TI Designs:
Capacitive-Based Liquid Level Sensing Sensor Reference Design

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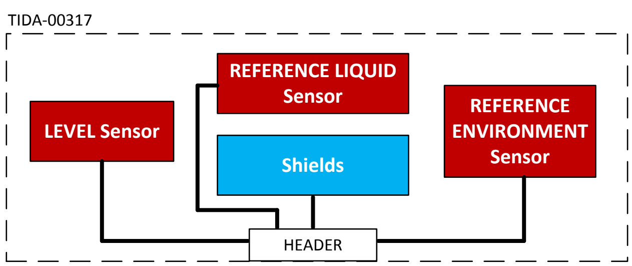
Block Diagram



Design Features

- Liquid level sensing using capacitive sensing technology
- Out-of-Phase (OoP) technique eliminates any proximity interference such as a human hand either nearby or in contact with the container
- Rigid-flex circuit allows the sensors to be placed on various shaped surfaces
- Liquid height resolution <1mm
- Includes the environmental reference sensor to help compensate for environmental changes (temperature, humidity, stress on container, etc…)
- Developed to be paired with the FDC1004EVM and FDC1004EVM GUI for quick prototyping evaluation

Featured Applications

- Home Appliances: refrigerators, coffee machines, humidifiers
- Automotive: fuel level, washer fluid, coolant level
- Medical: drug pens, insulin pumps, droplet counter

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1 Key System Specifications

Table 1: Key System Specifications

PARAMETER	SPECIFICATION	DETAILS
Sensor size	Sensitivity resolution <1mm	Section 4.4
Sensor configuration	Out-of-phase method for robustness	Section 4.3
Sensitivity	Level height resolution <1mm	Section 7.1
Parasitic capacitance interference	Tested with human body self-capacitance approaching sensor/container	Section 7.2

2 System Description

Various methods have been used to determine the liquid level height in water containers, but recently, capacitive sensing has gained popularity due to the accuracy and resolution of the measurements. The conventional capacitive technique has limitations with robustness since any external interference (for example – a human hand) causes capacitance drifts.

This TI Design demonstrates an alternative approach to the conventional capacitive sensing technique for liquid level. It provides the necessary barrier to minimize any interference to maximum the signal to noise ratio and overall robustness of the system. This approach is referred to as the Out-of-Phase (OoP) technique.

The OoP technique relies on a symmetrical sensor layout as well as using the shield drivers in a unique way to stabilize measurements. This sensor design paired with the FDC1004EVM and GUI allows the user a simple and rapid way to prototype and evaluate this liquid level technique.

This design guide addresses the theory behind the OoP technique, the sensor layout, and sensor design considerations for system environment changes. The scope of this design guide gives system designers a head-start in integrating TI's capacitive sensing technology into new liquid level applications that require robustness and high resolution.

3 Block Diagram

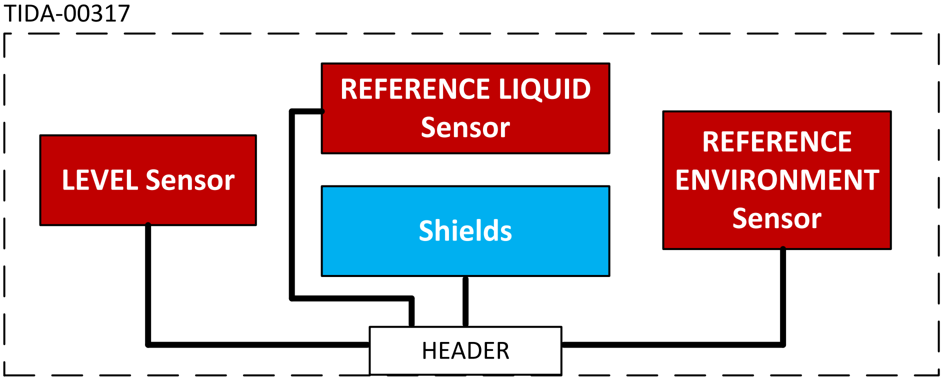

Figure 1: Capacitive-based liquid level sensing sensor block diagram

3.1 Highlighted Products

The capacitive-based liquid level sensing reference design is based on the FDC1004 capacitance-to-digital converter. However, it focuses on the sensor layout. It was designed to be paired with the FDC1004EVM and GUI as a modular system.

3.1.1 FDC1004EVM

The FDC1004EVM is a plug and play system to test and evaluate the FDC1004, 4-channel capacitive to digital converter. The EVM is a breakable PCB which consists of 3 sections:

1. MSP430F5528 microcontroller which acts as the USB to I2C bridge between a PC and the FDC1004.
2. The FDC1004
3. Touchless sensor to demonstrate the sensitivity of the FDC1004

Key benefits of the FDC1004EVM:

- Does not need additional hardware, calibration, nor any software programming
- Only requires the FDC1004EVM GUI to be installed on a host PC
- GUI is able to configure the FDC1004's registers, display the capacitive values on four graphs (one for each measurement), and export data in CSV format

4 System Design Theory

4.1 Level Height Calculations

Liquid level sensing is based on the theory of a ratiometric measurement, using three sensors as shown in Figure 2:

1. LEVEL – The capacitance of the LEVEL electrode is proportional to the liquid height (hw). It has to be as high as the maximum (MAX) allowed liquid level.
2. REFERENCE LIQUID (RL) – The REFERENCE liquid electrode accounts for the incremental unit measurements of the level electrode. The liquid level has to be higher than the RL height in order to have a liquid and temperature independent measurement system.
3. REFERENCE ENVIRONMENT (RE) – A second (optional) reference electrode accounts for container properties. It has to be placed above the maximum (MAX) allow level of liquid to isolate it from the liquid level, allowing it to track environmental factors rather than the primary target (the liquid in the container).

A key aspect of this approach is that all three sensors are driven with the same excitation signal. Changes in the excitation signal due to changing capacitance are measured and used to calculate the corresponding liquid level.

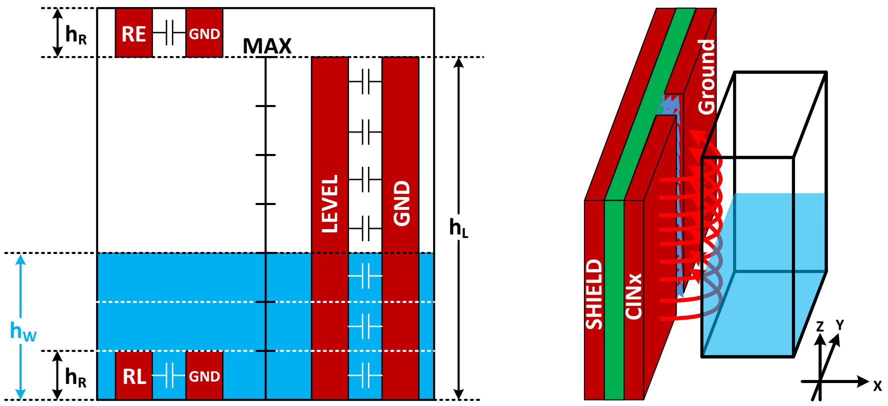

Figure 2: Ratiometric measurement setup

The working principle of the liquid level sensing involves measuring the fringing capacitance between the primary LEVEL electrode (CINx) and a ground (GND) electrode in the parallel fingers topology. The fringing capacitance becomes a function of the dielectric variation in the x-axis direction, and proportional to the liquid height, as given by:

$$C_{meas} \propto h_w \varepsilon_w + (h_L - h_w)\varepsilon_a$$

Equation 1: Capacitance proportional due to dielectric variation

Where

h_L = maximum height of the liquid
h_w = height of liquid
ε_w = dielectric of liquid
ε_a = dielectric of air

