Sarawoot Boonkirdram, Worawat Sa-ngiamvibool

Mahasarakham University

doi:10.15199/48.2015.08.23

A Novel Planar Interdigital Capacitor Level Sensor

***Abstract**. This paper presents a study of a novel planar inter digital capacitor level sensor. It was design by using capacitor principle and they have been fabricated using standard single side on printed circuit board (PCB) fabrication technology. This experiment is carried out by using our sensors are different from the past IDC by adding finger beside the first finger of IDC. The value of capacitance is depending on length width space and increment the water. The linearity response with correlation coefficient (R^2) was between 0.9782 to 0.9984. The results of the experiments provide an opportunity for further research in the development of low cost, small of sensor for measuring water level. The experimental also results show there is possibility of developing a sensor for water levels generally. A novel planar IDC level sensor has been fabricated to have better sensing performance. The advantage of this sensor is a very simple structure and inexpensive.*

.

Streszczenie.** W artykule zaproponowano nową koncepcję planarnego pojemnościowego czujnika poziomu. Do wykonania czujnik wykorzystano standardową technologią obwodów drukowanych. Otrzymano liniową funkcję przetwarzania ze współczynnikiem korelacji między 0.9782 a 0.9984. **Nowy planarny pojemnościowy czujnik poziomu

Keywords: Interdigital Capacitor(IDC), Capacitance, Water Level Measurement, Liquid level, Print Circuit Board (PCB).
Słowa kluczowe: czujnik poziomu wody, czujnik pojemnościowy.

Introduction

Today the liquid measurement used by the manufacturing industry is very important. The level of liquid that is contained in containers or tanks is one of importance in the measurement and control of the industry system [1]. For example the level of fruit juice in the tank, beer or wine tank. Measurement of the liquid in the food products and beverages industry needs to be careful to be sure that it is correctly managed in the planning process and that is avoid the lack of the important material in manufacture [2]. Because the value of the liquid level affect other parameters such as pressure, flow rate for example keeps the level of water unchanged and showing the status of the level of water in the holding tanks. Moreover it can protect and is able to avoid damage to equipment such as the motor of the water pump that may be damage because of its continual working while the tank or container that holds the water is empty or prevent water overflow when the water level in the tank rise which will affect the whole the process of manufactory not working. Therefore the liquid level sensor is an important and effective instrument for the manufacturing industry.

Experiments and Methods

Character of IDC level sensor can be used in water level measurements by measuring electrical properties. Sensor model invented from phenolic printed circuit board, which is a brown color. Phenollic PCB produce from the paper hold together by phenolic ration, which be used in general works, fit in with work that need to reduce cost, it is cheaper than PCB which is produced from other compounds and is as same as dielectric at 2.8. IDC level sensor composite of 2 conductive plates or more. All plates will connect to the power supply. Conductive plates will be separated by insulation called dielectric which blocks consistency flowing current. When dielectric material is placed in the electric field which cause conductive plates which are a different electric charge. The result is the capacitance between the conductive plates will be increased by the properties of the dielectric material that is placed. Each material will be a different dielectric value. This principle can be applied to be used as a sensor to measure properties of diverse materials, depending on the properties of the dielectric. When the conductive plates placed alternately between anode and cathode will cause the capacitance to increase as the capacitor is connected in parallel, called Inter-digital Capacitor. When connecting a capacitor to the power supply will cause the current to flow for a short period and takes the charge accumulated on the conductor. A novel planar IDC level sensor, the features and structures is similar to a finger or comb. Placing conductive plates alternately between anode and cathode in the horizontal, works by putting two terminal electrodes in the liquid to measure the liquid level. The capacitance of the capacitor can be calculated from the first equation (1).

(1)
$$C = \varepsilon_o \varepsilon_r \frac{A}{d}$$

where C is the capacitance (in farads,F), ε_0 is the permittivity of free space (8.854×10^{-12} F/m), ε_r is the relative static permittivity or dielectric constant (water= 1), A is the effective area (in square meters) where the finger length multiply by width and d is the effective spacing between finger is positive and negative electrode (in meters). From the equation above the capacitance is directly proportional to the area and inversely proportional to the distance between fingers. Thus, capacitance is bigger because the distance between fingers is smaller and the greater the area.

