

Characterization of IDC FEF Fingers for pH Sensor

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Abstract - This paper presents a study of making a pH sensor by using planar fringing field effect. This FEF sensor study is carried out by using Inter Digital Capacitor (IDC) technique on Printed Circuit Board (PCB). The main objective is to investigate the effectiveness of using IDC in order to reduce the cost of making pH sensor. This study focused on the effect of using different number of width between finger, length of finger, medium, and effect of ground. This paper also presents simulation and experimental data to characterize the sensor. In addition, the effect of series the IDC also been studied experimentally. The results show that the trend pattern of both simulation and experiment are similar and for the series IDC, the capacitance is decreasing as the number of series IDC increased.

Keywords - Inter Digital Capacitor; Fringing Electric Field; Ground; Printed Circuit Board; Simulation; pH sensor

1.0 INTRODUCTION

In past five decades, Inter Digital Capacitor (IDC) has been involved in many sensing applications. Properties of the IDC also have been studied by many authors and have shown high performance when being used as sensors involved with many scientific applications [1]. For example, interdigitated sensors are used in telecommunications, biotechnology, chemical sensing, dielectric imaging and acoustic sensors applications.

The simple method of realizing a capacitor in a coplanar wave guide is by providing a slot in the middle of the conductive strip. This will act like a parallel plate capacitor; the capacitance of a parallel plate capacitor is a direct function of the cross sectional area of the conductor, cross sectional area of the strip line of the coplanar wave guide is very small, so it is not possible to realize required value of capacitance using this method [2]. The area of interaction can be improved by incorporating a comb structured electrode in between the strip. Fig. 1 shows the basic structure of comb structured electrode applied to IDC.

PCB is an electronic assembly which is plugged into the main frame assembly of a complex electronic device or which may be used as the principle element of a simple electronic device. [3]. PCBs are inexpensive, and can be highly reliable. They require much more layout effort and higher initial cost than either wire wrap or point-to-point construction, but are much cheaper and faster for high-volume production [4].

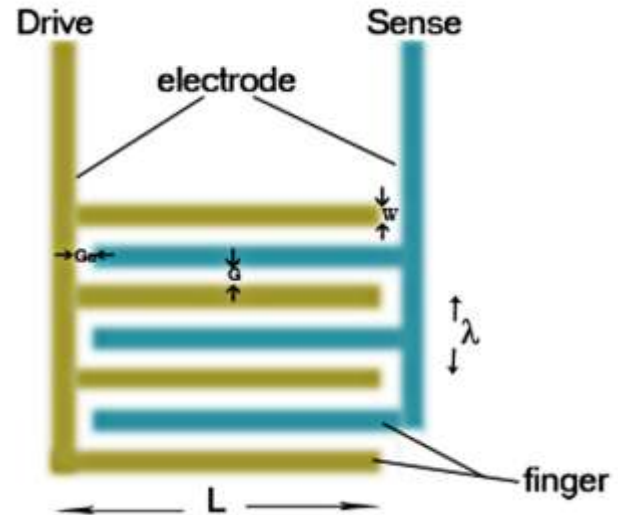


Fig. 1. Basic structure of IDC

Where; L = length of the finger
 W = width of the finger
 G = spacing between finger
 Ge = spacing at end of finger
 λ = spatial wavelength

Nowadays, the cost of producing one single sensor is very expensive. This is because of the circuit of the sensor itself are too complex. More complex the circuit means higher cost needed for the manufacturing. Since IDC provides a simple circuit with low cost, therefore this technique has been taken as an alternative to overcome this problem. The low cost of fabricating PCB also gives more advantage to achieve this objective.

Although there are many techniques can be use and apply to produce a sensor, but in this study the IDC technique was chosen to produce a pH sensor. The main objective of this study is to produce a low cost pH sensor. pH sensor is an electronic instrument used to measure the pH (acidity or alkalinity) of a liquid.

2.0 METHODOLOGY

This project consists of two parts which are simulation and experiment using actual IDC using PCB. The simulation in this project is using Finite Element Method Magnetics (FEMM) software. For simulation, there are 5 different medium to be tested which are simulation using air, water, and 3 others medium that have dielectric which is 20, 40 and 60.