To calculate the level of the liquid at any interval height, the formula below is used:

$$Level = h_{RL}\frac{C_{level} - C_{level}(0)}{C_{RL} - C_{RE}}$$

Equation 2: Level height calculation

Where

h_{RL} = the unit height of the reference liquid sensor (often 1)
C_{level} = capacitance of the LEVEL sensor
$C_{level}(0)$ = capacitance of the level sensor when no liquid is present (empty)
C_{RL} = capacitance of the REFERENCE liquid sensor
C_{RE} = capacitance of the reference environmental sensor

NOTE: If RE is not used in the system, replace C_{RE} with $C_{RL}(0)$ in the equation above.

Figure 2 also illustrates the use of a shield behind both electrodes, which focuses the sensing direction toward the liquid target and provides a barrier from any interference affecting the measurements from the backside. The FDC1004 features two dedicated shield drivers which can drive up to 400 pF capacitance each. The shield is driven with the same excitation signal as the other sensors. Because it is charged to the same potential as the other sensors, there is no electric field on the shield side of the sensors, so the only active field is in the direction of the liquid. The sensor size of RE should be the same size as RL so the measurements can be subtracted from one another. If the sensor sizes are not matched, a differential measurement cannot be performed since fringing capacitance is not linear/proportional to area size (unlike the parallel plate form).

Figure 3 illustrates an example of the capacitance of the LEVEL and REFERENCE electrodes based on the liquid level height. The capacitance of the LEVEL electrode increases linearly as the liquid level increases. Once the liquid level is above the h_R height, the RL capacitance saturates and becomes constant. The reference empty shows the behavior of the RE electrode and any change from environmental factors with this electrode can be used to eliminate the change seen on the level and RL electrode.

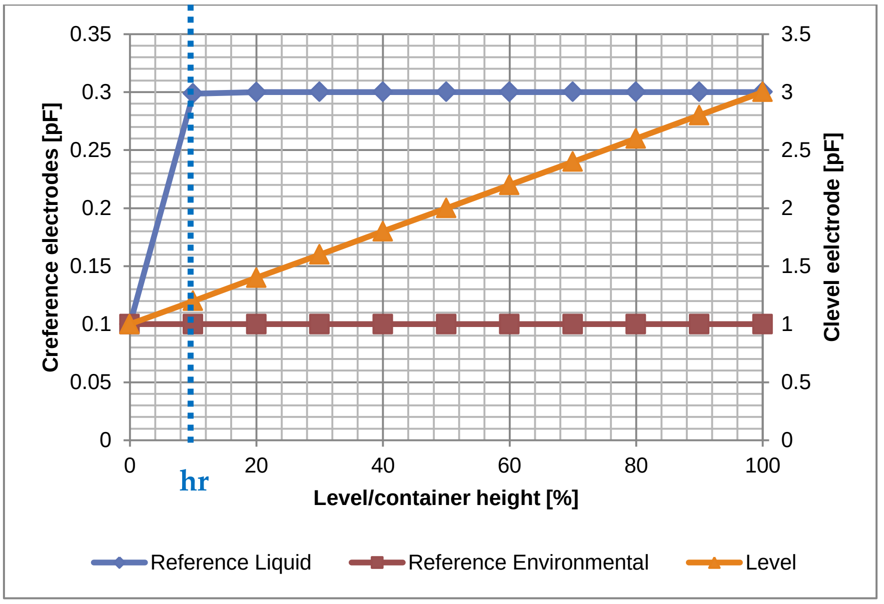

Figure 3: Capacitance measurements for LEVEL, RL, and RE electrodes

4.1.1 Gain and Offset Compensation

Even though the capacitance measurements are proportional to the liquid level height, the calculated level compared to the actual liquid level can vary dramatically. This is due to variations in the LEVEL, RL, and RE electrode capacitances for each liquid level interval. Gain and offset compensation for the system under measure is necessary in order to match the actual with the measured levels. A 1^{st} order linear correction algorithm as below can be applied to compensation for the variations:

$$Level' = Level * Gain + Offset$$

Equation 3: Linear correction algorithm

The FDC1004 allows gain and offset compensation per measurement and can be changed in real-time to adjust for system environment conditions.

4.2 The Out-of-Phase Liquid Level Technique

The conventional approach of using an electrode, connected to a channel input of the FDC1004, paired with a ground electrode works properly if the system is isolated from any external influence on the system capacitance. A problem arises with the introduction of any grounded interference or parasitic capacitance to the system. This interference causes deviations in capacitance measurements. These deviations can be significant enough so that it cannot be distinguished from small or large changes in the liquid level, ultimately compromising the accuracy and reliability of the system.

The electrical model of the liquid level system contains the capacitance/resistance of the water and the capacitance of the container (shown in Figure 4) from the CINx (LEVEL) electrode to the GND electrode. The measured capacitance as liquid level increases should be linear. When the human body presence (human hand) is in close proximity to the liquid source, an additional parasitic capacitance is introduced into the model and causes the potential difference due to the liquid to change relative to the absence of the hand. This potential difference corresponds to disturbances (as shown in the graph on the right in Figure 4) along the linear data plot. An alternative approach to mitigate this additional parasitic capacitance is the Out-of-Phase (OoP) technique.

