

Liquid Level Sensing with the Immersive Straw Approach

David Wang

ABSTRACT

The conventional and Out-of-Phase (OoP) liquid level sensing techniques are typically implemented for direct sensing or remote sensing applications. Sensors directly in contact with the liquid container maximize the performance of the system with minimizing sensor size, while remote sensing allows flexibility in system design. There are situations in which both of these sensor locations can exhibit false deviations in capacitance measurements from uncompensated environmental factors or the mechanical design does not allow direct/remote sensing. The immersive straw approach involves submerging the sensors directly in the liquid. The following application note describes the sensor design and compares the performance to direct and remote sensing applications.

Contents

1	Direct and Remote Sensing Concept	2
2	Immersive Straw Sensing Concept.....	3
3	Experiment Setup and Results.....	4
4	Design Considerations	6
5	Measurements	7

List of Figures

1	Direct and Remote Sensing Setups	2
2	Immersive Straw Sensing Setup.....	3
3	Immersive Straw Prototype and OoP Configuration Test Setup	4
4	Straw Prototype Design.....	4

List of Tables

1	Comparison Between Direct and Indirect Sensing	5
2	Comparison of LEVEL and REF Calculated Level Error	5
3	Immersive Straw Sensing Approach Measurements.....	7

1 Direct and Remote Sensing Concept

Direct and remote sensing is widely used in liquid level sensing applications. As shown in [Figure 1](#), direct sensing allows the sensors to be attached to the liquid container to minimize the spacing and dielectric constant variations to the liquid. This setup maximizes the performance and sensitivity of the system while minimizing the sensor size. Remote sensing enables the sensors to not be in contact with the container which allows flexibility in the system and mechanical design. Remote sensing is less desirable because larger sensors are typically required to keep the same performance compared to direct sensing.

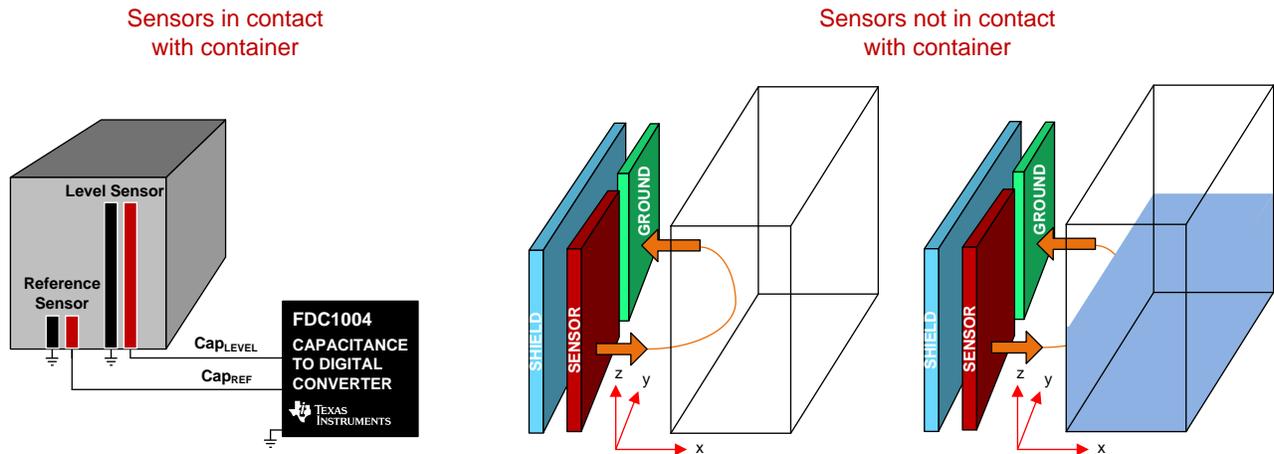


Figure 1. Direct and Remote Sensing Setups

One limitation with direct and remote sensing is that it may create compensation more difficult due to system conditions. For example, in liquid level sensing for gasoline tanks on automotive vehicles, the sensors are exposed to a variety of environmental conditions. If the sensors are directly attached to the side of the tanks and because the tanks are on the undercarriage of the vehicle, the sensors will be affected by all adverse weather conditions. It is possible to compensate for these conditions with an environmental reference sensor; however this may make the system design more complex due to the size of the sensors and the combinations of environmental factors to compensate for. This is a situation where the immersive straw approach, submerging the sensor system inside the liquid and container, becomes beneficial.

Another limitation with the conventional sensing setup is the mechanical design constraints. It is capable to do liquid level sensing with containers of different materials except for conductive materials. By using the immersive straw approach, liquid level sensing is possible.

