Characterisation of Inter Digital Capacitor for Water Level Sensor

Noor Aishah Binti Muhammad
Faculty of Electrical Engineering
Universiti Teknologi MARA
40500, Shah Alam, Selangor, MALAYSIA
Email: nooraishahmuhammad@gmail.com

Abstract **- Water levels sensors are studied by using Inter Digital Capacitor (IDC) technique on Printed Circuit Board (PCB). The effectiveness of using PCB is studied as to reduce the cost of making sensor. IDC technique is used to make the capacitance measurement of the solution became more effective. This paper reports the effects of width and spacing of the capacitor electrode on capacitance value. This paper also presents simulation and experimental data to characterize the sensor. The result shows that the capacitance value is directly proportional to the electrode's width and inversely proportional to the electrode's spacing. When the IDC is tested with different medium i.e. tap water and distilled water, the capacitance value for tap water is much bigger compared to distilled water.**

Keyword Inter digital Capacitor, Printed Circuit Board, and Simulation

1.0 INTRODUCTION

Level sensors detect the level of substance that flows, including liquids, slurries, granular materials, and powders. The substance can be measured using a container or can be in its natural form i.e. lake or river. The level measurement can be either continuous or point values [1]. Continuous level sensors measure the exact amount of substance in a certain place and level within a specified range, while point-level sensors only indicate whether the substance is above or below the sensing point. The level sensors can measure using capacitance value. The different levels have a different capacitance value.

The application of water level sensor is to maintain a constant water level to avoid material wastage in the process plant [2]. Besides, the applications also include switching pumps on and off to avoid overflow, dry running and indicating water level in an empty tank to avoid wear and tear and production stoppage.

Inter digital capacitor is a finger like or comb like periodic pattern of electrodes deposited on a broad selection of substrates which could be opaque, porous or transparent, e.g., silicon or glass, where dielectric film coats these electrodes [3]. Interdigital capacitor is also coplanar waveguide formed on a substrate and having a centre line and a ground plane. As shown in Fig. 1, each electrode consists of many fingers. Each finger has a width and spacing between any two adjacent fingers . The distance of the periodic inter digital cell is called a unit cell which could be defined as the distance between the centre lines of the adjacent fingers belonging to the same electrode. Inter digital capacitor is used because it more effective to measure the capacitance values.

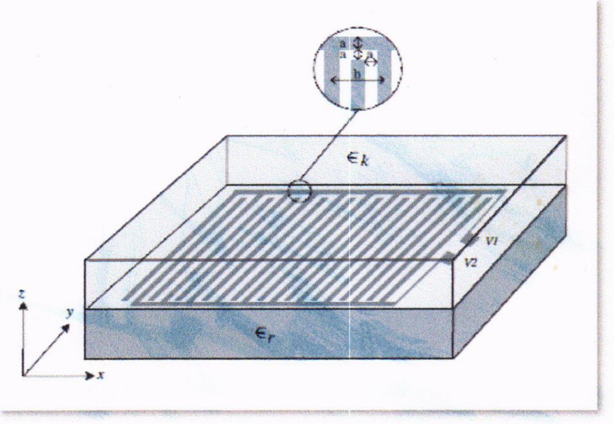


Fig. 1: Inter Digital Capacitor (IDC) [3]

A printed circuit board (PCB) consists of copper wire printed on a board which makes up a circuit for electronic devices [4]. Modern electronic products increasingly demand smaller PCB's [5]. It is often produced using an automated assembly process in order to produce the high volumes required. To remain reasonable, manufacturers have to improve the competence of their assembly line [6, 7].

PCBs are cheaper, and can be highly reliable [8]. It requires higher initial cost and more layout effort than either circuits but it much cheaper and faster for high-volume production.

The purpose of this paper is to reduce the cost of a sensor when using IDC techniques for water level sensor. Water level sensor is an electronic instrument used to measure the water level of liquids. In this study, the water level sensor is fabricated using PCB because PCB is cheaper and highly reliable.

Nowadays, the cost of making sensor is very expensive. This is because the circuit that used in sensor is very complex. Using IDC with simple circuit and also use PCB make the cost is more inexpensive.

