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The Non-Substrate Interdigital Capacitor Level Sensor

Abstract. *This paper presents the non-substrate interdigital capacitor level sensor. The interdigital capacitor level sensor is designed and fabricated to be two types that are the fabricated with an epoxy substrate and with none substrate. Each type is separated to be 6 models that are designed with difference dimensions of the width, the gap and the length of the hard copper (H04) lines circuit for comparing and obtaining the high linearity model. The fabricated with none substrate can sense the maximum capacitance of 877.56 nF that is higher than the maximum capacitance of the sensor with substrate of 341.12 nF. The higher range of the capacitance of the circuit with none substrate, provides the wide range to sense the water level with high accuracy that is suitable to develop to be the standard level sensor in the future.*

Streszczenie. *W artykule opisano czujnik pojemnościowy bez podłoża. Czujnik analizowano dla różnych geometrii miedzianego meandra Czujnik może być wykorzystywany do pomiaru poziomu wody.* ***Projekt pojemnościowego czujnika poziomu wody***

Keywords: Interdigital Capacitor, Level Sensor, Non-Substrate .
Słowa kluczowe: czujnik pojemnościowy, czujnik poziomu wody.

Introduction

Nowadays the development of the reception for water measure machine spread all over the industrial field, meteorology, and environment to analyze such as the humidity in air, liquid measurement, water quality, etc. These are necessary for developing the receptor to be used in those works. Interdigital Electrode Capacitor [1-3] is one of the interesting receptors due to the simple design and uncomplicated which is the measurement of the value of capacitor increasing in accordance with the height of liquid. Then, convert the capacitor value to interpreted and measure the desired volume

Firstly, from the literature review of the research on the development of the receptors which have been developed in many forms such as the capacitance measurement of liquid by using the long metal or large sheet [4-5] and the development of capacitance measurement in cylinder shape [6-9]. Some researchers had developed the receptor which is Interdigital Electrode Capacitor (IDC) used in measuring the humidity of soil, the resistant of electric wire, and the humidity in concrete [10-11], measuring percentage of the sugar concentration [12], and the level of liquid: water or milk [13-18]. Since, the undesirable IDC of these mentioned research are designed on the print circuit board (PCB) with substrate. This substrate causes the least value of capacitance in the unprecise scale. Particularly, Interdigital Electrode Capacitor Level Sensor, the liquid surface will not touch all areas of receptor on the other side. Therefore, the Non-Substrate Interdigital Capacitor Level Sensor is more precisely and could apply with the precise works in the future.

The Interdigital Capacitor Level Sensor uses the principle of the parallel of copper line circuit which have anode and cathode. The number of copper line circuit which is increased in parallel will make the capacitance increase as well.

The typical design of Interdigital Capacitor Level Sensor as shown the structure in Figure 1 starts from find the C_{pu} in equation 1 and 2 which has the component ε_0 is permittivity of free space (8.854×10^{-12}F/m), ε_1 is the relative permittivity of the material under test, ε_2 is the relative permittivity of material between electrodes and ε_3 is the relative permittivity of the PCB substrate. K (x) is elliptic integral of the first kind and *a* is the width size of segment *b*, which is the duration of the segments. Finding the total capacitors of Interdigital Capacitor Level Sensor in equation 3 including L is the length of segment and N is the number of segments. [12]

$$C_{PU} = \varepsilon_0\left(\frac{\varepsilon_1+\varepsilon_3}{2}\right)\frac{K\left(\sqrt{1-(x)^2}\right)}{K(x)} + \varepsilon_0\varepsilon_2\frac{h}{a} \tag{1}$$

$$x = \frac{a}{b} \tag{2}$$

$$C = C_{PU}(N-1)L_1 \tag{3}$$

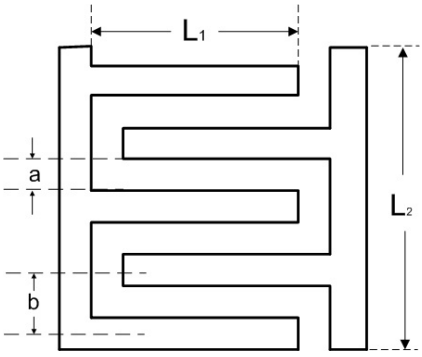

Fig.1. Structure of Interdigital Capacitor Level Sensor

The researcher has designed the origin of Interdigital Capacitor Level Sensor to calculate and put the number in equation (1-2) to find the capacitor with parameters, h=0.105 mm, a=2 mm, b=2 mm, L=15 mm and N=20. The free space permittivity $\varepsilon_1 = \varepsilon_2 = 1$, and the relative permittivity of substrate (Epoxy) $\varepsilon_3 = 4.6$. The total calculated capacitance is 0.2789 pF. If there is the measurement of water level, it will have the electric value more than the air in eightyfold and will change the capacitors based on the touch between copper sheet and the water level.

