SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348-8379/ https://doi.org/10.14445/23488379/IJEEE-V10I8P106

Volume 10 Issue 8, 62-66, August 2023

Original Article

Determination of Water Level using 2-Side Interdigital Capacitor Sensor Non-Substrate

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Received: 06 June 2023 Revised: 10 July 2023 Accepted: 07 August 2023 Published: 31 August 2023

Abstract *- This research paper explores the design and operational efficacy of a non-substrate 2-side interdigital capacitor sensor for precise water level measurement. The sensor design, with a 1 mm gap, a copper line width of 1 mm, an adjacent line distance of 2 mm, and a total of 20 lines on each side, capitalizes on the permittivity disparity between air and water to track changes in water levels. The study encompasses two experimental configurations: one employing a copper plate and the other utilizing a PCB (FR4) with a relative permittivity of 4.6. The findings reveal that the sensor's capacitance alters in response to fluctuations in water levels, which is attributed to the varying contact between the copper lines and the water surface. Notably, the non-substrate sensor demonstrated a significant increase in capacitance of 236 nF/mm, with a correlation coefficient (R2) of 0.9981. These results highlight the potential of the 2-Side Interdigital Capacitor Sensor Non-Substrate as an effective tool for accurate water level measurement, emphasizing the importance of sensor design in achieving precise outcomes.*

Keywords *- 2-side interdigital capacitor, Level sensor, Non-substrate.*

1. Introduction

The Water level in wells or various water storage sources is crucial for maintenance and control [1]. However, measuring water levels efficiently and accurately is not straightforward as it often requires high-cost, complex technology [2-3]. Therefore, Interdigital Capacitor Sensor (IDCS) has emerged as a cost-effective and less complex alternative for water level [4] measurement due to its high accuracy and efficiency [5-6]. The current research aims to present a method of water level measurement using an IDC sensor, a technique that is easy to use and highly effective. The IDC sensor operates based on the principle of electrical property detection that varies with changing water levels. The working principle of the Interdigital Capacitor Sensor is based on the electrical capacitance that changes according to the area between the water level and the sensor's contact surface [8-11].

A change occurs when there is a change in the contact area of the electric field.The IDC sensor was developed by Sarawut [12] and was designed to have teeth on both sides to compensate for the gap between the teeth of the Interdigital Capacitor Sensor [13]. This design allows the sensor to perceive values more precisely. Jagrapron [14] designed a non-substrate Interdigital Capacitor Sensor to increase the capacitance value of the Interdigital Capacitor Sensor.From studying these two designs, a 2-Side Interdigital Capacitor Sensor (2s-IDCS) with non-substrate was developed to compensate for the gap between the conductor and increase the contact area with the changing water level. This development is expected to increase the sensor's resolution and accuracy in measurement. This research fills the gap in the current understanding of IDC sensor usage for water level measurement. It provides a comprehensive study of the sensor's design and its impact on the accuracy and efficiency of water level measurement. The original contribution of this research is the development of a 2s-IDCS with non-substrate, which is expected to enhance the accuracy and efficiency of water level measurement.

2. Theory and Principles

The 2s-IDCS with non-substrate is a device composed of a copper plate with a thickness of 1 mm. It is designed to have an interdigitated structure consisting of the length of the electrode (L1), the length of the IDC (L2), the width of the electrode (a), the gap between the electrodes (b), and the thickness of the copper plate (h). This configuration resembles multiple capacitors connected in parallel.

As depicted in Figure 1, the working principle of the 2s-IDCS is based on the capacitance variations of the sensor when the water level changes. These variations occur due to the modification of the dielectric permittivity between the gaps of the finger.