2 Immersive Straw Sensing Concept

Immersive straw sensing allows the sensor system to be completely contained within the target liquid as shown in Figure 2. As the liquid level increases, the liquid flows through a tube with the sensors attached on the outside of the tube. The sensors cannot be directly exposed to the liquid so a larger tube is placed around the inner tube (as shown on the right side of Figure 2) with the gap between the tubes sealed off from the liquid. This restricts the flow of the liquid to travel up the inner tube and through the generated electric fields.

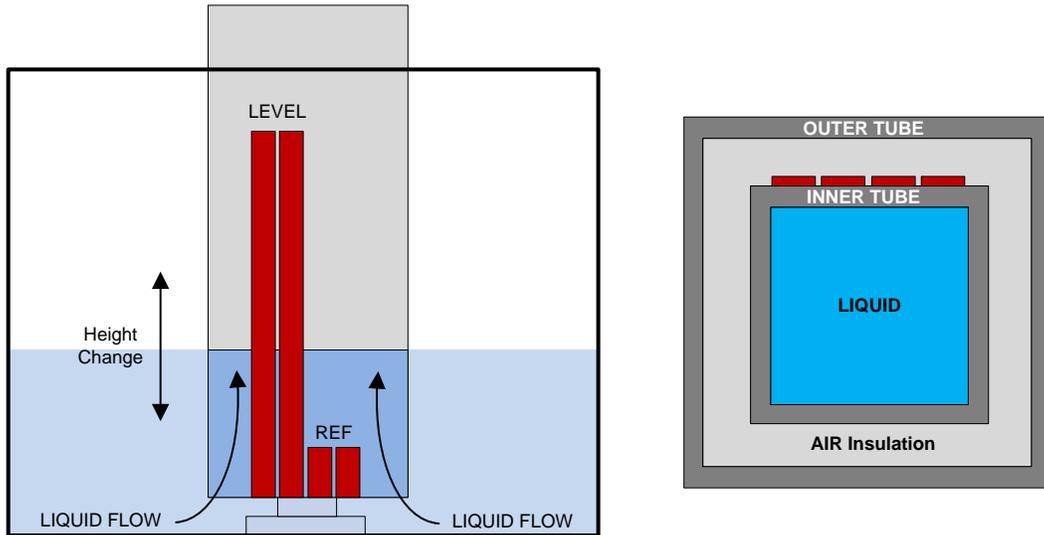


Figure 2. Immersive Straw Sensing Setup

The system will be extremely robust, reliable, and isolated from various environmental conditions and stray parasitic capacitance if the immersive straw approach is paired with the OoP technique.

3 Experiment Setup and Results

To verify the immersive straw sensing concept, a prototype was developed and measurements were collected. [Figure 3](#) shows the prototype and test setup. Two acrylic square tubes of different dimensions were used so that the smaller tube (with the sensors attached to) fits directly in the larger tube, as described in the previous section. Water was used as the liquid target. The container was filled with water at different height intervals. Notches at the bottom of the outer tube allowed the water to flow through the inner tube.

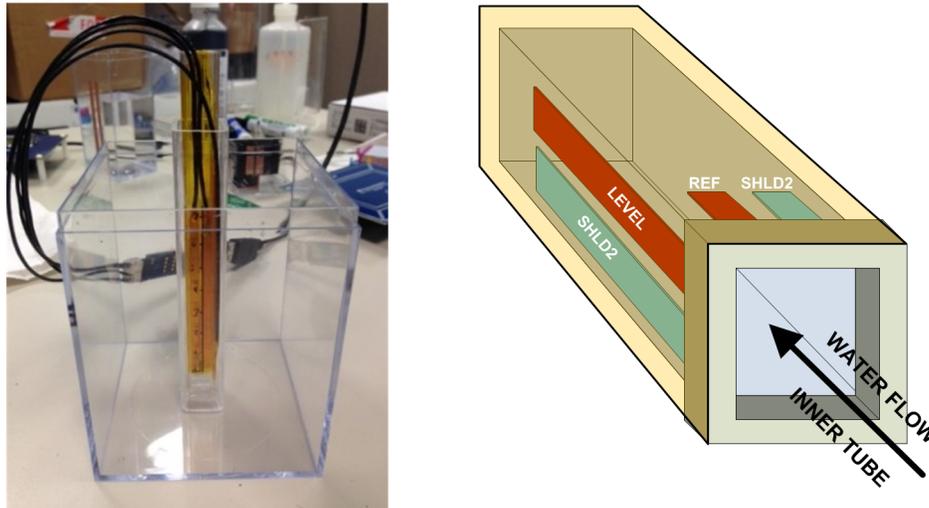


Figure 3. Immersive Straw Prototype and OoP Configuration Test Setup

The sensors were cut to a width of 0.3cm with 3M copper tape and configured with the OoP technique. The LEVEL sensor height was 7cm and the REF sensor height was 1cm. Due to the size constraints of the square tubes, the LEVEL and REF sections were attached to adjacent sides of the inner tube. Shielded cables were used and routed within the insulated air gap so the water surrounding the system does not affect the measurements as the water rises. [Figure 4](#) shows the tube prototype design in detail.