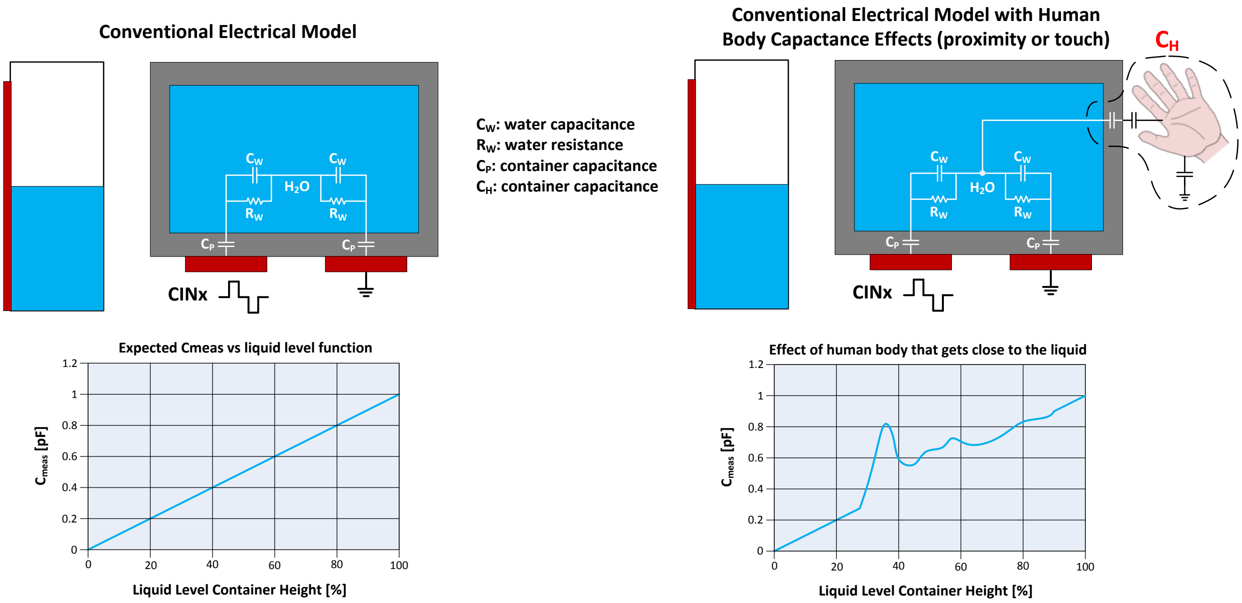

Figure 4: Comparison of the conventional electrical model with and without human body presence

The OoP technique relies on a symmetrical sensor layout as well as using the shield drivers in a unique way to counteract the effects of the human body capacitance and stabilize measurements. In the conventional approach, the liquid experiences a voltage potential difference to GND. In the OoP technique, the liquid potential is kept constant during the excitation/drive phases by using a differential capacitive measurement, thus eliminating the human body capacitance effects from the measurements.

Figure 5 shows the comparison of the conventional and OoP electrical model. The OoP technique takes advantage of the unique features of the FDC1004 to drive a CINx electrode and a SHLDy electrode in differential mode to make the voltage potential at node C_H fixed. The SHLDy electrode takes the place of the GND electrode and is actively driven. Specifically, the FDC1004 is configured for differential mode (CINx – CINy), for example CIN1 – CIN4. In this case by default, SHLD1 is in-phase with CIN1 and SHLD2 is in-phase with CIN4. Because CIN1 and CIN4 are 180 degrees out of phase with respect to each other, node CH is maintained at a constant potential. *See the FDC1004 datasheet for more information about differential mode configurations and how the shields are paired with the channels.*

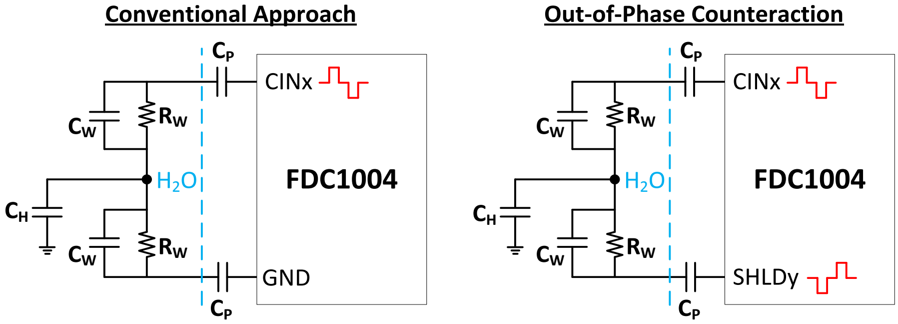

Figure 5: Comparison of conventional approach and OoP electrical model

4.3 Sensor Layout

The OoP technique is effective because the capacitance towards the liquid seen by the in-phase and the out-of-phase excitation/driver signal is the same. This approach relies heavily on symmetry of the channel and shield electrodes. If there is any mismatch, the liquid will not be at a constant potential. *Symmetry* is the key. Figure 6 shows the sensor stack up that incorporates shield barriers on the backside of the electrodes. OoP works because the FDC1004 can be configured for differential mode. Most other capacitive to digital converters cannot be configured this way.

To implement the OoP method of liquid level sensing using the FDC1004, the following sensor assignments can be used:

- CIN1 – LEVEL electrode
- CIN2 – REFERENCE LIQUID electrode (RL)
- CIN3 – REFERENCE ENVIRONMENT electrode (RE) – optional
- CIN4 – Floating, no electrode attached

FDC1004 measurements would be configured as follows:

- MEAS1 = CIN1 (CHA) – CIN4 (CHB). CIN1 is set as the positive input channel, and CIN4 is set as the negative input channel.
- MEAS2 = CIN2 (CHA) – CIN4 (CHB). CIN2 is set as the positive input channel, and CIN4 is set as the negative input channel.

With MEAS1 and MEAS2 in differential mode, CIN1/2 is in-phase with SHLD1 and CIN4 is in-phase withSHLD2. CIN1/2 and CIN4 are out-of-phase by 180 degrees. The SHLD2 electrode adjacent to CHx needs to be shielded by another SHLD2 electrode adjacent to SHLD1 to match in-phase and out-of-phase excitation/drive symmetry, shown in Figure 6.

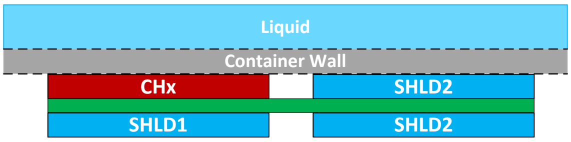

Figure 6: OoP technique sensor layout for LEVEL and REF sections

To allow further symmetry, SHLD1 and SHLD2 (furthest away from the liquid) are exactly the same size as the SHLDs for the LEVEL electrode (shown in Figure 7). SHLD1 and SHLD2 are shared between LEVEL and RL. Because the FDC1004 samples the capacitance channels sequentially, when it reads the capacitance for the LEVEL measurement, the RL electrode is floating but the SHLD1 and SHLD2 paired with the RL section are connected during the LEVEL measurement. Creating symmetry between the LEVEL and RL sections is as important as symmetry within each measurement section.