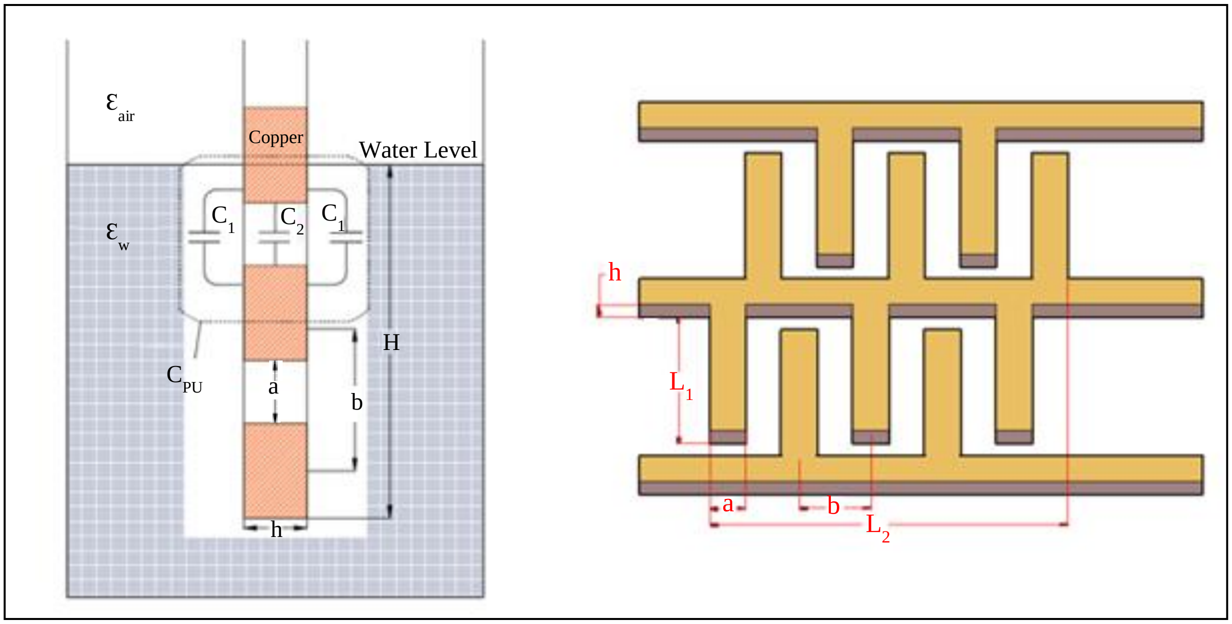

Fig. 1 Structure and parameter of 2-side Interdigital Capacitor Sensor (2s-IDCS)

The Capacitance Per Unit (CPU) can be calculated using the equation:

$$C_{PU} = 2C_1 + C_2 \quad (1)$$

$$C_{PU} = 2\left[\varepsilon_0 \frac{\varepsilon_w}{2} + \frac{k\left(\sqrt{1-\left(\frac{a}{b}\right)^2}\right)}{k\left(\frac{a}{b}\right)}\right] + \varepsilon_0 \varepsilon_w \frac{h}{a} \quad (2)$$

$$C_{PU1} = \varepsilon_0 \varepsilon_w K \ , \ C_{PU2} = \varepsilon_0 \varepsilon_{air} k \quad (3)$$

$$\text{When } k = \left[\frac{k\left(\sqrt{1-\left(\frac{a}{b}\right)^2}\right)}{k\left(\frac{a}{b}\right)} + \frac{h}{a}\right] \quad (4)$$

In Equation 2, ε_0 represents the permittivity of free space (8.854×1012 F/m), ε_{air} is the relative permittivity of the air, ε_w is the relative permittivity of the water, CPU1 refers to the portion of CPU when the Interdigital Capacitor (IDC) is in contact with air (0.020 nF/m), CPU2 refers to the portion of CPU when the IDC is in contact with water (1.640 nF/m), and K is the elliptic integral of the first kind.

$$C_{IDC} = LC_{PU1}\left(\frac{h}{a} - 1\right) + LC_{PU2}\left(\frac{L_2 - H}{a}\right) \quad (5)$$

The 2s-IDCS with non-substrate is designed with a gap of 1 mm, (a) copper line width of 1 mm, adjacent line (b) distance of 2 mm, and a total of 20 lines on each side. The sensor utilizes the free space permittivity $\varepsilon_0 = \varepsilon_{air} = 1$, while water has a dielectric constant ε_w 80 times higher than air. The capacitance changes as the water level fluctuate [7], affecting the contact between the copper lines and the water surface. This sensitivity enables precise water level measurement using the sensor, providing an effective solution. The 2s-IDCS with a substrate is fabricated using PCB (FR4) material with a relative permittivity of 4.6. The design ensures its dimensions are identical to the 2s-IDCS with a non-substrate version. The calculated value of Cpu1 is 0.012 nF/m and the calculated value of Cpu2 is 0.956 nF/m.