IDC applied for the water level will be measuring the capacitance that occurs between dielectric materials two kinds are water and air. Water is precious electric over air, about 80. And electric air has values around 1. So when IDC contact with more water, the capacitance will increases as the water level increase. The capacitance between the conductive plates [7] is as equation (2).

(2)
$$C_{PU} = \varepsilon_o \frac{(\varepsilon_w + \varepsilon_S)}{2} \frac{K\left[\sqrt{\left\{1-\left(\frac{w}{b}\right)^2\right\}}\right]}{K\left[\frac{a}{b}\right]} + \varepsilon_o \varepsilon_{wa} \frac{h}{a}$$

The capacitance of the IDC is the sum of the capacity immersed in water and capacity in air. C_{PU} is capacitance between conductive plates. ε_0 is dielectric constant of air space. ε_{wa} is dielectric constant of water. ε_s is the substrate material. A novel planar IDC level sensor in Fig.1 were defined by parameters using letters of the alphabet defined to follow, *a* is the width of the conductive plate, *b* is the distance between conductive plates, *t* is thickness of conductive plate is 35μm, K[a/b] is function of elliptic integrals of modulus. If it is set to L is the length of the conductive plates which the amount is *N*. The total capacitance of the IDC as equation (3).

(3) $$C_{C1} = \mathrm{NLC_{PU}}$$

An IDC design showed a top view on PCB in Fig.1. The novel planar interdigital capacitor level sensor were designed have two positive electrodes and one negative electrode at end separated.

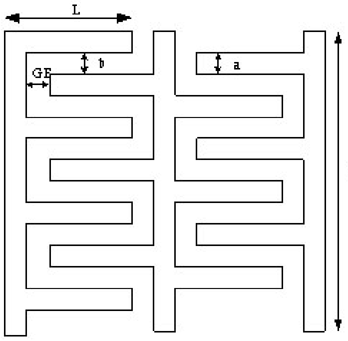

Fig.1. Details regarding the dimensions of a new planar interdigital capacitor level sensor.

An IDC level sensor can change the length the width and spaces between the conductive plates that would cause a change in the capacitance. Fig.2 shows that a novel planar IDC level sensor was designed by a add of IDC another conductive plate (C_{c2}) connected in series with the conductive plate IDC's first set(C_{c1}). Advantages of adding another conductive plate is the ability to measure the water level thoroughly. As a continuation of the capacitance obtained from IDC second set. Because IDC first series will have spaces between the conductive plates the basic properties of the capacitor affects lack of continuity and consistency of the capacitance in the event of a change or an increase or decrease in the level of water by a small amount. Adding IDC second series of a novel planar IDC level sensor to reduce the limitations of the basic properties of the capacitor model by the IDC first series. The capacitance of a novel planar IDC level sensor (C_T) can be calculated using the forth equation (4).

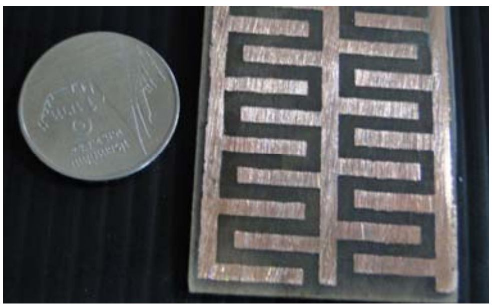

Fig.2. A novel planar IDC level sensor was designed by a add of IDC another conductive plate

An IDC level sensor can change the length the width and spaces between the conductive plates that would cause a change in the capacitance. Fig.2 shows that a novel planar IDC level sensor was designed by a add of IDC another conductive plate (C_{c2}) connected in series with the conductive plate IDC's first set(C_{c1}).