2.0 DESIGN

PCB is designed using a CAD Software. There are 8 different designs of IDC sensor in this experiment. Each design has different width, W, and spacing, G with constant height, H, of 15 cm and length, L of 3 cm as shown in Fig. 2 and Fig. 3.

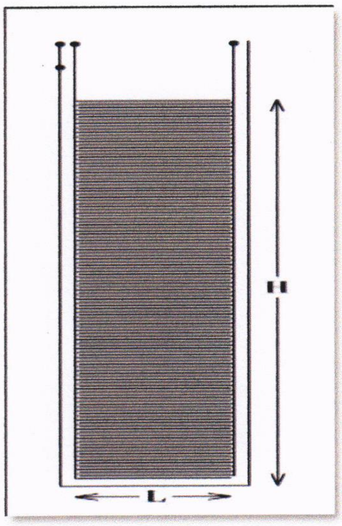


Fig. 2: Test structure for width and spacing 0.5mm

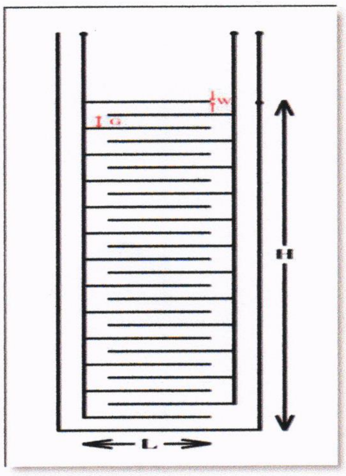


Fig. 3: Test structure for width 1.0 mm and spacing 5.0mm

3.0 METHODOLOGY

This project consists of two parts which are simulation and experiment using actual IDC on PCB. Experiment is start from fabrication to create the sensor using PCB technique. After complete the PCB, the PCB was tested using distilled water and tap water to investigate the different between the 2 medium. Besides, different design for IDC also investigated using distilled water and tap water. The lab equipment used in this experiment is LCR meter. This equipment is used to measure the capacitance value for all design using different medium.

3.1 SIMULATION

For simulation purpose, Finite Element Method Magnetics (FEMM) Software is used to measure the capacitance value of the IDC. The factor to be considered in this simulation is the dielectric of the material used i.e. air, water, copper and FR4. The voltage that used in simulation is 3V for drive and 0V for ground and sense. Therefore the dielectric for water in simulation is 80.

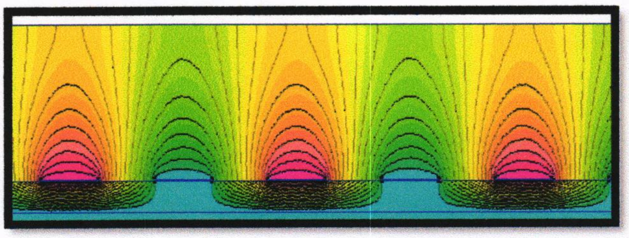


Fig. 4: The result of simulation for water level sensor using FEMM

3.2 FABRICATION

The second part of the study is to realise the sensor on the actual PCB. The main process that used in this fabrication is laminate process, exposed process, etching process, photoengraving process and thinning process. The exposed process is take 10 second to make design is passed onto the photo-resist. Therefore etching process is used to remove unwanted area and photoengraving process is used to remove unwanted copper layer on circuit board. Next, the rest of the photo-resist which covers the copper layer removed in thinning process. Lastly, to connect the different layer with different point, the holes also needed to enable leaded component to be mounted on the PCB. This process is known as drilling process.

3.3 EXPERIMENT SETUP

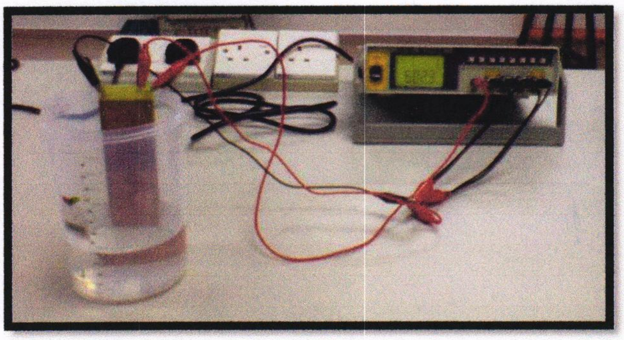


Fig 5: Experiment setup for water level sensor

The Figure shows the experiment setup for water level sensor. The equipment that used in laboratory work is LCR mater. LCR meter is used to measure the capacitance value for different depth of medium. The medium that used in this experiment is distilled water and tap water.