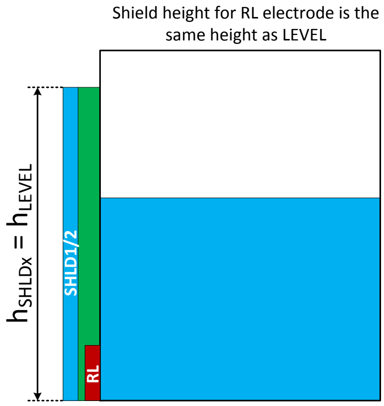

Figure 7: Side view of SHLD electrode height compared to RL electrode height

4.4 Sensor Design Considerations

When designing the sensor portion, the size of the electrodes and the coupling between the electrodes and the container need to be considered. Follow the guidelines below to ensure maximum performance from the sensor system:

- Increasing electrode width increases sensitivity (non-linearly)
- Gap between sensor electrode and shield reference electrode should be ¼ to ½ of the width of the electrode. Increasing it more does not provide additional sensitivity to the system.
- Sensitivity and resolution will be dependent on the width of the electrodes, the gap between the electrode, the spacing between the electrodes and the container, the container material, and the thickness of the container.
- Insulation material between the two layers of electrodes will typically be FR4. Standard PCB thickness is acceptable. Minimizing that gap between the two layers will offer better shielding but will slightly reduce sensitivity. Optimization for this parameter is system dependent.
- Minimize gap between the electrodes and the container. Reduced sensitivity will occur if air gaps are present.
- If liquid level sensing application requires remote sensing (electrodes are not in contact with the container), maximize electrode widths to compensate for air gaps, dielectric constant variations and wall thicknesses of the container and main housing.

This TI Design has a sensitivity resolution of <1mm based on the guidelines above.

5 Getting Started Hardware

5.1 Hardware Overview

The TI Design hardware is shown below in Figure 8 and is comprised of the LEVEL electrode, REFERENCE LIQUID electrode, REFERENCE ENVIRONMENT electrode, and the associated shield electrodes. This sensor design, when paired with the FDC1004EVM and GUI, allows the user a simple and rapid way to prototype and evaluate this liquid level technique. The rigid-flex circuit is designed so that the rigid PCB allows the header to be connected to the FDC1004EVM connector while the flex circuit is capable of being placed on a variety of shaped surfaces.

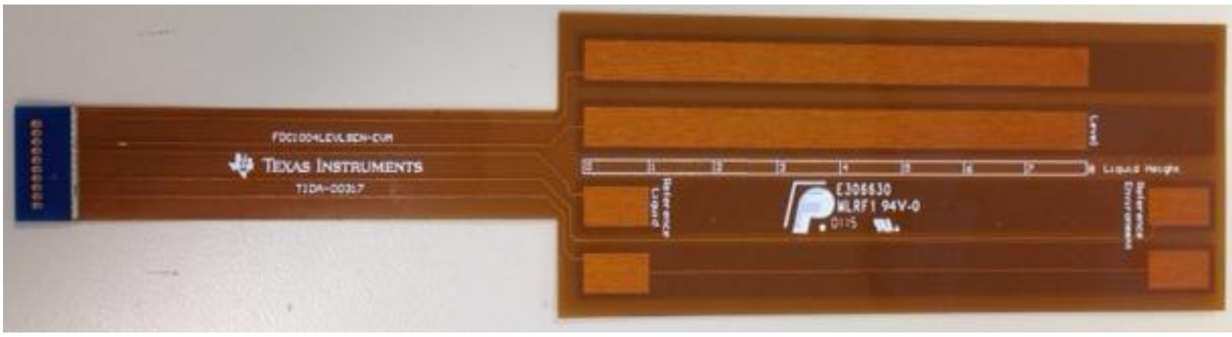

Figure 8: TI designs hardware

The following sensor assignments are used when paired with the FDC1004EVM.

- CIN1 – LEVEL electrode
- CIN2 – REFERENCE LIQUID electrode (RL)
- CIN3 – REFERENCE ENVIRONMENT electrode (RE)
- CIN4 – Floating, no electrode attached

The RE electrode is not required to calculate the height of the liquid, but it can be used in conjunction with the rest of the electrode measurements to compensate for environmental changes.

5.2 FDC1004EVM GUI Configuration

The FDC1004EVM and GUI are used with this TI design hardware to obtain capacitance measurements to calculate the height of the liquid level. Follow the steps below to setup the FDC1004 for OoP liquid level operation:

1. Select the *CONFIGURATIONS* tab
2. Press the *RESTORE FROM DEFAULTS* button to change all registers to default values
3. Change the following settings as seen below in Figure 9:
    - MEAS1 CHA: CH1
    - MEAS1 CHB: CH4
    - MEAS2 CHA: CH2
    - MEAS2 CHB: CH4
    - MEAS3 CHA: CH3
    - MEAS3 CHB: CH4

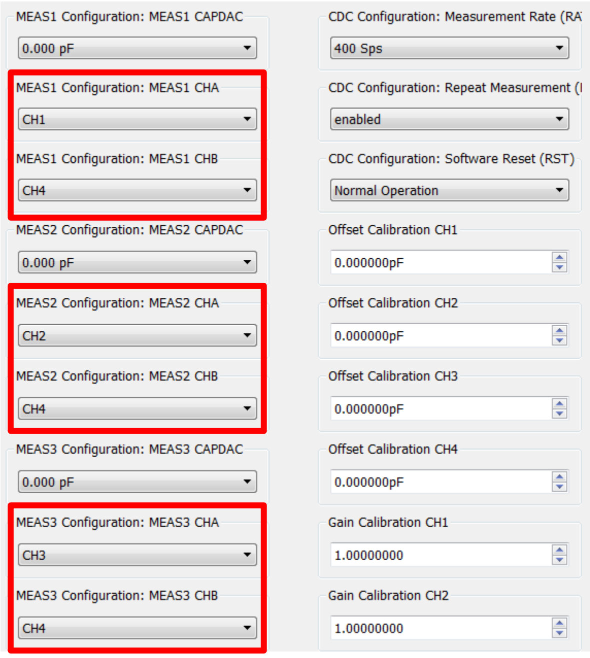

Figure 9: FDC1004EVM GUI configuration settings

NOTE: CDC configuration measurement rate and uC sampling rate can be changed based on the system requirements.

6 Test Setup

The test setup can be seen in Figure 10. The sensor design was applied to a 5.9cm (D) by 5.9cm (W) by 12.9cm (H) plastic container (wall thickness of 2mm) with 3M 200MP adhesive transfer tape. The side that has the level measurement markings should be adhered to container. A tape that is less adhesive than the 3M 200MP series tape can be used. The only concern is to minimize the air gap between the flex circuit and container wall.