Advantages of adding another conductive plate is the ability to measure the water level thoroughly. As a continuation of the capacitance obtained from IDC second set. Because IDC first series will have spaces between the conductive plates the basic properties of the capacitor affects lack of continuity and consistency of the capacitance in the event of a change or an increase or decrease in the level of water by a small amount. Adding IDC second series of a novel planar IDC level sensor to reduce the limitations of the basic properties of the capacitor model by the IDC first series. The capacitance of a novel planar IDC level sensor (C_T) can be calculated using the forth equation (4).

(4) $$C_T = C_{C1} + C_{C2}$$

When C_T is the sum of the capacitance of a novel planar IDC level sensor from sum of the capacitance of the IDC first set(C_{c1}) combined with the capacitance of the IDC second set(C_{c2}). The details concerning the size of a novel planar IDC level sensor that were invented and used in this experiment as Table 1 by a novel planar IDC level sensor measurements used in this experiment consists of 12 models with different of the length the width and the space between conductive plate. The constant height is 150mm. The length of conductive are 5, 10, 15 and 20mm. The width and the space between the conductive plates are 1, 2 and 4mm.

Table 1. Table of the novel planner IDC level sensor has a variety length, width and space difference.

IDC models	b (mm)	a (mm)	L (mm)
1	1	1	5
2	1	1	10
3	1	1	15
4	1	1	20
5	2	2	5
6	2	2	10
7	2	2	15
8	2	2	20
9	4	4	5
10	4	4	10
11	4	4	15
12	4	4	20

After fabrication process completed, the novel planner IDC level sensor was inspect of defects on PCB by check the conductor being continuity of conductive and separated parts and removed unwanted small copper. Because small copper are mounted on a substrate, its will affect performance of a novel planar IDC level sensor measure the level. It also increases the parasitic capacitance. Fig.3 shows the final fabricated novel planner IDC level sensor.

Fig.3. The fabricated the novel planner IDC level sensor.

The Experiments to study the response of the capacity of the novel planner IDC level sensor. The water level varies with the capacity water in different studies from 1 to 40 levels. The novel planner IDC level sensor used in this experiment has different length width and the space and there are twelve models have been used during in experiment. The equipment used in this experiment is a LCR meter for read from the capacitance measurements.

(Aligent LCR-800 Basic Measurement Accuracy 0.05%. Includes Kelvin Clip Leads). The IDC sensor is connected to positive terminal, negative and ground terminal at LCR meter before the sensor will be immersed in the water. A frequency of 10KHz is set up at the LCR meter and set the voltage used in 1.0V for drive and 0V for ground. This equipment is used to measure the value for capacitance to the variation in water level. The experimental setup shows in Fig.4

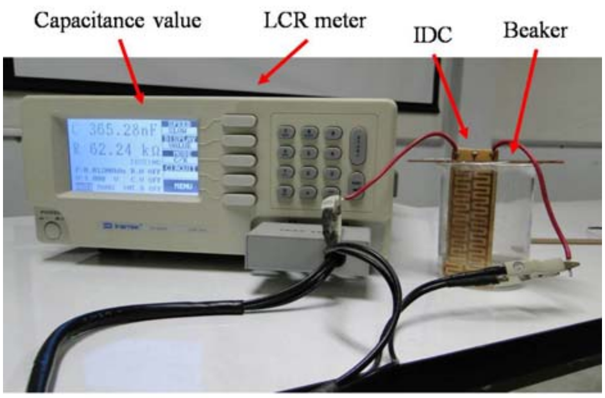

Fig.4. The experimental setup for measure capacitance value.

In this experiment LCR meter has been used to investigate the capacitance value for the forty different water level in the beaker shows in Fig.5. The water supply temperature of the water is 25–30°C. The novel planner IDC level sensor in the beaker and adjusted to an upright installation. In order to read the values accurate and with least errors. Then increments water into the beaker of 2mm and read the capacitance to measure the water level by using LCR meter. The experiment is repeated until the water level reached a level forty.