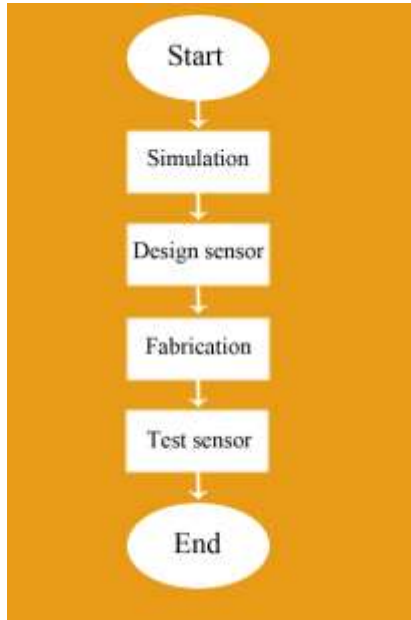


Figure 2: Flowchart of overall process

First of all, the simulation must be done by using FEMM software. In this software there are 6 different value of width and 6 different value of gap had been designed and simulated to see the changes of the capacitance value.

After all of the simulation had been done, the best design that we had choose is 0.4 gap 0.4 width, 0.6 gap 0.6 width, and 0.8 gap 0.8 width. This is because the sensor is more accurately fabricated when the width of the FEF is bigger than 0.3.

After the sensor was designed by following the required value of width and gap, the fabrication process was done in fabrication lab. The design of sensor can be done by many software such as Express PCB, PCB Wizard, Protel and ect. When the sensor had been fabricated, the sensor was testing in real experiment to get the value of the capacitance in some sample of liquid that have different value of pH.

3.0 RESULTS AND DISCUSSION

This study is to investigate the effects of Ground, number, width and length of finger and effect of using different number of width, length of finger and medium. For simulation, there are 5 different medium to be tested which are simulation using air, water, and 3 others medium that have dielectric 20, 40 and 60.

3.1 Simulation

The FEMM software is the software that been used in this study of FEF. In this software the design of IDC can be illustrated and run to get the wave of electric field and the capacitance value.

Table 1: Capacitance with different medium at 0.2 gap

W/ ϵ_r	Capacitance (pF)				
	Air(1)	M1=20	M2=40	M3=60	Water(80)
0.2	5.00	19.8	35.1	50.5	65.9
0.4	6.52	21.9	37.9	54.0	70.0
0.6	7.85	23.3	39.5	55.6	71.8
0.8	9.15	24.6	40.8	56.9	73.0
1	10.4	25.9	42.1	58.3	74.4
1.2	11.7	27.2	43.4	59.5	75.7

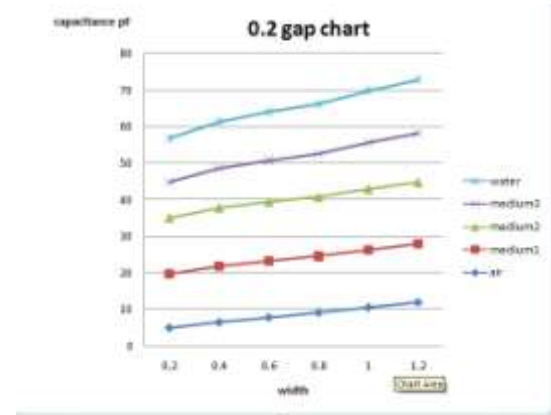


Figure 3: Chart of capacitance versus width of the finger with constant 0.2 gap at different medium of liquid

The figure above shows that the value of the capacitance proportional to the value of the width. The maximum value is 75.7 and the minimum value is 5. The difference is about 70.7.

Table 2: Capacitance with different medium at 0.4 gap

W/ ϵ_r	Capacitance (pF)				
	Air(1)	M1=20	M2=40	M3=60	Water(80)
0.2	4.47	14.2	24.1	34.0	43.9
0.4	5.87	15.8	26.0	36.2	46.4
0.6	7.18	17.2	27.4	37.6	47.8
0.8	8.46	18.4	28.7	38.9	49.1
1	9.74	19.7	30.0	40.2	50.4
1.2	11.0	21.0	31.2	41.5	51.7

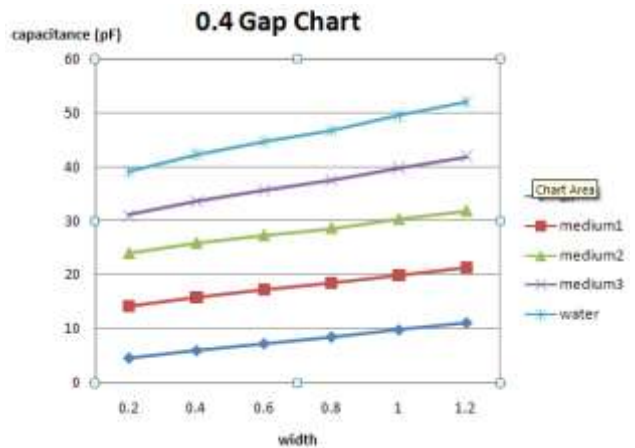


Figure 4: Chart of capacitance versus width of the finger with constant 0.4 gap at different medium of liquid

The figure above shows that the value of the capacitance proportional to the value of the width. The maximum value is 51.7 and the minimum value is 4.47. The difference is about 47.23.