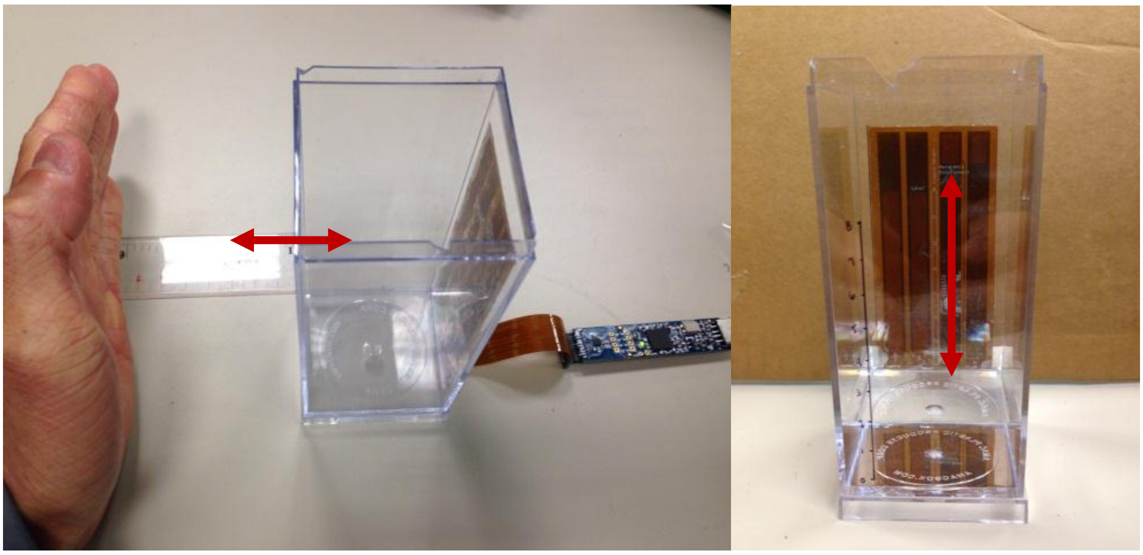

Figure 10: Test setup

The FDC1004EVM (with the sensor portion removed as shown in Figure 11) has a 50mil pitched right angled female connector solder to the FDC1004 portion. Pin1 of the connector was mated with pin1 of the header on the TI design. The FDC1004EVM was connected to the USB port of a computer to be used with the FDC1004EVM GUI. The FDC1004 and GUI were configured as described in Section 5.2. The ruler was used to determine the distance of the human hand from the container when collecting data with parasitic capacitance measurements

Figure 11: FDC1004EVM with sensor portion removed

Water was used as the liquid for the test data. Other liquids can be used in place of water. Liquids that are viscous and that leave a film or residue when dried will not have consistent measurements since the remnants of the liquid on the sides of the container will affect the capacitance seen by the sensors.

7 Test Data

7.1 Liquid Level Data

Baseline level measurements from height 0cm (empty) to height 8cm, at 1cm intervals, were collected without the presence of any human body capacitance. These measurements were then repeated with the human hand in close proximity to the container at distances between 5cm to 0cm away at 1cm intervals. Data was obtained by using the FDC1004EVM GUI. Each measurement was an average of 30 sampled points at a 100ms sampling interval and CDC rate of 100SPS. Measurements were taken for the LEVEL electrode, RL electrode, and RE electrode. The data was post-processed using Equation 2.

Figure 12 shows the capacitance at the different water level heights (blue plot) with no interference. As expected, the capacitance is linear. The red plot shows the sensitivity of the system for each interval level. Slight fluctuations occurred due to manual estimation of the water height rather than adding a metered amount of water. The system has an average sensitivity of 507fF per 1cm of water and is capable of detecting 0.1mm of water height change (with a 3fF detection condition).

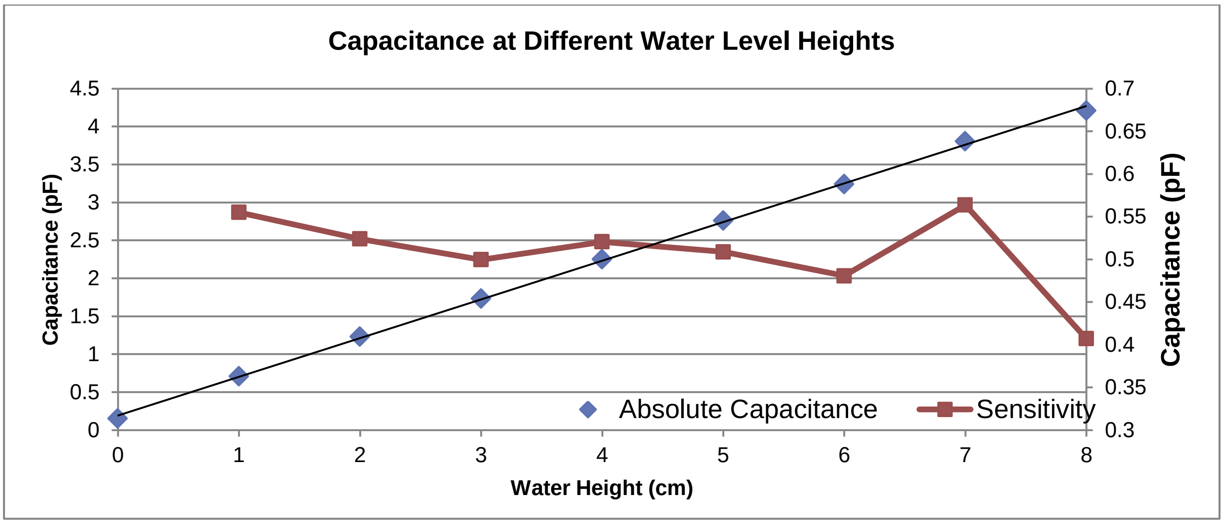

Figure 12: Measured baseline capacitance at different water level heights

From the capacitance measurements seen in Table 2, the level of the water was calculated using the level equation, Equation 2. Figure 13 illustrates the difference between the uncompensated levels and the actual levels. As the water level increases, the error in the calculated level gets significantly worse due to variations in LEVEL and RL capacitance for each level interval. A 1^{st} order linear correction algorithm (Equation 3) was applied with a gain and offset setting of 0.9 and -0.05, respectively. These gain and offset values were obtained by minimizing the overall error between the actual level and corrected level. The orange and red traces in Figure 13 illustrate that the corrected levels match the actual levels fairly well compared to the uncompensated level data. The last column of Table 2 shows that at levels between 25% and 100% exhibit a worst case error of ~2%. As the level decreases to 0, the error increases because of the fringing capacitance variations of the LEVEL and RL.

Table 2: Baseline level calculation data

ACTUAL LEVEL (cm)	LEVEL CAPACITANCE (pF)	RL CAPACITANCE (pF)	UNCOMPENSATED LEVEL (cm)	ERROR FROM EXPECTED (%)	CORRECTED LEVEL (cm)	ERROR FROM EXPECTED (%)
0	0.1525	-1.042	0	0	0	0
1	0.7075	-0.5746	1.1920	19.20	1.0228	2.28
2	1.2315	-0.5669	2.2797	27.97	2.0018	0.09
3	1.7311	-0.5718	3.3702	37.02	2.9832	-0.56
4	2.2517	-0.5723	4.4864	48.64	3.9878	-0.31
5	2.7605	-0.5745	5.6002	60.02	4.9902	-0.20
6	3.2412	-0.5750	6.6395	63.95	5.9256	-1.24
7	3.8048	-0.5745	7.8426	84.26	7.0083	0.12
8	4.2119	-0.5758	8.7412	74.12	7.8171	-2.29
Gain: 0.9 Offset: -0.05						