Fig.5. Forty different water level in the beaker.

Results and Discussion

The experiment was conducted to find the linear response of a novel planar IDC level sensor. The trial level sensor water level was from 1 to 40. Raising the water level by 2mm each time and measuring the capacitance of the IDC by LCR meter with a meter to read the data from the measured capacitance at the same time. A comparison was made in the measured capacitance of the IDC with a total of 12 different models. The results in Fig.6 show the relation between the water level and the capacitance of a novel planar IDC level sensor. Measured with a LCR meter to measure the response is linear throughout the measurement range from 1 to level 40. The linearity response with correlation coefficient (R^2) were between 0.9782 and 0.998. A novel planar IDC level sensor with the length of the conductor is 15mm width and spacing was 1mm. The best response linear correlation coefficient (R^2) was 0.998. The capacity was between 0.002 to 429.12nF. A novel planar IDC level sensor with the length of conductor plates at 20mm. the width and the spaces between the conductors was 1mm. its capacitance was 837.51nF, which is the largest novel planar IDC level sensor models.

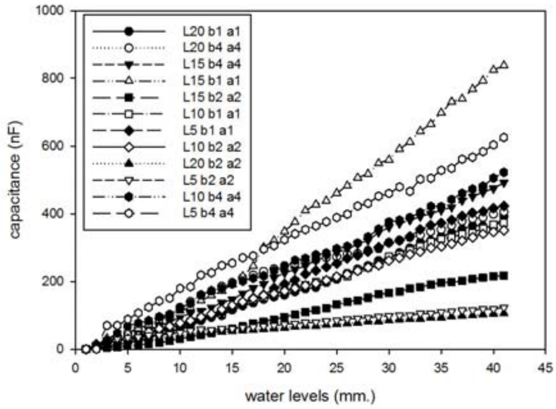

Fig.6. Graph the linear response capacity of the novel planner IDC level sensors.

The result of the next experiment was to determine the effect of the difference between the length and width of the spaces between the conductors. A novel planar IDC level sensor. The length of the conductors varied from 5, 10, 15 and 20mm. The width and the spaces between the conductors were 1, 2 and 4mm.

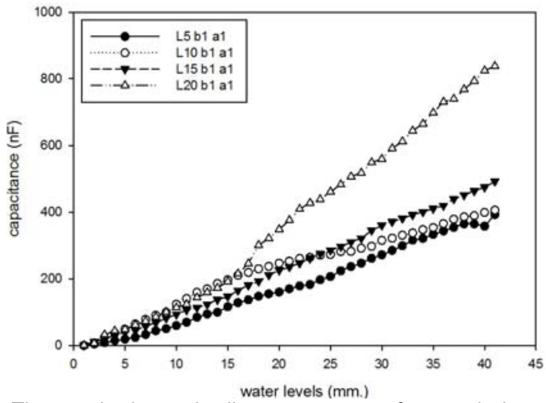

Fig.7 The graph shows the linear response of a novel planar IDC level sensor. Sensors on the lengths of the conductive plates were 5, 10, 15 and 20mm, the width and the spaces between the conductive plates were 1mm.

In Fig.7 it will be noticed that the largest increase in capacitance was a novel planar IDC level sensor, the conductors length was 20mm, the width and the spaces between the conductors were 1mm. When the height of the water level was at 40 the results showed clearly that using a novel planar IDC level sensor with a value of 20mm, the length of the conductor, the w idth and the space between the conductors were 1mm. would provide capacitance between 0.046 to 837.51nF. The linearity response with correlation coefficient (R^2) was 0.994. A novel planar IDC level sensor with the length of the conductor 15mm. the width and conductor spacing were 1mm. would provide capacitance between 0.002 to 492.12nF. The linearity response with correlation coefficient (R^2) was 0.998. When the height of the water was at a level of 40. A novel planar IDC level sensor with the length of the conductor 10mm. the width and conductor spacing were 1mm. would provide capacitance between 0.015 to 405.72nF. The linearity response with correlation coefficient (R^2) was 0.982. When the height of the water level at 40 and a novel planar IDC level sensor with a value of 5mm with the length of the conductor, the width and the space between the conductors were 1mm. would provide capacitance between 0.101 to 392.43nF. And the linearity response with correlation coefficient (R^2) was 0.996.