Table 3: Capacitance with different medium at 0.6 gap

$W \setminus \epsilon_r$	Capacitance (pF)				
	Air(1)	M1=20	M2=40	M3=60	Water(80)
0.2	4.33	12.1	19.7	27.3	34.9
0.4	5.71	13.5	21.3	29.1	36.8
0.6	7.00	14.9	22.7	30.4	38.2
0.8	8.28	16.1	24.0	31.7	39.5
1	9.56	17.4	25.2	33.0	40.7
1.2	10.8	18.7	26.5	34.3	42.0

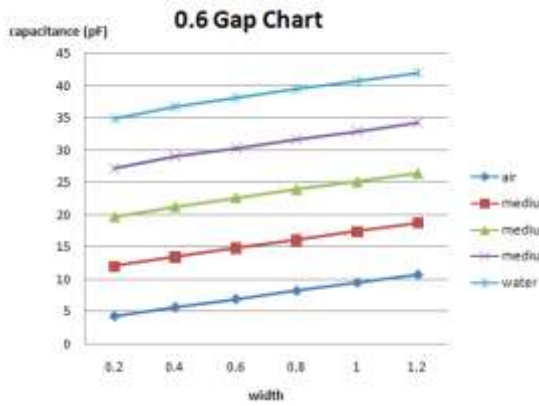


Figure 5: Chart of capacitance versus width of the finger with constant 0.6 gap at different medium of liquid

The figure above shows that the value of the capacitance proportional to the value of the width. The maximum value is 42 and the minimum value is 4.33. The difference is about 37.67.

Table 4: Capacitance with different medium at 0.8 gap

$W \setminus \epsilon_r$	Capacitance (pF)				
	Air(1)	M1=20	M2=40	M3=60	Water(80)
0.2	4.30	11.0	17.4	23.7	30.0
0.4	5.65	12.5	18.9	25.3	31.7
0.6	6.95	13.8	20.3	26.7	33.1
0.8	8.23	15.0	21.5	28.0	34.4
1	9.51	16.3	22.8	29.2	35.6
1.2	10.8	17.6	24.1	30.5	36.9

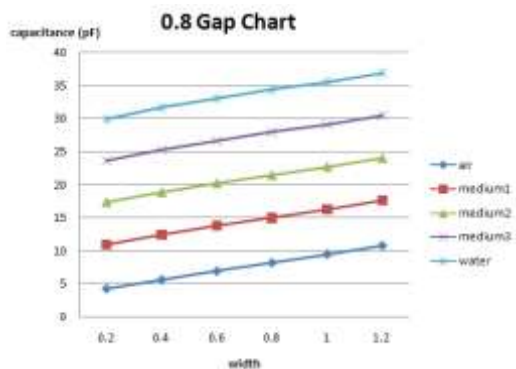


Figure 6: Chart of capacitance versus width of the finger with constant 0.8 gap at different medium of liquid

The figure above shows that the value of the capacitance proportional to the value of the width. The maximum value is 36.9 and the minimum value is 4.3. The difference is about 32.6.

Table 5: Capacitance with different medium at 1.0 gap

$W \setminus \epsilon_r$	Capacitance (pF)				
	Air(1)	M1=20	M2=40	M3=60	Water(80)
0.2	4.28	10.5	16.1	21.6	27.1
0.4	5.65	11.9	17.6	23.2	28.7
0.6	6.93	13.2	18.9	24.5	30.0
0.8	8.22	14.5	20.2	25.8	31.3
1	9.49	15.7	21.4	27.0	32.6
1.2	10.8	17.0	22.7	28.3	33.9

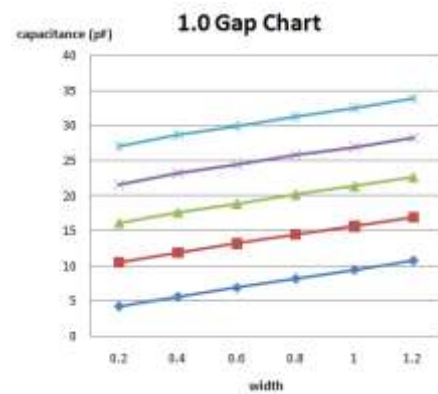


Figure 7: Chart of capacitance versus width of the finger with constant 1.0 gap at different medium of liquid

The figure above shows that the value of the capacitance proportional to the value of the width. The maximum value is 33.9 and the minimum value is 4.28. The difference is about 29.62.