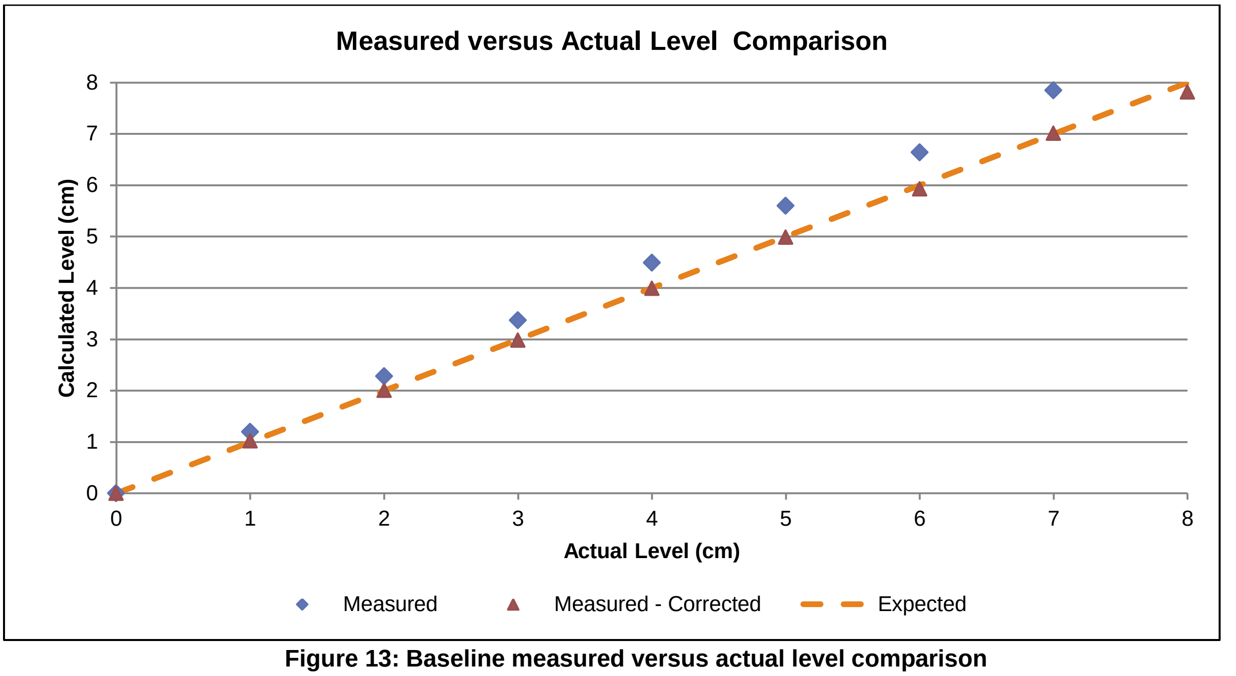

Figure 13: Baseline measured versus actual level comparison

7.2 Parasitic Capacitance Interference

Parasitic capacitance interference is a major concern for the conventional liquid level approach, but the OoP technique reduces the amount of parasitic capacitance interference seen by the electrodes. Table 3 displays a subset of the collected data and the error based on the change in water level height. As the hand approaches closer to the tank, the parasitic influences increases, but its overall influence, as the water level height increases, decreases. The OoP method operates in differential mode and the data in Table 3 are not gain and offset compensated.

Table 3: Hand interference capacitance measurements

		LEVEL Measurement			RL Measurement				
Water Level (cm)	**Hand Distance (cm)**	**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 (%)**	**Uncompensated Level (cm)**	**Error (%)**
0	Baseline	0.1525			-1.0402				
	3	0.1480	-4.5000		-1.0429	-2.7000			
	2	0.1472	-5.3000		-1.0438	-3.6000			
	1	0.1453	-7.2000		-1.0446	-4.4000			
	0	0.1427	-9.8000		-1.0460	-5.8000			
1	Baseline	0.7075			-0.5746			1.1920	
	3	0.7001	-7.4000	-1.3333	-0.5792	-4.6000	-0.9880	1.1879	-0.35
	2	0.6986	-8.9000	-1.6036	-0.5798	-5.2000	-1.1168	1.1861	-0.49
	1	0.6963	-11.2000	-2.0180	-0.5812	-6.6000	-1.4175	1.1847	-0.61
	0	0.6928	-14.7000	-2.6486	-0.5837	-9.1000	-1.9545	1.1836	-0.71
2	Baseline	1.2315			-0.5669			2.2797	
	3	1.2237	-7.8000	-0.7229	-0.5702	-3.3000	-0.6972	2.2791	-0.03
	2	1.2222	-9.3000	-0.8619	-0.5710	-4.1000	-0.8663	2.2798	0.00
	1	1.2199	-11.6000	-1.0751	-0.5720	-5.1000	-1.0775	2.2798	0.00
	0	1.2146	-16.9000	-1.5663	-0.5744	-7.5000	-1.5846	2.2802	0.02
3	Baseline	1.7311			-0.5718			3.3702	
	3	1.7236	-7.5000	-0.4751	-0.5746	-2.8000	-0.5978	3.3744	0.12
	2	1.7221	-9.0000	-0.5701	-0.5753	-3.5000	-0.7472	3.3762	0.18
	1	1.7202	-10.9000	-0.6905	-0.5757	-3.9000	-0.8326	3.3750	0.14
	0	1.7161	-15.0000	-0.9502	-0.5768	-5.0000	-1.0675	3.3742	0.12
4	Baseline	2.2517			-0.5723			4.4864	
	3	2.2407	-11.0000	-0.5240	-0.5749	-2.6000	-0.5557	4.4879	0.03
	2	2.2392	-12.5000	-0.5955	-0.5749	-2.6000	-0.5557	4.4846	-0.04
	1	2.2368	-14.9000	-0.7098	-0.5755	-3.2000	-0.6839	4.4853	-0.03
	0	2.2304	-21.3000	-1.0147	-0.5775	-5.2000	-1.1113	4.4908	0.10
5	Baseline	2.7605			-0.5745			5.6002	
	3	2.7534	-7.1000	-0.2722	-0.5760	-1.5000	-0.3221	5.6030	0.05
	2	2.7513	-9.2000	-0.3528	-0.5764	-1.9000	-0.4080	5.6033	0.06
	1	2.7495	-11.0000	-0.4218	-0.5770	-2.5000	-0.5368	5.6066	0.12
	0	2.7455	-15.0000	-0.5752	-0.5780	-3.5000	-0.7516	5.6101	0.18

Compared to a separate experiment conducted for the conventional liquid level approach (with similar sensitivity as this experiment), the OoP has a significant advantage by keeping the voltage potential of the water constant. The data in Table 4 compares the OoP against the conventional liquid level approach based on calculated level error at one specific water level. As shown, the influence of parasitic capacitance from the human hand degrades the baseline measurement tremendously in the conventional approach. This TI design had an overall calculated level error of ~0.7% (Table 3) whereas the comparable conventional liquid level design had an overall calculated level error of ~9% (Table 4).