3. Experimental Method

The experiment was divided into two parts to compare the results obtained. The first part used a copper plate thickness of 1 mm. to match the designed size, which is a = 1 mm, b = 2 mm, N = 20 (per side), L = 5 mm, 10mm, and 15mm. In designing and building a liquid level sensor, the value of a 2-way interdigital capacitor non-substrate material cut by wire cut because the material is not connected according to Figure 2. It is necessary to hold the head and tail with a transparent acrylic sheet to keep the sheet level and correct.

Part 2 2s-IDCS with a substrate which in research creates to compare capacitance values between liquid level sensor values of digital inter-capacitance storage 2-way baseless material and baseless material according to Figure 2 Measured by RLC Meter Keysight model E4980A with an accuracy of 0.05%.

By passing Kelvin Clip, measure using parallel circuit mode, frequency signal 1 KHz at 1 Voltp-p as shown in Figure 3 by connecting between liquid level sensor values of digital inter-capacitance storage baseless material capacitor horizontal line with measuring device at frequency 1 KHz electric voltage 1 volt through Kelvin Clip Leads set.

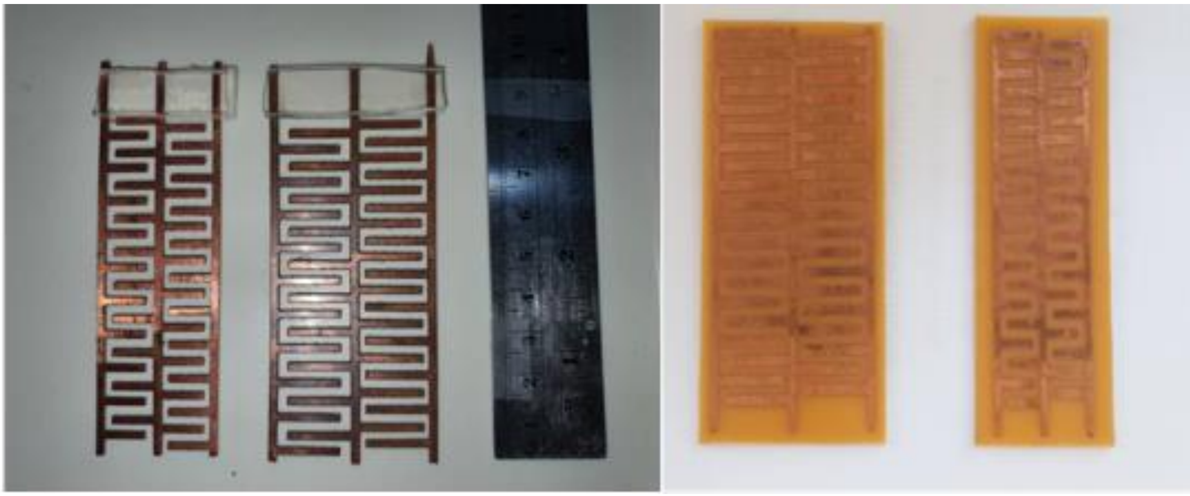

Fig. 2 2s-IDCS with non-substrate by copper plate thick 1 mm and 2s-IDCS with substrate by PCB (FR4)