Table 6: Capacitance with different medium at 1.2 gap

$W \setminus \epsilon_r$	Capacitance (pF)				
	Air(1)	M1=20	M2=40	M3=60	Water(80)
0.2	4.28	10.2	15.3	20.3	25.2
0.4	5.64	11.6	16.8	21.8	26.8
0.6	6.92	12.9	18.1	23.1	28.1
0.8	8.21	14.2	19.3	24.4	29.3
1	9.49	15.4	20.6	25.6	30.6
1.2	10.8	16.7	21.9	26.9	31.9

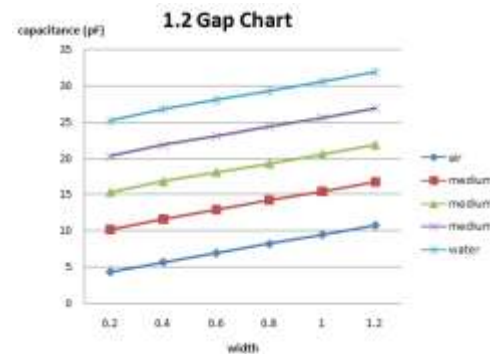


Figure 8: Chart of capacitance versus width of the finger with constant 1.2 gap at different medium of liquid

The figure above shows that the value of the capacitance proportional to the value of the width. The maximum value is 31.9 and the minimum value is 4.28. The difference is about 27.62.

3.11 Discussion from simulation result

From the simulation results, we can see that the value of the capacitance will increase when the width of the finger is increase. For different dielectric permittivity, the capacitance value is proportional with the dielectric permittivity. For gap of the finger, the capacitance value will decrease when the gap is increase.

3.111 Relationship between capacitance and medium

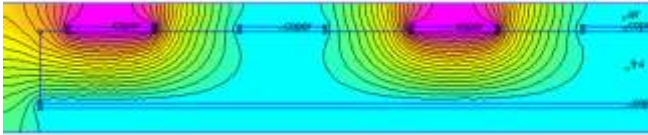


Figure 9: Electric field with 0.6width 0.6 gap in air (1 dielectric permittivity)

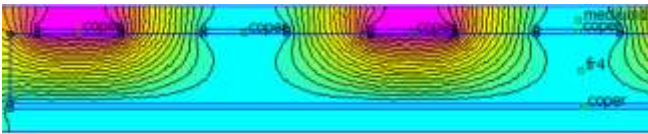


Figure 10: Electric field with 0.6width 0.6 gap in medium 1 (20 dielectric permittivity)

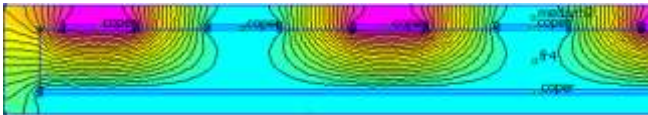


Figure 11: Electric field with 0.6width 0.6 gap in medium 2 (40 dielectric permittivity)

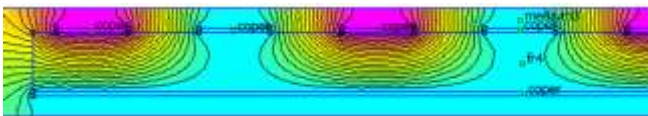


Figure 12: Electric field with 0.6width 0.6 gap in medium 3 (60 dielectric permittivity)

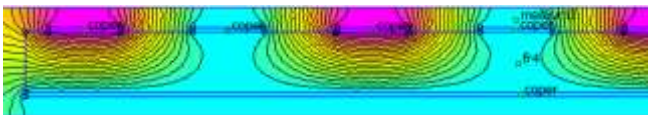


Figure 13: Electric field with 0.6width 0.6 gap in water (80 dielectric permittivity)

All the figures above are the wave from the simulation process from the different medium with same width and gap. From the simulation we can see the different wave had been produced from different medium that been used. The wave of electric field between drive and sensor become more huge when the dielectric permittivity is in big value

The value of capacitance is increased when the dielectric of the medium is increased. The value of the capacitance is proportional with the dielectric permittivity of medium.