Table 4: OoP and conventional liquid level technique comparison

	Hand Distance (cm)	**Change in Cap From Baseline (fF)**		**Calculated Level Error (%)**	
		Conventional	**OoP**	**Conventional**	**OoP**
5cm Water Level	5	57.0	-4.4	-1.83	-0.02
	4	67.1	-5.4	-2.13	0.05
	3	80.9	-7.1	-2.72	0.05
	2	106.0	-9.2	-3.38	0.06
	1	135.9	-11.0	-4.62	0.12
	0	317.8	-15.0	-8.98	0.18

8 Design Files

8.1 Schematics

To download the Schematics for each board, see the design files at TIDA-00317.

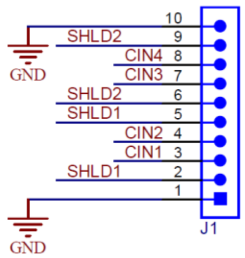

Figure 14: Schematic

8.2 Bill of Materials

To download the Bill of Material (BOM), see the design files at TIDA-00317.

Table 5: BOM

Designator	Quantity	Value	Description	Package Reference	Part Number	Manufacturer
!PCB1	1		Printed Circuit Board		FDC1004LEVLSEN-EVM	Any
J1	1		Header, 50mill, 10x1, Tin, Through Hole	Header 10x1	850-80-010-10-001101	Preci-Dip

8.3 Layout Plots

To download the Layout Plots, see the design files at TIDA-00317.