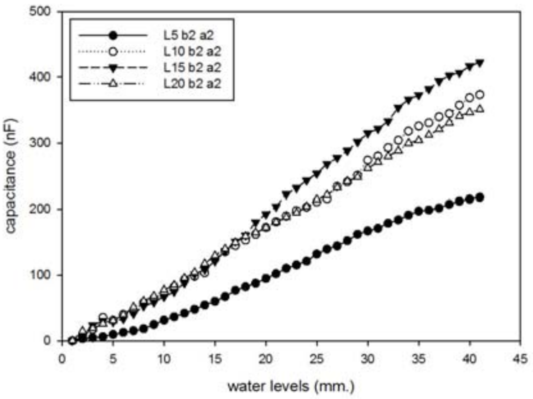

Fig.8 The graph shows the linear response of a novel planar IDC level sensor. Sensors on the lengths of the conductive plates were 5, 10, 15 and 20mm, the width and the spaces between the conductive plates were 2mm.

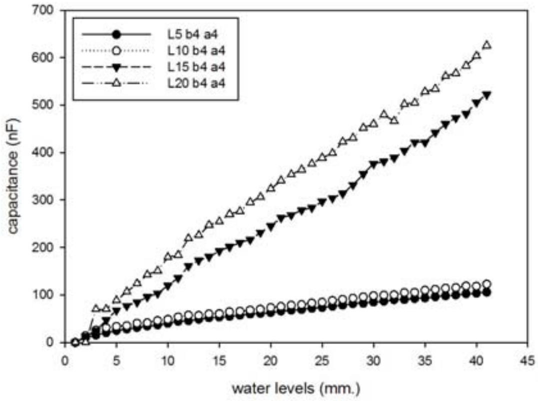

Fig.9 The graph shows the linear response of a novel planar IDC level sensor. Sensors on the lengths of the conductive plates were 5, 10, 15 and 20mm, the width and the spaces between the conductive plates were 4mm.

In Fig.8 it will be noticed that the largest increase in capacitance was a novel planar IDC level sensor, the conductors length was 20mm, the width and the spaces between the conductors were 2mm. When the height of the water level was at 40 the results showed clearly that using a novel planar IDC level sensor with a value of 20mm, the length of the conductor, the width and the space between the conductors were 1mm. would provide capacitance between 0.006 to 612.1nF. The linearity response with correlation coefficient (R^2) was 0.991. A novel planar IDC level sensor with the length of the conductor 15mm. the width and conductor spacing were 1mm. would provide capacitance between 0.007 to 422.62 nF. The linearity response with correlation coefficient (R^2) was 0.994. When the height of the water was at a level of 40. A novel planar IDC level sensor with the length of the conductor 10 mm. the width and conductors pacing were 1mm. would provide capacitance between 0.005 to 373.31nF. The linearity response with correlation coefficient (R^2) was 0.996. When the height of the water level at 40 and a novel planar IDC level sensor with a value of 5mm with the length of the conductor, the width and the space between the conductors were 2mm. would provide capacitance between 0.041 to 217.62nF. And the linearity response with correlation coefficient (R^2) was 0.991.