3.112 Relationship between capacitance and width

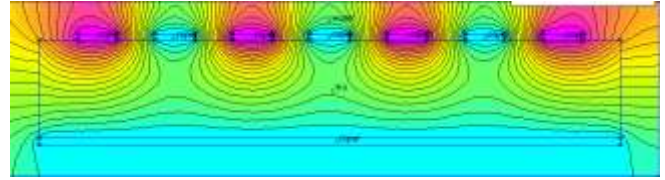


Figure 14: Electric field with 0.2 width 0.2 gap in water (80 dielectric permittivity)

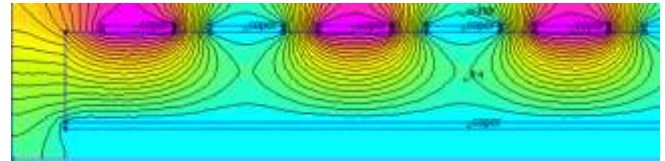


Figure 15: Electric field with 0.4 width 0.2 gap in water (80 dielectric permittivity)

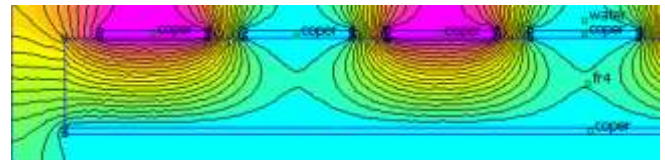


Figure 16: Electric field with 0.6width 0.2 gap in water (80 dielectric permittivity)

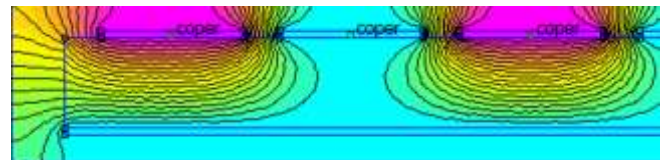


Figure 17: Electric field with 0.8 width 0.2 gap in water (80 dielectric permittivity)

Figures above are the wave from the sensor in the simulation process. The entire sample is by using water medium, constant value of gap and variable value of width. We want to see the effect of width to the wave of simulation and the value of the capacitance. From the simulation, by changing the width of the sensor will affect the wave and the value of the capacitance. The wave of electric field is become smaller when the width of drive and sense is smaller. The electric field is rounding smaller at sense. By increasing the width, the electric field coverage area is become bigger. The value of the capacitance will increase by increasing of the width value. This is because when the wavelength is increased, the penetration depth also increases and this will affect the capacitance value [1, 8, 10, 11].

3.113 Relationship between capacitance and gap

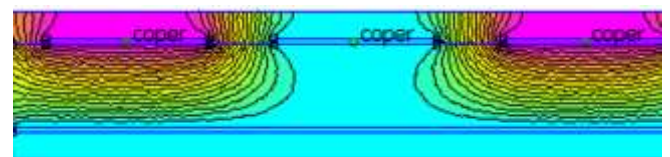


Figure 19: Electric field with 1.0 width 0.4 gap in water (80 dielectric permittivity)

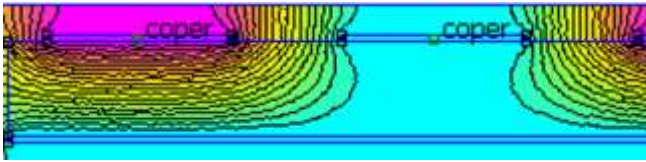


Figure 20: Electric field with 1.0 width 0.6 gap in water (80 dielectric permittivity)

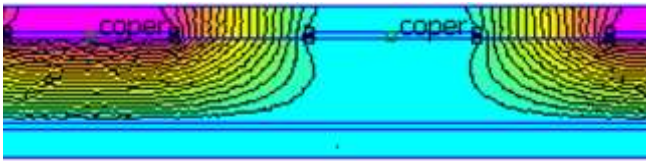


Figure 21: Electric field with 1.0 width 0.8 gap in water (80 dielectric permittivity)

These figures are the result from the simulation that use water as the medium, constant value of width and the variable value of gap. From the simulation, we can see the effect of changing the value of gap to the value of the capacitance. The wave of electric field can't intercept between drive and sense because the gap between them are become bigger. That's why the capacitance value was decreasing when the gap is increase. The value of the capacitance will decrease when the gap distance is decrease

3.2 Experiments

For the experiment parts, the sample that been used have 3 sets which one set had 3 different gap and width of finger. The total of the sensor that had been fabricated is 9 which has divided into 3 sets; set A, B and C.