4.0 RESULT AND ANALYSIS

This study is to investigate the effect of solution, width, spacing, and depth of the water. In the simulation, the medium used is only water but in the experiment, the mediums used are distilled water and tap water. In addition, the conditions studied are also different for both investigations. As for simulation, the width size of the fingers is maintained as the spacing is varied but for experiment, the study is focused on different sizes of width and spacing.

4.1 SIMULATION

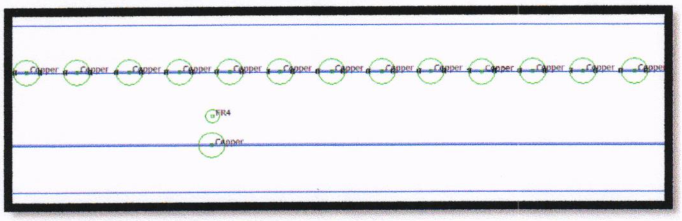


Fig 6: The Design of water level sensor for width and spacing 0.5mm using FEMM

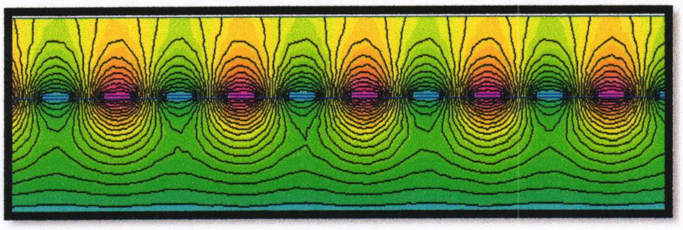


Fig. 7: Result of simulation for width and spacing 0.5mm using FEMM

From the Fig. 6 and Fig. 7, it shows the design and result of water level sensor using FEMM software. When decreasing the width and spacing of the electrode, the number of finger will increase.

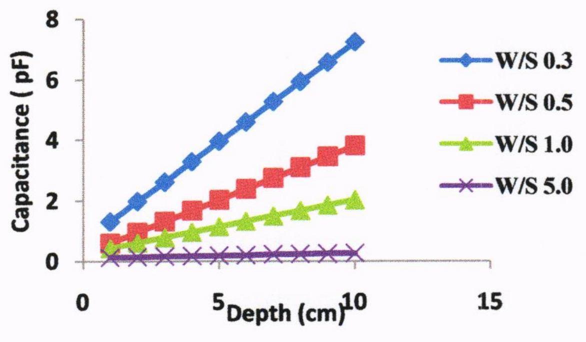


Fig. 8: Graph of capacitance (pF) for different width and spacing against depth (cm)

The simulation result in Fig. 8 shows the pattern of graph using water as the medium of the test. The graph showed that the smaller width and spacing give higher capacitance value. This is because when the wavelength increases, the penetration depth is also increases and this will affect the capacitance values.

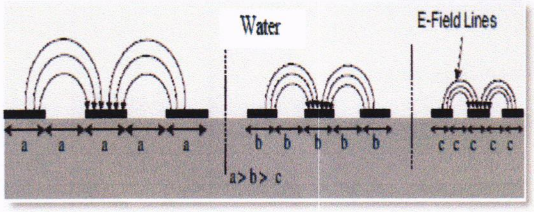


Fig. 9: IDC shows penetration depth dependent on the spacing between the electrodes

By referring to Fig. 9, the wider the distance between the electrodes, the stronger the electric field will penetrate between the electrodes [9]. As the electric field increases, the current induced at the electrode will also increases and will lead to the increase in the capacitance values. Therefore, for devices with larger electrodes, the energy of the fringe field is small to the total capacitive energy, but for small devices the fringe field energy comes to dominate [10].