Experimental method

For the design of experiment, there will be two main parts to compare the capacitor which one is the capacitance measurement with Epoxy the relative permittivity of substance $\varepsilon_3 = 4.6$, the density of copper is h=0.105 mm as shown in Fig. 2 for 6 models that has the difference in size of a, b, and L in Table 1.

Another part is the capacitance measurement without epoxy substrate. The density of hard copper (H04) is h = 0.105 mm as shown in Fig. 3 for 6 models in Table 2 with the various size of a, b, and L as shown in Table 2.

Table.1. the IDC level sensor has a variety length, width and space difference with epoxy substrate.

IDC model	b (mm.)	a (mm.)	L (mm.)
1	2	1	15
2	2	2	15
3	3	1	15
4	2	1	10
5	2	2	10
6	3	1	10

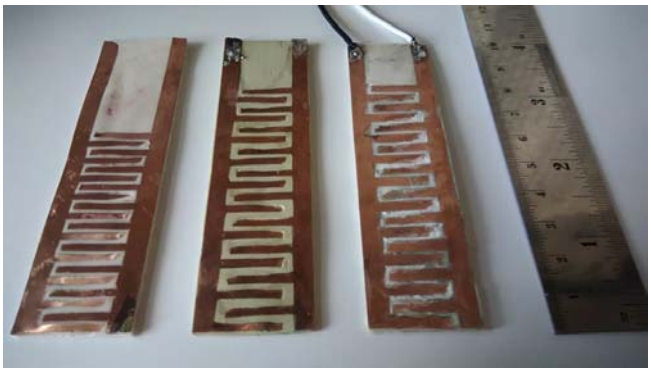

Fig.2. The fabricated the novel IDC level sensor with epoxy substrate .

Table.2. Table of the IDC level sensor has a variety length, width and space difference with non epoxy substrate .

IDC model	b (mm.)	a (mm.)	L (mm.)
1	2	1	15
2	2	2	15
3	3	1	15
4	2	1	10
5	2	2	10
6	3	1	10

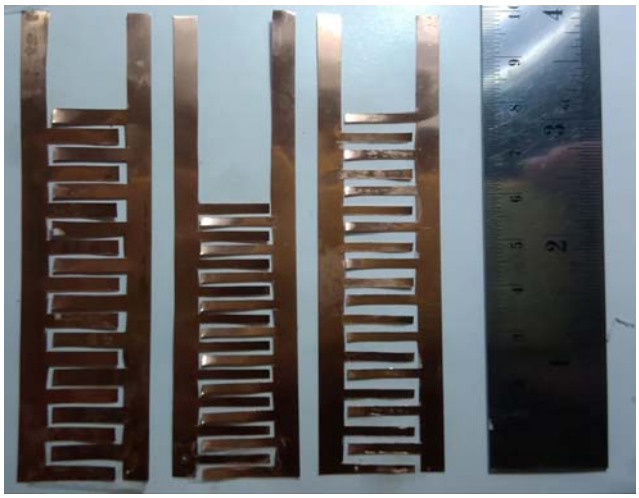

Fig.3. The fabricated IDC level sensor with non-substrate .

Then, calculating the capacitor with epoxy substrate of 6 models as Table 1 and without epoxy substrate of 6 models in Table 2 by using LCR Meter (GW intstek LCR – 817) which the attribution of measurement accuracy is 0.05%. Includes Kelvin Clip Leads. The experimental method used the parallel mode which each model will be measured the values from 0-80 mm by the each time is 5 mm, 16 periods in total. Calculating each 3 period repeatedly to find the best capacitor values, as shown in Fig. 4.

The second part to use Interdigital Capacitor Level Sensor by choosing the high linearity model which has a = 2 mm, b=2 mm and L=15 mm with epoxy substrate and without epoxy substrate. The method is using the sensor through extended module LM393 and interpreting through microcontroller from Serial Monitor in order to compare with LCR Meter with each model will measure from 0-80 mm with each 5 mm of periods for 16 times in total and measure repeatedly in each 3 periods to find the capacitance values, as shown in Fig. 5

Fig.4. The measurement setup for IDC level sensor.