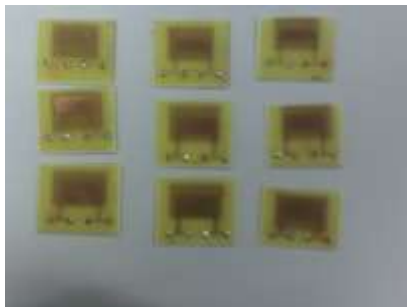


Figure 22 : Fabricated sensor

For each set, there were 3 different sensors;

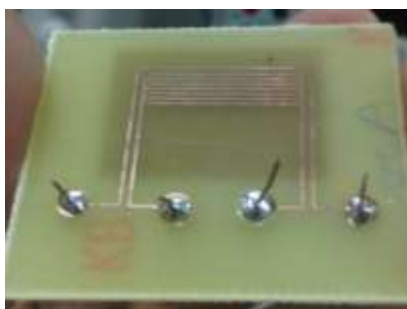


Figure 23: Sensor with 0.4 gap and 0.4 width

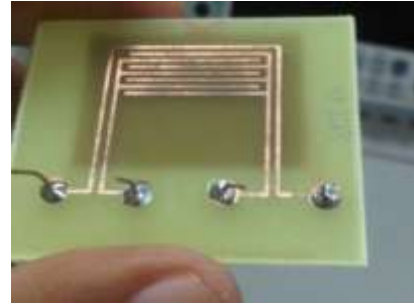


Figure 24: Sensor with 0.6 gap and 0.6 width

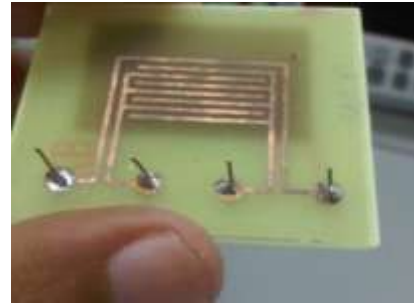


Figure 25: Sensor with 0.8 gap and 0.8 width

For the experimental the sensor had been tested in air, water and 3 different liquid that have different pH value which is pH 11, 9 and buffer water. In this experiment, we also study about the effect of the grounding to the capacitance value. LCR meter had been used to measure the capacitance value.

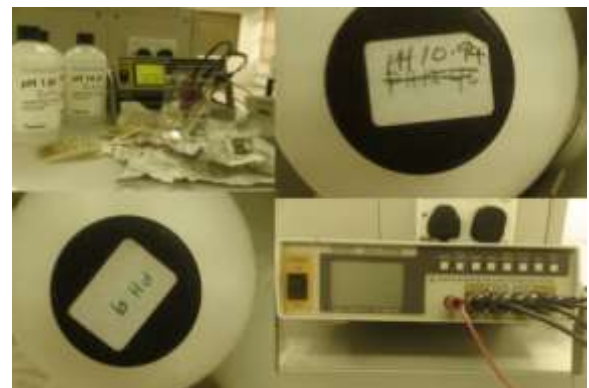


Figure 26: The apparatus of the experiment

3.21 Experiment result and discussion

3.211 Effect of ground

This test is to see the effect of grounding to the capacitance value.



Figure 27: sensor setup to be grounded or not

Table 7: The result for 3 different sensors in set A for the effect of grounding

Width/Gap(mm)	Capacitance (pF)			
	Ungrounded		Grounded	
	air	water	air	water
0.4/0.4	8.1	15	6	9.3
0.6/0.6	9.4	20.2	7.5	10.1
0.8/0.8	10.0	24.1	8.9	10.9

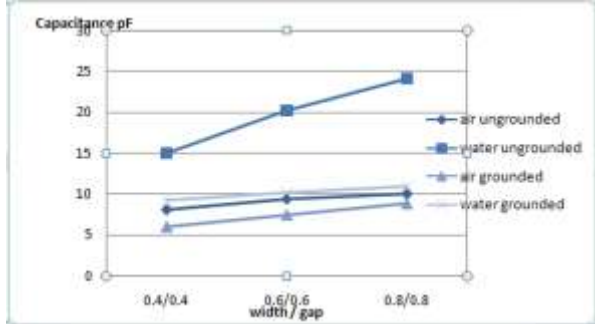


Figure 28: Chart of capacitance versus width and gap for ungrounded and grounded using set A