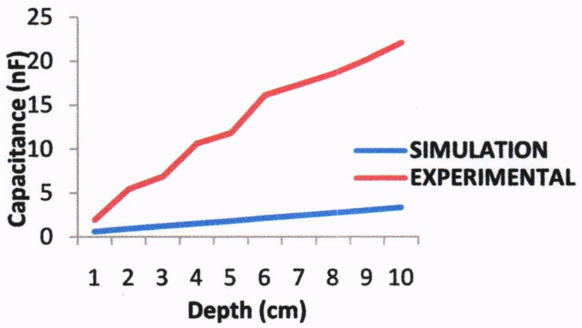


Fig. 10: Graph of capacitance (nF) for simulation and experimental against depth (cm)

From Fig. 10, ones will notice that the capacitance values are bigger for the experiment. In addition, the percentage difference from both studies is almost 100 percent. Because of that, the trend of graph for experimental can be predicted.

4.2 MEDIUM

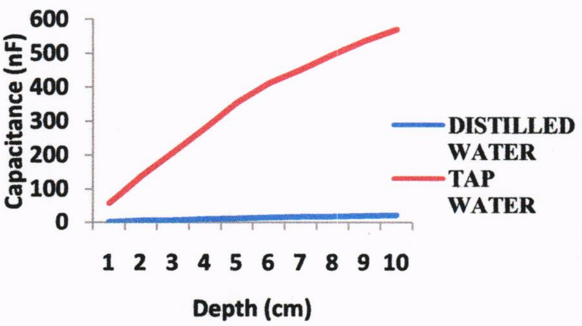


Fig. 11: Graph of Capacitance (nF) for different solution against Depth (cm)

The medium that used is 2 types which are distilled water and tap water. The graph showed the capacitance value for tap water is higher compare to distilled water. This is because the tap water consist a lot of positive H+ ions and negative OH^- ions that will effect the concentration of the medium.

$$\sigma = qn\mu_n + qp\mu_p \quad (1)$$

Where σ = conductivity
q = charge
n = concentration of electron
p = concentration of hole
μ_n = mobility of electron
μ_p = mobility of hole

This Equation (1) shows conductivity is directly proportional to the concentration. Therefore, increment in concentration will increase the conductivity

$$Resistivity, \rho = \frac{V}{IK} = \frac{R}{K} \quad (2)$$

$$Conductivity, \sigma = \frac{1}{\rho} \quad (3)$$

Based on Equation (2) and (3), resistivity is inversely proportional to conductivity [11].

$$|Z| = \frac{1}{2\pi fC} \ll R \quad (4)$$

By referring to Equation (2), (3) and (4), the conductivity is directly proportional to the capacitance value. Because of that, the capacitance value of the tap water is bigger than distilled water.

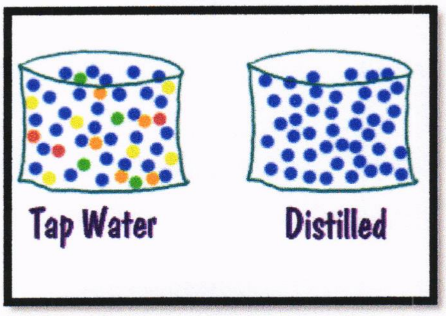


Fig. 12: The different ion in distilled water and tap water

From the Fig. 12, it can be shows that distilled water is a pure substance. That fact means that there are just water molecules in the liquid. The tap water has many mixtures inside it compare to distilled water. A mixture would be a glass of water with other things dissolved inside such as salt. Each of the substances in that glass of water keeps the original chemical properties. Because have other things inside the tap water, it will effect the dielectric permittivity of the medium. Therefore the reading of capacitance value will increase for tap water.

4.3 Width And Spacing Design

The next study is to investigate the effect of varying the width and spacing of the fingers. There are two conditions studied in this part which are same width and spacing and different width and spacing.

4.3.1 Same Width And Spacing Design

Varying the width and spacing is same as varying the wavelength of the IDC. In this part, both width and spacing are maintained the same. The value for width and spacing are 0.3mm, 0.5mm, 1.0mm and 5.0mm.