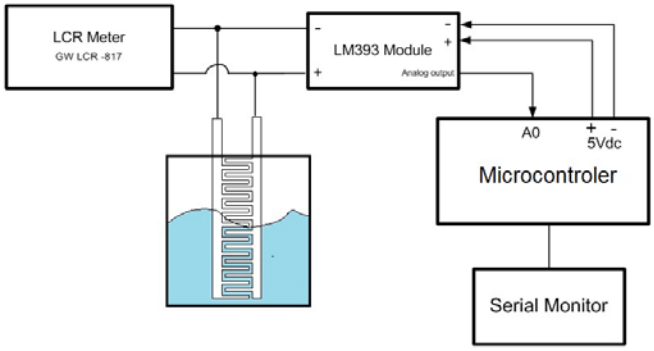

Fig.5. The novel IDC level sensor system with microcontroller

Results and Discussion

For the first part of experiment with epoxy substrate 6 models in Table 2, the first model has the capacitance value of 0.12- 488.21 nF where the correlation coefficient (R^2) is 0.966. The second model has the capacitance value of 0.28 – 355.87 nF where the correlation coefficient (R^2) is 0.973. The third model has the capacitance value of 0.11 – 536.44 nF where the correlation coefficient (R^2) is 0.982. The fourth model has the capacitance value of 0.13-210.21 nF where the correlation coefficient (R^2) is 0.982. The fifth model has the capacitance value of 0.27-168.87 where the correlation coefficient (R^2) is 0.987. The sixth model has the capacitance value of 0.16 – 225.44 nF where the correlation coefficient (R^2) is 0.988, as shown in Fig. 6.

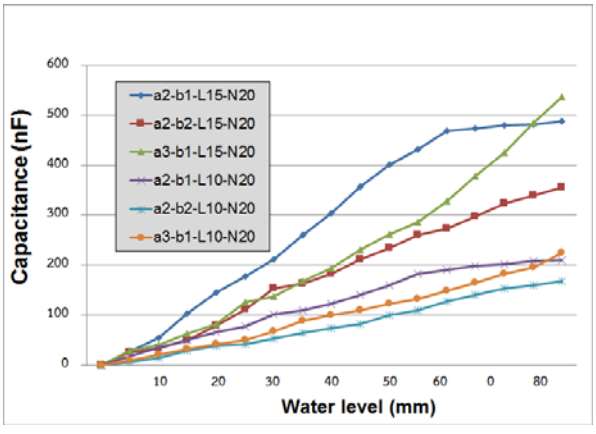

Fig.6. Experiments result of the capacitance measurement using the sensor with epoxy substrate of the 6 models

The result of the experiment with non-substrate 6 models is in Table 2. The first model has the capacitance value of 0.12- 753.81 nF and where the correlation coefficient (R^2) is 0.967. The second model has the capacitance value of 0.87 – 658.56 nF and where the correlation coefficient (R^2) is 0.997. The 3rd model has the capacitance value of 0.16 – 877.56 nF and where the correlation coefficient (R^2) is 0.994. The 4th model has the capacitance value of 1.03 – 442.56 nF and where the correlation coefficient (R^2) is 0.982. The 5th model has the capacitance value of 0.27-168.87 and where the correlation coefficient (R^2) is 0.981. The 6th model has the capacitance value of 0.26 – 531.28 nF and where the correlation coefficient (R^2) is 0.977 as shown in Fig. 7.

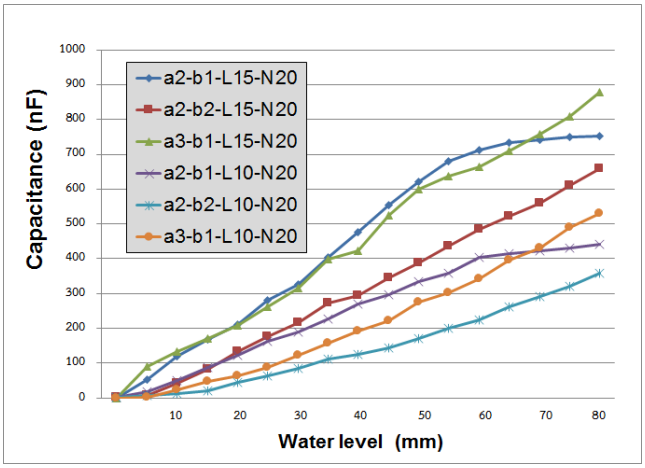

Fig.7. Experiments result of the capacitance measurement using the sensor with non-substrate of the 6 models

Table.3. Experiments result of the capacitance measurement using the sensor with epoxy substrate and non-substrate