Table 8: The result for 3 different sensors in set B for the effect of grounding

Width/Gap(mm)	Capacitance (pF)			
	Ungrounded		Grounded	
	air	water	air	water
0.4/0.4	8	12.8	5.9	9.5
0.6/0.6	9.1	17.2	7.3	10
0.8/0.8	9.7	22.3	8.1	11.1

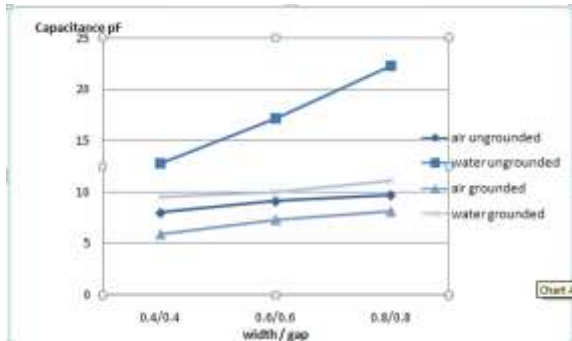


Figure 29: Chart of capacitance versus width and gap for ungrounded and grounded using set B

Table 9: The result for 3 different sensors in set C for the effect of grounding

Width/Gap(mm)	Capacitance (pF)			
	Ungrounded		Grounded	
	air	water	air	water
0.4/0.4	8.1	14.5	6.2	9
0.6/0.6	9.2	17.5	7.5	10.3
0.8/0.8	9.9	21.8	8.7	10.9

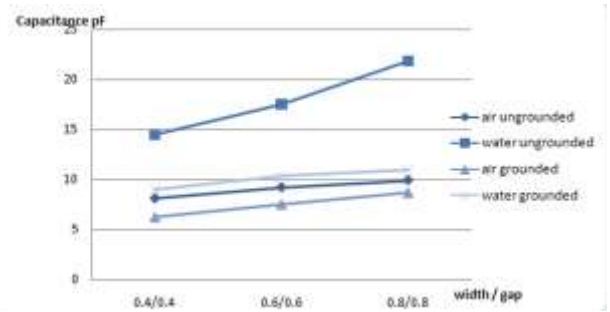


Figure 30: Chart of capacitance versus width and gap for ungrounded and grounded using set C

The table and graphs shows that the value of the capacitance is increasing when the size of width and gap is increasing. The result is follows the rules of the IDC. From the result we can see that the different values of capacitance when the sensor was being grounded or not.

When the sensor was being grounded there is no others external noise or signal that will interrupt in the sensor. The grounding is being used in the sensor to neutralize the noise. This is because a grounded backplane deposited on the bottom side of the substrate provides shielding from external perturbations, defines ground potential, and confines the electric field to the upper-half space [5].

3.212 pH test: all the result below are being test in grounding effect in order to minimize the noise.

Table 10: Result of capacitance in different pH for set A

Width/Gap	Capacitance pF			
	pH 11	pH 9	pH 7	Buffer Water
0.4/0.4	10.2	9.9	9.3	8.1
0.6/0.6	10.9	10.3	10.1	8.6
0.8/0.8	11.4	10.6	10.9	9.7

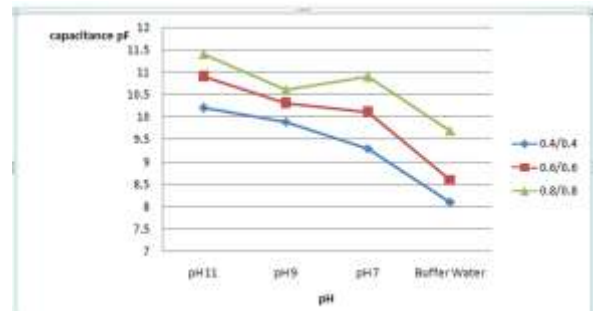


Figure 31: Chart of capacitance versus pH with different sensors for set A

Table 11: Result of capacitance in different pH for set B

Width/Gap	Capacitance pF			
	pH 11	pH 9	pH 7	Buffer Water
0.4/0.4	9.7	9.2	9.5	8
0.6/0.6	10.3	10.1	10	9
0.8/0.8	11.7	10.8	11.1	9.3

