6	1.2
Average Sensitivity (fF)	262	94	207
Percentage Change From Direct Sensing (%)		–64	–21
Percentage Change Between Remote Sensing Cases (%)		120	120

3 Low-Conductive and High-Conductive Liquid Sensitivity Comparison

The same experiment described in Section 2 was conducted with water mixed with dish soap (soap water) to determine whether the conductivity and properties of the two liquid types affect system performance. Figure 5 shows the same decreasing logarithmic relationship of remote sensing distance versus capacitance for various liquid heights. Both liquids have comparable results.

One issue with using soap water as the target liquid is the effect of foam buildup. The average sensitivity of the LEVEL sensor for each remote sensing distance for soap water was slightly different compared to just water due to the effect of foam buildup as the soap water is disrupted (Table 5). As the remote sensing distance increases, the foam buildup has less influence to the sensitivity. The density and dielectric constant of the foam has a noticeable effect on the LEVEL measurement. With direct sensing, the effect of the foam causes the sensitivity to increase 14%, while at 2-mm remote sensing distance, the foam affects the sensitivity by 5%. The 5% error equates to a 4 fF change which may not be entirely from the foam but from variations in the amount of liquid poured (±1 mL). The 14% error, on the other hand, can be associated with foam buildup since the 35 fF of change would result in an approximately 4-mL liquid difference. The effect from the foam buildup is unpredictable, thus the error from the sensitivity could vary.

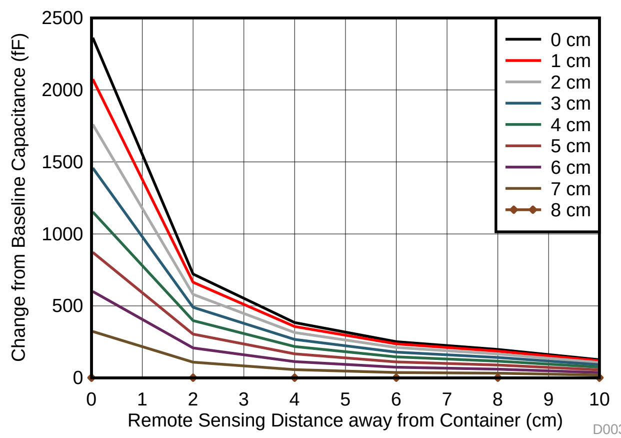

Figure 5. Remote Sensing Distance vs Capacitance for Soap Water

Table 5. Average Sensitivity Comparison of Water and Soap Water (LEVEL sensor)

Remote Sensing Distance (mm)	Water		Soap Water	
	Average Sensitivity (fF)	Percentage Change from Direct Sensing(%)	Average Sensitivity (fF)	Percentage Change from Direct Sensing(%)
0	262.34		297.95	
2	94.35	–64.03	90.12	–69.75
4	52.86	–79.85	48.03	–83.88
6	29.31	–88.83	31.41	–89.46
8	21.98	–91.62	24.69	–91.71
10	15.44	–94.12	15.73	–94.72

4 Conclusion

In summary, direct and remote sensing has its own advantages and disadvantages. Direct sensing has the benefit of being higher sensitivity with minimizing sensor solution size, but since the sensors are located directly on the container. Remote sensing allows the designer more flexibility in their mechanical constraints and end-product aesthetics. This flexibility comes at a cost of performance and sensitivity compared to direct sensing. The sensitivity of remote sensing compared to direct sensing has a decreasing logarithmic relationship. Most of the sensitivity reduction happens within the first few millimeters and then tapers offs. To have the same performance, the sensor widths for remote sensing need to be much larger to compensate for the logarithmic relationship to distance. The sensor widths are dependent on a variety of factors including the container, thickness of the container, remote sensing distance, and other mechanical constraints. Similar performance is exhibited for both low and high-conductive liquids, so conductivity of the liquid does not affect sensitivity, but the properties of the liquid may have any effect (that is: foam buildup for the soap water). Overall, it is possible to do remote sensing for liquid-level sensing applications but designers need to be aware of the performance limitations and the parameters to adjust to compensate for it.

Revision History

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

- Changed y axis units on *Remote Sensing Distance vs Capacitance for Water*.. 4
- Changed y axis units on *Remote Sensing Distance vs Capacitance for Soap Water*. 5

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

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