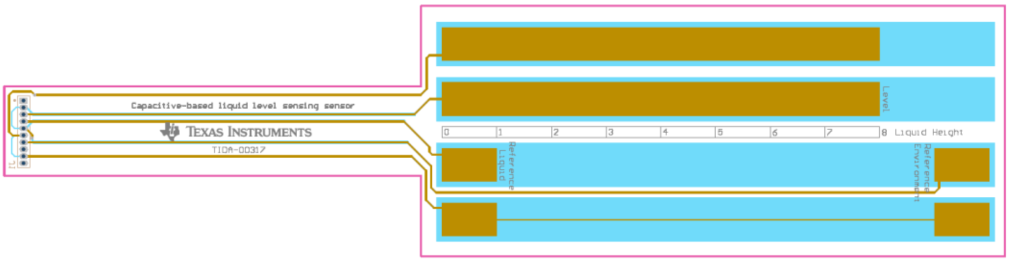

Figure 15: X-ray plot

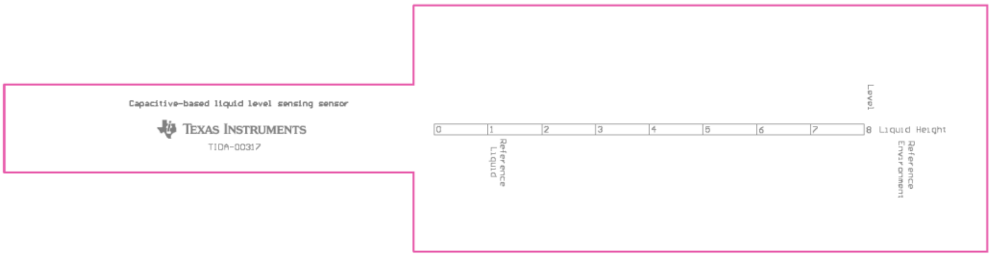

Figure 16: Top Overlay

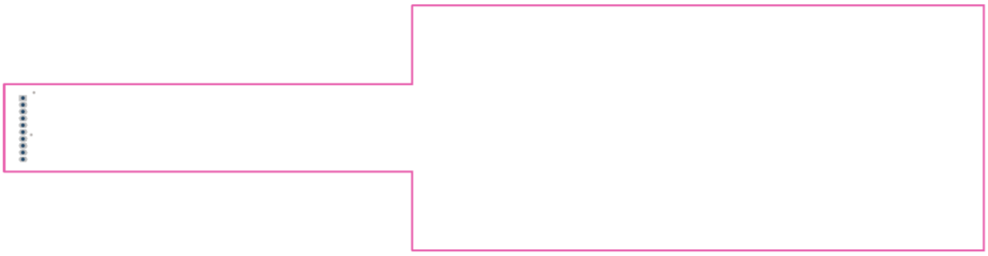

Figure 17: Top Layer

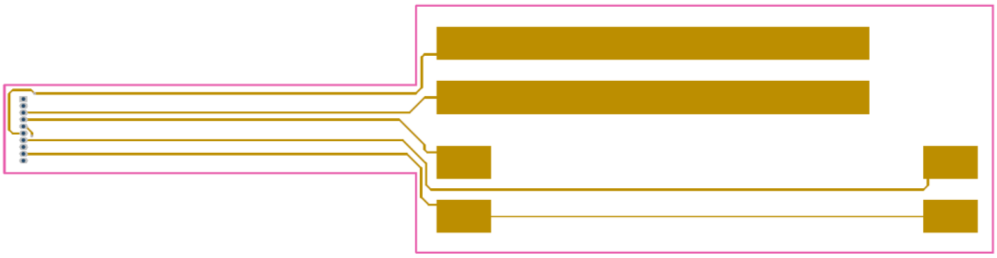

Figure 18: Mid1 Layer

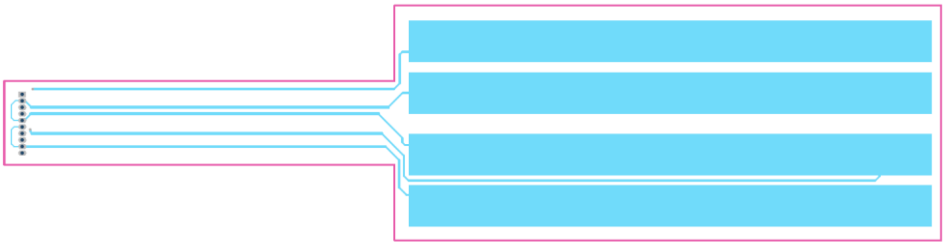

Figure 19: Mid2 Layer

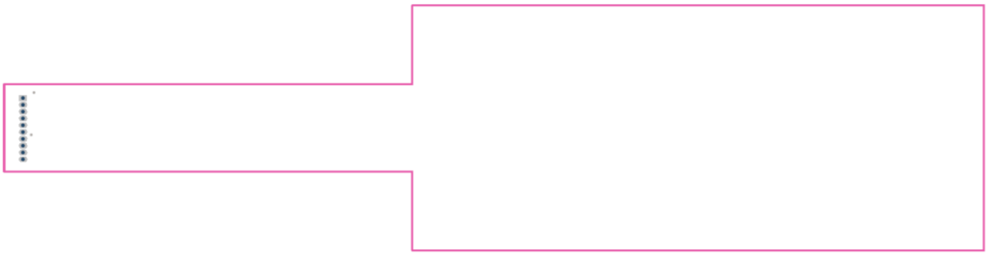

Figure 20: Bottom Layer

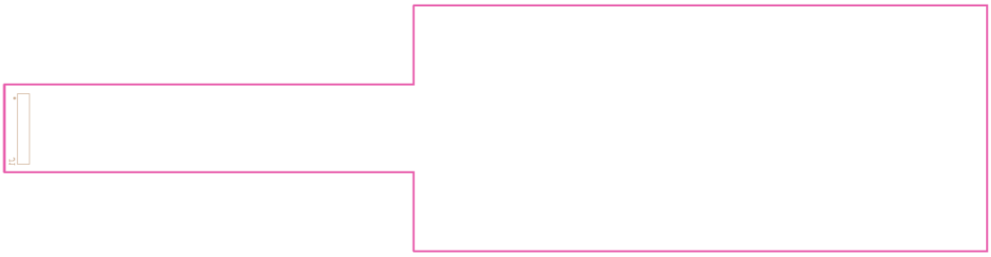

Figure 21: Bottom Overlay

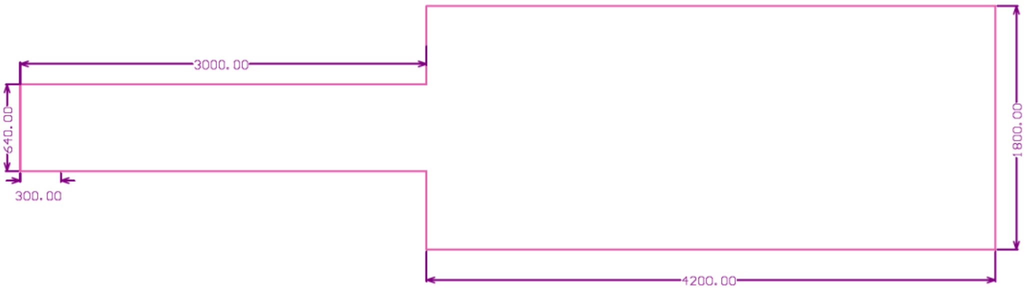

Figure 22: Board Dimensions

8.4 Layout Guidelines

Follow the guidelines in Section 4.4 and the guidelines below to ensure maximum performance from the sensor system:

- Minimize the trace length from the FDC1004 channel and shield inputs to the electrodes
- Route the channel and shield pairings together from the FDC1004 to the electrodes. The shield signal should be directly below channel trace (on the next layer below) to protect from parasitic capacitance interference. The shield should be the same trace width or slightly larger than the channel input when routing the traces together.
- Do not route the channel or shield signals through other channel or shield electrodes. It decreases the effectiveness of the electrode and can affect performance.
- Total PCB and individual layer height can be either can standard board thickness or smaller. Smaller dielectric material thickness between the channel and shield layers will allow the system to be more robust but sensitivity will decrease slightly.

8.5 Gerber files

To download the Gerber files for each board, see the design files at TIDA-00317.

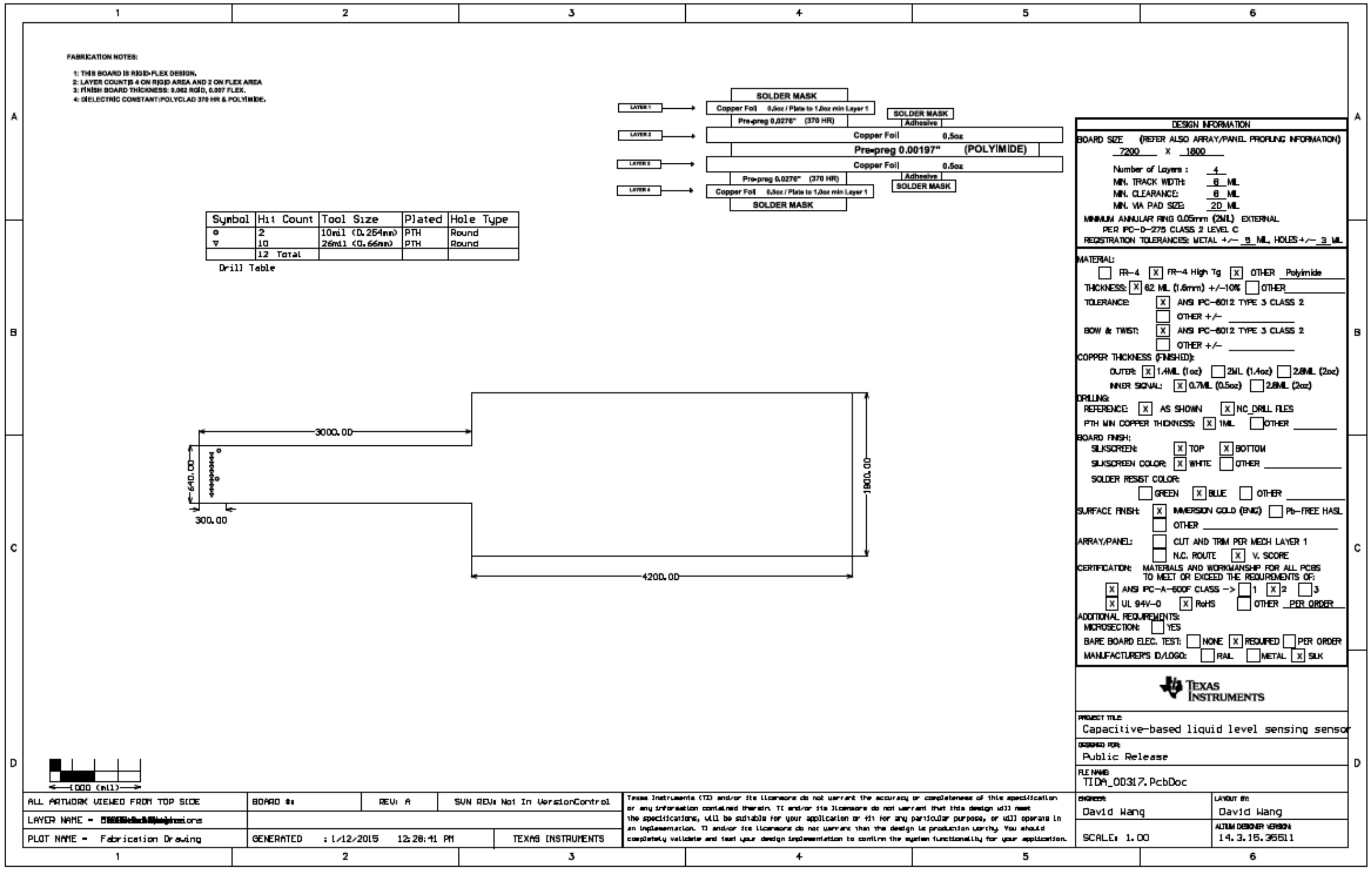

Figure 23: Gerber Files

9 References

1. Capacitive Sensing: Out-of-Phase Liquid Level Technique, SNOA925

10 About the Author

David Wang is an Applications Engineer at Texas Instruments, where he is responsible for developing and supporting the capacitive sensing solutions and technology. David brings to this role his experience in system-level design and integration expertise. David earned his Bachelors of Science in Electrical Engineering (BSEE) from the University of Florida in Gainesville, FL and Masters of Science in Electrical Engineering (MSEE) from Stanford University in Stanford, CA.