In Fig.9 it will be noticed that the largest increase in capacitance was a novel planar IDC level sensor, the conductors length was 20mm, the width and the spaces between the conductors were 4mm. When the height of the water level was at 40 the results showed clearly that using a novel planar IDC level sensor with a value of 20mm, the length of the conductor, the width and the space between the conductors were 4mm. would provide capacitance between 0.043 to 625.7nF. The linearity response with correlation coefficient (R^2) was 0.993. A novel planar IDC level sensor with the length of the conductor 15 mm. the width and conductor spacing were 2mm. would provide capacitance between 0.028 to 552.18nF. The linearity response with correlation coefficient (R^2) was 0.996. When the height of the water was at a level of 40. A novel planar IDC level sensor with the length of the conductor 10mm. the width and conductors pacing were 4mm. would provide capacitance between 0.003 to 112.87nF. The linearity response with correlation coefficient(R^2) was 0.97. When the height of the water level at 40 and a novel planar IDC level sensor with a value of 5mm with the length of the conductor, the width and the space between the conductors were 4mm. would provide capacitance between 0.001 to 105.98nF. And the linearity response with correlation coefficient (R^2) was 0.98.

Conclusions

This experiment has presented results of the linear response a novel planar IDC level sensor with the length, the width and conductor spacing to measure the water level all 40 level. By adding water level 2mm. per each and measure the capacitance that occurs at each level by LCR meter instrumentation. The experiment shows that a novel planar IDC level sensor that be new invented by series connect the first IDC with another one. Make a linearity response with correlation coefficient and continuity of capacitance measurements. Although the level of water changed or increased in a small amount. The results of the experiment also shows that a novel planar IDC level sensor is simple, not complicate structure, not expensive, be able to invent by general PCB and be able to use to measure water level generally. Moreover the result that describes above also present that sensor which prefer be very useful for Industrial process that relate to measure the level of liquid.

.

REFERENCES

[1] Satish Chandra Bera, Jayanta Kumar Ray, and Subrata Chattopadhyay. A Low-Cost Noncontact Capacitance-Type Level Transducer for a Conducting Liquid.,IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT, 2006, VOL. 55, NO. 3.

[2] Deeter Float Level Sensor. 466 Commerce Street, Tallmadge, OHIO, TheDeeter group. Retrieved, 2009-05-05.

[3] Georgi Nikolov and Boyanka Nikolova, “Virtual techniques forliquid level monitoring using differential pressure sensors”, 2008, RCENT,Vol9 ,no. 2(23).

[4] FerranReverter ,Xiujun Li and Gerard C.M. Meijer,Liquid-level measurement system based on a remote grounded capacitive sensor. Sensors and Actuators, 2007, A 138 1–8.

[5] Lindquist, A. S. A.-A. a. R. G. Capacitive InterdigitalSensor with Inhomogeneous Nematic Liquid Crystal Film. Electrical and Computer Engineering Department. Huntsville, University of Alabama in Huntsville, 2008**,** 13.

[6] Laville, C., Pellet, C. Interdigitated humidity sensors for a portable clinical microsystem. IEEE Transactions on Biomedical Engineering, 2002, 49 (10), 1162-1167.

[7] Radke, S.M., Alocilja, E.C. Design and fabrication of a micro impedance biosensor for bacterial detection. IEEE Sensors Journal, 2004, 4 (4),434-440.

[8] Radke, S.M., Alocilja, E.CA high density microelectrode array biosensor for detection of E. coli O154:H7. Biosensors and Bioelectronics, 2005. 20 (8),1662-1667.
[9] Radke, S.M., Alocilja, E.C. A microfabricated biosensor for detecting foodborne bioterrorism agents. IEEE Sensors Journal, 2005. 5 (4), 744-750.
[10] Varshney, M., Li, Y. Interdigitated array microelectrodes based impedancebiosensors for detection of bacterial cells. Biosensors and Bioelectronics, 2009. 24 (10), 2951-2960.
[11] Syaifudin, A.R.M., Jayasundera, K.P.,Mukhopadhyay, S.C. A low cost novel sensing system for detection of dangerous marine biotoxins in seafood. Sensors and Actuators B: Chemical, 2009. 137 (1),67-75.

The correspondence address is:
Sarawoot Boonkirdram, Faculty of Engineering, Mahasarakham University, Tambon Khamriang, Kantharawichai District, Maha Sarakham 44150 Thailand. e-mail: sboonkirdram@snru.ac.th
e-mail: sboonkirdram@snru.ac.th