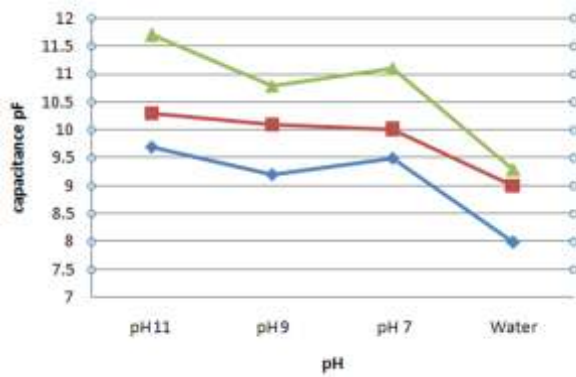


Figure 32: Chart of capacitance versus pH with different sensors for set B

Table 12: Result of capacitance in different pH for Set C

Width/Gap	Capacitance pF			
	pH 11	pH 9	pH 7	Buffer Water
0.4/0.4	9.9	8.9	9	7.8
0.6/0.6	10.7	10	10.3	8.7
0.8/0.8	11.2	10.9	10.9	9.5

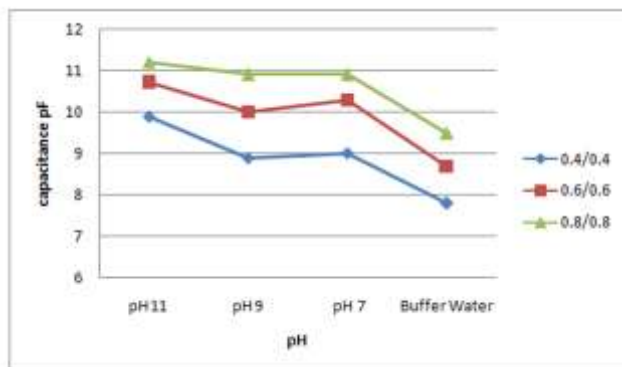


Figure 33: Chart of capacitance versus pH with different sensors for set C

From all the results in 3 sets of sensors, the capacitance value is decrease when the alkaline is decrease until it neutral at pH 7 and the capacitance is decrease when the acid is increase.

For different sets of sensor the result is different although the sensors have the same dimension for width and gap. This is because the fabricated process is not at the best state. The sensors are not fabricated perfectly same with the designation.

Table 13: Comparison between simulation and experiment result

Width/Gap (mm)	Capacitance (pF)					
	simulation		experiment		% differences	
	Air	Water	Air	Water	Air	Water
0.4/0.4	5.87	46.4	6	9.3	2.2	399
0.6/0.6	7.18	47.8	7.5	10.1	4.4	378
0.8/0.8	8.46	49.1	8.9	10.9	5.2	350

By referring to the table, the results show that the experimental is same with the simulation that the capacitance value will increase when the size of the finger is increase. The differences between simulation and experiment for medium air are not too much. These

differences is causes by the fabricated sensor that has not been fabricated exactly same as the design model. But when the sensor is tested in water, the differences between simulation and experiment was too large. This was happened because of the equipment that been used for the experiment is not complete enough in order to get the exactly same value as the simulation. There have many noise and error that disturb the process of the testing.

4.0 Conclusion

The effect of using different number of gap between finger, width of finger, medium, and effect of ground had been proved. Air, water, and 3 others medium (20, 40 and 60) had been used as the material in simulation parts.

For experiment setup, the materials that been used were air, water, pH 11, pH 9 and buffer water. These pH buffers were used in the experiment as replacements for 3 others medium to differentiate the capacitance value of each pH buffer.

The results show that the presence of Ground in IDC provides shielding from external perturbations. It is also shown that the increasing of width and gap of the finger will increase the values of the capacitance. From the results, it had shown that the value of the capacitance was increasing when the pH is increasing from acid to alkaline. The value of capacitance also increases when the dielectric permittivity increased.

For the future development, it is recommended to have a study of the sensor testing. This is because, as can be seen from the result that there have many noise in the testing. This is the point good in order to get the truth value of the capacitance.

5.0 ACKNOWLEDGEMENT

The author would like to thank the supervisor of this project, Mr Azrif Bin Manut for guiding me for the experiment and using FEMM software for the simulation part. A part of that, thanks to Fabrication Laboratory, Mr Ahmad Riduan Bin Zakaria for giving the authority to use the lab and all the equipments of PCB fabrication purpose, Mr Mohd Faizul Bin Md Idros for sponsoring accublack paper for PCB design print purpose and Network Laboratory technician, Mr Mohd Azwan Roseley for giving the authority to use Dual Display LCR Meter and the lab. Last but not least, a big thank to Faculty of Electrical Engineering of Universiti Teknologi MARA (FEE-UiTM) for providing all the facilities to complete this project.

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