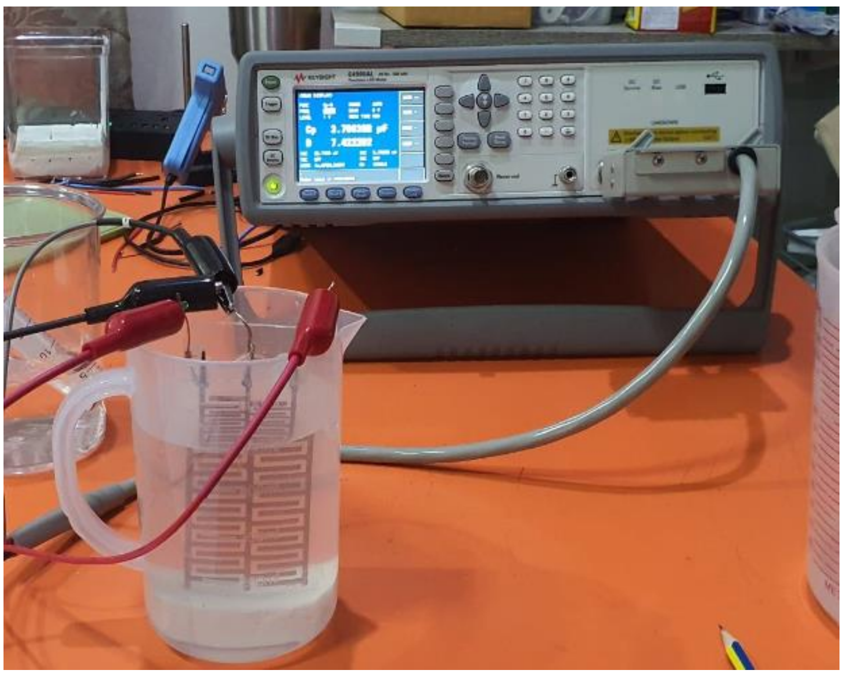

Fig. 3 The experimental measurement

4. Results and Discussion

The analysis aimed to determine the correlation of capacitance values from 2s-IDCS with substrate and non-substrate, measured using an LCR Meter at 1 kHz. The experimental results are presented as follows:

Table 1. Comparison of capacitance values from 2s-IDC sensor with substrate and non-substrate

2s-IDC model	Minimum (nF)	Maximum (nF)	(R^2)	Correlation of capacitance
a1b2L5	9.20	420.40	0.9991	y = 51.751x
a1b2L10	51.76	623.16	0.9980	y = 73.741x + 4.8371
a1b2L15	49.20	910.00	0.9943	y = 99.221x + 56.071
a1b2L5 non-sub	9.10	421.00	0.9964	y = 49.3x
a1b2L10 non-sub	40.00	1530.00	0.9966	y = 184.29x
a1b2L15 non-sub	102.00	1970.00	0.9981	y = 236.39x + 5.1241

Form Table 1, The results indicate that at a frequency of 1 kHz, the capacitive sensor with non-substrate(a1b1L15) exhibited the highest capacitance value, followed by the sensor with non-substrate(a1b1L10) and the sensor with the substrate (a1b1L15). The capacitive sensor with the substrate (a1b1L10) showed the lowest capacitance value. It is worth noting that the trendline slopes and R2 values indicate a strong correlation between capacitance values and the tested parameters.