Figure 4. Straw Prototype Design

Table 1 shows the comparison between direct sensing for the conventional and OoP techniques versus the OoP technique with the immersive straw sensing at one water level height. The immersive straw sensing approach performs better than the conventional liquid level sensing, but slightly lags behind the direct sensing with OoP based on the change in capacitance from the baseline measurement. The overall error for the immersive straw sensing was ~1.5% (shown in Table 3) compared to direct sensing using OoP and the conventional setup at ~0.7% and ~11% respectively.

Table 1. Comparison Between Direct and Indirect Sensing

	Hand Distance (cm)	Change in Cap From Baseline (fF) LEVEL MEASUREMENT			Calculated Level Error (%)		
		Direct Sensing (Conventional)	Direct Sensing (OoP)	Immersive Straw Sensing (OoP)	Direct Sensing (Conventional)	Direct Sensing (OoP)	Immersive Straw Sensing (OoP)
5cm Water Level	5	57.0	-4.4	8.4	1.83	-0.02	-0.11
	4	67.1	-5.4	10.0	2.13	0.05	-0.08
	3	80.9	-7.1	11.8	2.72	0.05	-0.07
	2	106.0	-9.2	15.2	3.38	0.06	-0.10
	1	135.9	-11.0	18.8	4.62	0.12	-0.09
	0	317.8	-15.0	32.3	8.98	0.18	-0.05

Even though the absolute change in capacitance for direct sensing (OoP) is smaller compared to immersive sensing, the calculated level error is larger. This discrepancy is based on both the change in the LEVEL measurement and REF measurement. The calculated level uses the ratiometric difference between the LEVEL and REF capacitance values to determine the appropriate level height. If the change in capacitance for the LEVEL and REF do not change at the same rate, then the error for the calculated level will not be minimized. The error from the hand interference based on change in water level value (examples shown in Table 2) can provide an estimate of how close the LEVEL and REF change as the hand interference approaches towards the container. The error from the hand interference based on the change in water level can be larger, but if both the LEVEL and REF change at the same rate, the calculated level will cancel it out.

Table 2. Comparison of LEVEL and REF Calculated Level Error

Error from Hand Based on Change in Water Level (%)		Calculated Level Error (%)
LEVEL	REF	
-2.6486	-1.9545	-0.71
-1.1171	-0.7517	-0.37
-0.9502	-1.0675	0.12
-1.5663	-1.5846	0.02
-0.5283	-0.5071	-0.02
-1.0751	-1.0775	0.00

4 Design Considerations

There are several factors that could have affected the performance of the immersive straw sensing compared to direct sensing even though both are using the OoP sensor configuration. One main factor is that since the sensors were cut out manually, each of the sensors could be slightly different in size. Symmetry is very important for the OoP technique and mismatched sensor sizes will cause an imbalance between the in-phase and out-of-phase excitation drive strength. This results in the system being more susceptible to stray parasitic capacitance. With the liquid surrounding the system now, the sensor mismatch would affect the performance more significantly compared to the direct sensing setup.

Another factor would be the size of the sensors, the direction of the interferer relative to the sensors, and dimensions of the container. If the container is small and the sensors are large, the electric fields could extend to the area where the hand is approaching and couple directly to the sensors. Performance will slightly vary if the direction of the interferer relative to the sensors is different. If the hand interference is approaching towards the backside of the shields, then the error performance will be slightly better compared to the hand approaching towards the front side of the LEVEL and REF sensors.

Minimizing the sensor size and maximizing the area from the sensors to the edge of the container will provide the most robust and consistent system.

Overall with a refined prototype, the immersive straw sensing approach offers designers more flexibility in where the sensors are located in the system and with similar performance results to direct sensing with the OoP technique.