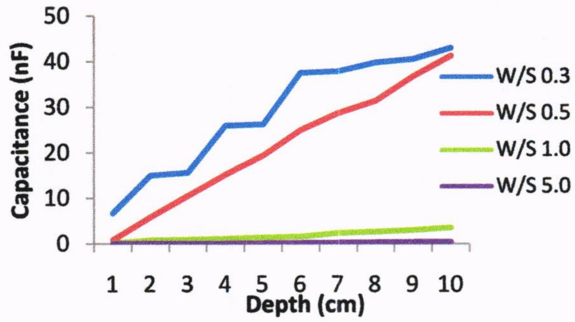


Fig. 13: Graph of capacitance (nF) for distilled water against Depth (cm)

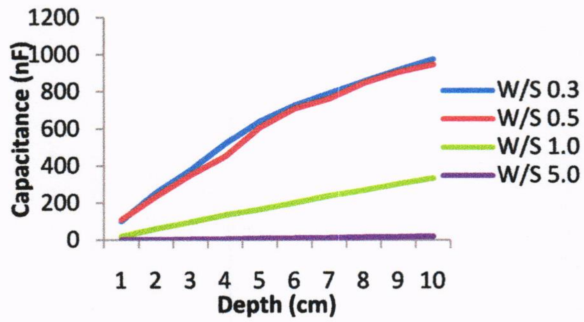


Fig. 14: Graph of capacitance (nF) for tap water against Depth (cm)

Based on Fig. 13 and Fig. 14 above, noticed that the increment value of capacitance is bigger for width and spacing of 0.3 mm when the depth of water is increase from 1 – 10 cm. This is because the mutual capacitance is a very sensitive measure of spacing if a conductor is near a capacitor electrode [12]. It can be substantiated with this equation:

$$C = \frac{\varepsilon A}{d} \quad (5)$$

Where C= capacitance
ε = dielectric permittivity
A= area
d= distance

From the equation, the capacitance is directly proportional to the surface area and inversely proportional to the distance between electrodes [13]. Therefore, capacitance is larger as the distance is smaller. Besides, the greater the area covered by material under test, the greater is the measured capacitance [14]. For a fixed spatial wavelength, greater electrode area means higher measurement sensitivity. In addition, sensitivity decreases exponentially with increasing distance from the plane of sensor electrodes [15].

4.3.2 Different Width and Spacing Design

This part is to investigate the effect of varying the different of width and spacing of the electrodes. The values are (0.3mm/0.5mm), (0.5mm/1.0mm), (1.0mm/5.0mm) and (1.0mm/0.5mm).

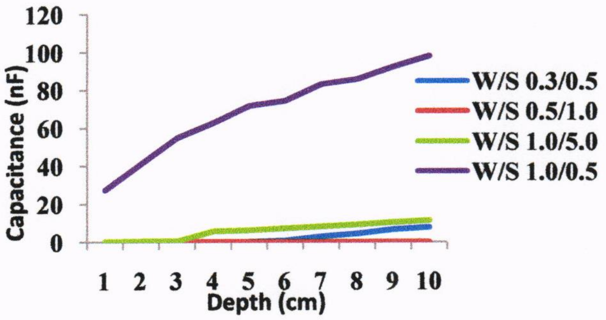


Fig. 15: Graph of Capacitance (nF) for distilled water against Depth (cm)

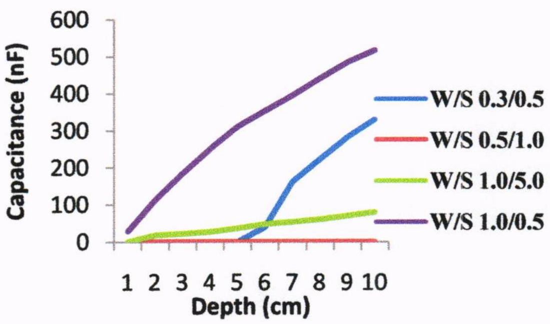


Fig. 16: Graph of Capacitance (nF) for tap water against Depth (cm)

From the graphs in the Fig. 15 and Fig. 16 above, IDC with width of 1.0 mm and spacing of 0.5 mm have bigger capacitance values. This is because larger finger width and wider spacing reduce the overall conductor losses. It also increases the parasitic capacitance and the physical size of the device. The losses are highly dependent spacing width and finger width [16]. Besides, increasing the wavelength, it will also reduce the overall conductor losses.