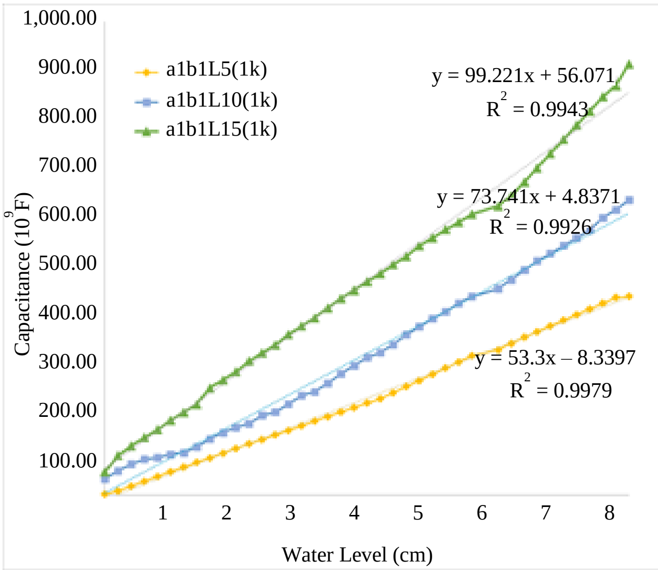

Fig. 4 Capacitance values from the 2s-IDC sensor with the substrate

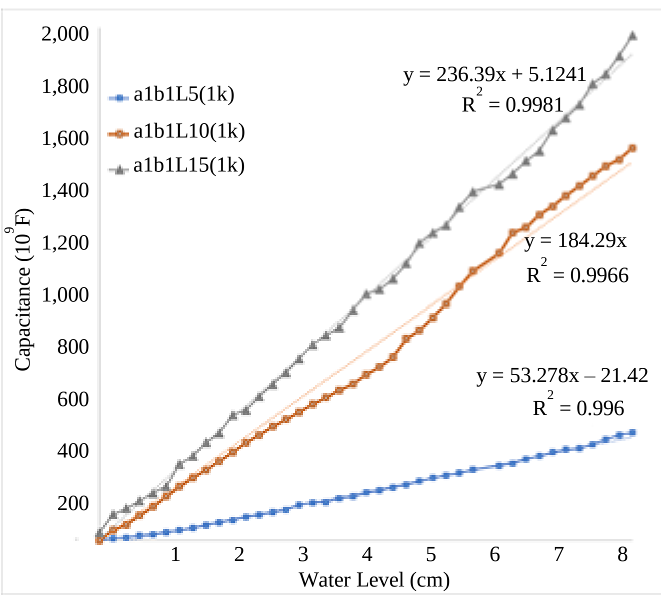

Fig. 5 Capacitance values from the 2s-IDC sensor with non-substrate

The results From Figure 5, it is evident that at a frequency of 1 kHz, the capacitive sensor with non-substrate(a1b1L15) exhibited the highest capacitance value, measuring 1.97 µF.

The corresponding slope of the trendline was 0.23 µF, and the coefficient of determination (R2) was found to be 0.9981. Following that, the capacitive sensor with non-substrate (a1b1L10) demonstrated the next highest capacitance value, which was 1.73 µF.

The trendline slope for this sensor was also 0.18 µF, and the R2 value was 0.9966.Moreover, the capacitive sensor with the substrate (a1b1L15) showed a maximum capacitance value of 0.91 µF, with a trendline slope of 0.099 µF and an R2 value of 0.9787. Further analysis revealed that the capacitive sensor with the substrate (a1b1L10) had the lowest capacitance value among all tested sensors, measuring 0.42 µF. The slope of its trendline was determined to be 0.07 µF, and the R2 value was 0.9980. Comparatively, the capacitive sensor with non-substrate(a1b1L5) had the same capacitance value of 0.42 µF as the previous sensor but with a slightly lower trendline slope of 0.05 µF. The R2 value for this sensor was calculated to be 0.9964.

Finally, the capacitive sensor with non-substrate (a1b1L5) showed the lowest capacitance value of 0.42 µF among all the tested sensors, with a trendline slope of 0.04 µF. The R2 value for this sensor was found to be 0.9655.

5. Conclusion

In conclusion, the testing of 2s-IDCS with substrate and non-substrate for capacitance measurement under changing water levels revealed that both sensors exhibited increased capacitance with increased water quantity. The 2s-IDCS with non-substrate demonstrated higher capacitance values than the sensor with the substrate at the same water level. The study on capacitance measurement of both sensors under changing water levels demonstrated that the dielectric constant in the vicinity of the sensors varied as the water level fluctuated, leading to changes in capacitance values.

Consequently, the capacitance values of both sensors were affected by changes in water levels. These findings are consistent with previous research by Boonkirdram [12], which presented dual-sided digital capacitive sensors for water level measurements, showing increased capacitance with increased water quantity. Furthermore, the results align with the work of Obma[1], who investigated capacitive sensors with substrate and non-substrate and found that the non-substrate influenced the water level's impact on capacitance values.

The study provides valuable insights into the behaviour of 2s-IDCS with substrate and non-substrate under varying water levels, contributing to a better understanding and optimization of their performance in water level measurements. These findings are essential for the development of accurate and reliable capacitive sensors for diverse applications in the future.

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