IDC model	a (mm.)	b (mm.)	L (mm.)	Capacitive(Max) Substrate	Capacitive(Max) Non Substrate
1	2	1	15	488.21 nF	753.81 nF
2	2	2	15	355.87 nF	658.56 nF
3	3	1	15	536.44 nF	877.56 nF
4	2	1	10	210.21 nF	442.56 nF
5	2	2	10	168.87 nF	358.56 nF
6	3	1	10	225.44 nF	531.28 nF

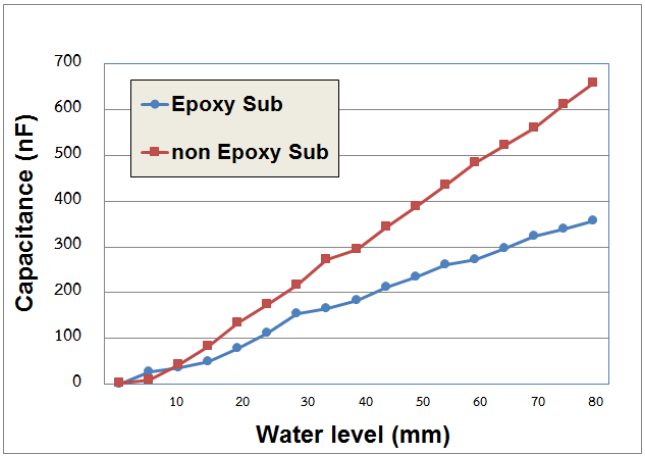

Fig.8. The comparison of the model with epoxy substrate and non-substrate of the 2nd model (a=2mm,b=2mm ,L=15mm)

From the result of experiment of 2nd model (a = 2 mm ,b=2 mm and L=15 mm) with Epoxy board and without printed circuit board, comparing the capacitor values is shown in Fig. 8 that the model with Epoxy board has the capacitance value of 0.67 – 355.87 nF and where the correlation coefficient (R^2) is 0.997 and model without board has the capacitance value of 0.87 – 658.56 nF and where the correlation coefficient (R^2) is 0.994. Thus, the distance of capacitor values from maximum is 80 mm at 302.69 nF.

The result of the part two experiment of the comparison between the capacitor values from micro-controller and LCR Meter with with epoxy substrate and non-substrate of the 2nd model (a=2mm,b=2mm ,L=15mm) is shown in Fig.10. The model with epoxy substrate has the capacitor values of 0-320.45 nF from micro-controller and where the correlation coefficient (R^2) is 0.995 from LCR Meter is 0.67 – 355.87 nF and where the correlation coefficient (R^2) is 0.997. For the model non-substrate, the capacitor value of 0 – 620.45 nF from micro-controller and where the correlation coefficient (R^2) is 0.995 and from LCR Meter is 0.17-658.356 nF and where the correlation coefficient (R^2) is 0.985.

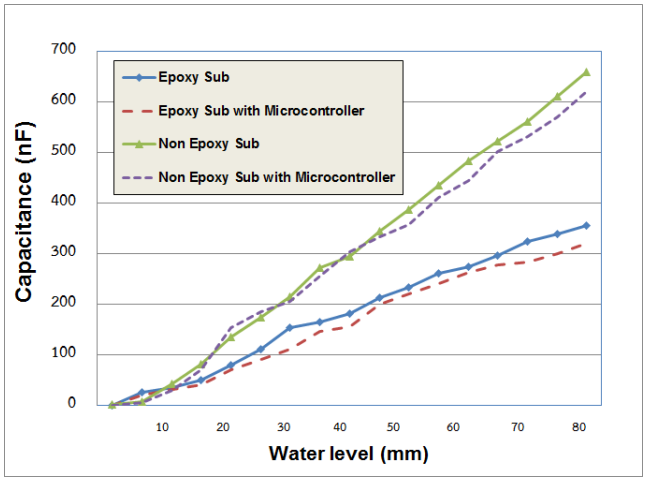

Fig.9. The comparison of the capacitor value from the micro-controller and LCR Meter with Epoxy board and without board in the 2nd model (a=2mm,b=2mm ,L=15mm)

According to the experiments, the Non-Substrate Interdigital Capacitor Level Sensor can be applied with micro-controller and be converted to precise value because it has the increased capacitor value with board up to 302.69 nF. Therefore, it could extend the area to precisely measure water level.

Conclusions

This research shows the Non-Substrate Interdigital Capacitor Level Sensor which the resulf of the experiment has the maximum value at 877.56 nF. It causes the increasing capacitor values with board up to 302.69 nF and could be extented the area of water level for accurate and precise data. Also, it can apply with the micro-controller and can develop this into the standard of water level measurement and connect to the internet network IOT in the future.

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