5 Measurements

Table 3. Immersive Straw Sensing Approach Measurements

Water Level (cm)	Hand Distance (cm)	LEVEL Measurement			REF Measurement			Calculated Level (cm)	Error (%)
		Capacitance (pF)	Change in Cap from Baseline (fF)	Error from Hand based on change in water level (%)	Capacitance (pF)	Change in Cap from Baseline (fF)	Error from Hand based on change in water level (%)		
0	Baseline	3.5131			1.1332				
	3	3.5148	1.7000		1.1341	0.9000			
	2	3.5149	1.8000		1.1342	1.0000			
	1	3.5149	1.8000		1.1341	0.9000			
	0	3.5128	-0.3000		1.1319	-1.3000			
1	Baseline	3.8410			1.4241			1.1272	
	3	3.8453	4.3000	1.3114	1.4253	1.2000	0.4125	1.1373	0.90
	2	3.8458	4.8000	1.4639	1.4248	0.7000	0.2406	1.1409	1.22
	1	3.8455	4.5000	1.3724	1.4243	0.2000	0.0688	1.1419	1.30
	0	3.8409	-0.1000	-0.0305	1.4199	-4.2000	-1.4438	1.1434	1.43
2	Baseline	4.1808			1.4203			2.3257	
	3	4.1846	3.8000	0.5691	1.4222	1.9000	0.6618	2.3235	-0.09
	2	4.1848	4.0000	0.5991	1.4222	1.9000	0.6618	2.3242	-0.06
	1	4.1851	4.3000	0.6440	1.4222	1.9000	0.6618	2.3253	-0.02
	0	4.1839	3.1000	0.4643	1.4212	0.9000	0.3135	2.3292	0.15
3	Baseline	4.4628			1.4185			3.3288	
	3	4.4709	8.1000	0.8529	1.4203	1.8000	0.6309	3.3361	0.22
	2	4.4722	9.4000	0.9898	1.4205	2.0000	0.7010	3.3383	0.29
	1	4.4738	11.0000	1.1583	1.4207	2.2000	0.7711	3.3416	0.38
	0	4.4760	13.2000	1.3899	1.4207	2.2000	0.7711	3.3492	0.61
4	Baseline	4.7518			1.4153			4.3910	
	3	4.7624	10.6000	0.8557	1.4174	2.1000	0.7444	4.3958	0.11
	2	4.7647	12.9000	1.0414	1.4178	2.5000	0.8862	4.3978	0.15
	1	4.7677	15.9000	1.2836	1.4184	3.1000	1.0989	4.3990	0.18
	0	4.7761	24.3000	1.9617	1.4200	4.7000	1.6661	4.4038	0.29
5	Baseline	5.0835			1.4131			5.6106	
	3	5.0953	11.8000	0.7514	1.4154	2.3000	0.8217	5.6067	-0.07
	2	5.0987	15.2000	0.9679	1.4161	3.0000	1.0718	5.6048	-0.10
	1	5.1023	18.8000	1.1971	1.4167	3.6000	1.2862	5.6056	-0.09
	0	5.1158	32.3000	2.0568	1.4190	5.9000	2.1079	5.6078	-0.05
6	Baseline	5.3753			1.4109			6.7058	
	3	5.3904	15.1000	0.8109	1.4133	2.4000	0.8642	6.7022	-0.05
	2	5.3951	19.8000	1.0633	1.4139	3.0000	1.0803	6.7047	-0.02
	1	5.3998	24.5000	1.3156	1.4146	3.7000	1.3324	6.7047	-0.02
	0	5.4224	47.1000	2.5293	1.4183	7.4000	2.6647	6.6969	-0.13
7	Baseline	5.6348			1.4051			7.8032	
	3	5.6516	16.8000	0.7918	1.4078	2.7000	0.9930	7.7877	-0.20
	2	5.6573	22.5000	1.0605	1.4086	3.5000	1.2872	7.7858	-0.22
	1	5.6641	29.3000	1.3810	1.4097	4.6000	1.6918	7.7794	-0.31
	0	5.6979	63.1000	2.9740	1.4147	9.6000	3.5307	7.7613	-0.54

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as "components") are sold subject to TI's terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI's terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers' products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers' products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI's goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or "enhanced plastic" are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have **not** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products

Audio	www.ti.com/audio
Amplifiers	amplifier.ti.com
Data Converters	dataconverter.ti.com
DLP® Products	www.dlp.com
DSP	dsp.ti.com
Clocks and Timers	www.ti.com/clocks
Interface	interface.ti.com
Logic	logic.ti.com
Power Mgmt	power.ti.com
Microcontrollers	microcontroller.ti.com
RFID	www.ti-rfid.com
OMAP Applications Processors	www.ti.com/omap
Wireless Connectivity	www.ti.com/wirelessconnectivity

Applications

Automotive and Transportation	www.ti.com/automotive
Communications and Telecom	www.ti.com/communications
Computers and Peripherals	www.ti.com/computers
Consumer Electronics	www.ti.com/consumer-apps
Energy and Lighting	www.ti.com/energy
Industrial	www.ti.com/industrial
Medical	www.ti.com/medical
Security	www.ti.com/security
Space, Avionics and Defense	www.ti.com/space-avionics-defense
Video and Imaging	www.ti.com/video

TI E2E Community

e2e.ti.com