4.4 Different Water Level

In this part, the depth of water is varied to investigate the different in water level to the capacitance value. The depths of water varied in study are 1cm, 2cm, 3cm, 4cm, 5cm, 6cm, 7cm, 8cm, 9cm, and 10 cm. The designs of water level sensor used are same as the previous parts which are same width and spacing design and different width and spacing design.

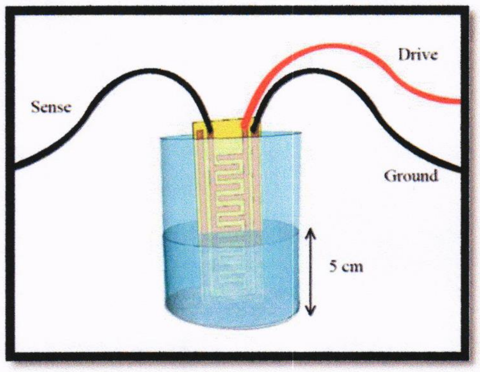
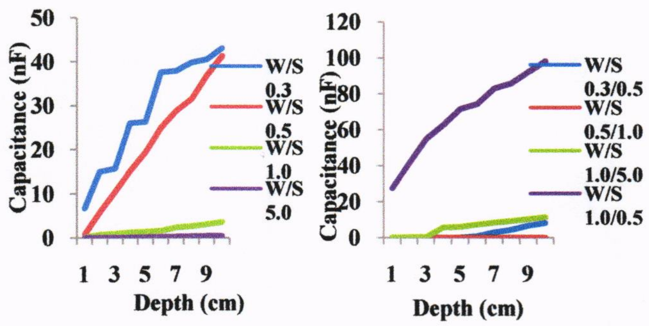


Fig.17: Experimental diagram for 5 cm depth



(a) (b)

Fig. 18: Relationship between the capacitance and depth of water for distilled water; (a) same width and spacing design, (b) different width and spacing design

Fig. 18 shows the relationship between the capacitance and depth of water for distilled water and tap water. The design that used is same and different width and spacing design. The figure shows the increment of capacitance value when depth of water is increase.

In medium have many positive H+ ions and negative OH- ions and these ions will move to the positive and negative electrodes of the sensor when a DC voltage applied to the electrode. The ions are converted to oxygen gas at the positive electrode and hydrogen gas at the negative electrode. These gases effectively form an insulation barrier at the electrodes and increasing the apparent resistance that in turn decreases the apparent conductivity of the solution [17].

$$|Z| = \frac{1}{2\pi f C} \ll R \quad (4)$$

Equation (4) shows the relationship between the capacitance and resistivity. Based on the equation, the increasing in resistivity will reduce the capacitance value.

Therefore, when water level sensor is dipped into medium the resistivity will reduce and conductivity of a solution is increasing. It also will increase the capacitance value.

5.0 CONCLUSION

The study of the effect of varying the width and spacing of electrodes of the IDC sensor is reported through experiment and simulation. Two medium are used as the material under test of the experiment i.e. distilled water and tap water. The measured capacitance for both mediums shows an increment as increase the level of the IDC dipped into the mediums and vice-versa. Moreover, as the width and spacing of the electrode is decreased, the capacitance value captured is increase. Besides, different solution gives the different concentration of the OH^- and H^+ ions. As the concentration increases, the conductivity also increases and this condition results can make an increment of the capacitance value. In addition, the simulation using FEMM software gives smaller capacitance values. From the experiment, pattern of results produced are similar to simulation results. For future the development of this project, it is recommended to add heating coil to the sensor. This feature is to dry out the sensor when it is removed from the container. This is because if the sensor surface is wet, it will affect the capacitance value. The capacitance value will increase if there are liquids on the sensor.

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