Study And Analysis Factor That Can Improve The Fringing Electric Field (FEF) Soil Moisture Sensor for Agriculture Applications

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***Abstract*—this paper presents a study on the effect of the dimension and the width of sense and drive electrode to the sensitivity of the fringing electric filed (FEF) sensors. Fringing electric filed (FEF) sensor has been used for non-invasive measurement of material of properties such as temperature and hardness. FEF also been used to detect existence or concentration of material within the test environment. Using the FEF application the FEF moisture sensor is made to detect the volumetric water content (VWC) in soil. In this study, the simulation and testing has been done to characterize the sensor. The simulation is using Finite Element Method Magnetic (FEMM) while sensor is tests using LCR meter to get capacitance value. Through capacitance value the volumetric water content (VWC) can be measured. Before testing is conducted the sensor needs to fabricate using Printed Circuit Board (PCB). The result between simulation and testing then been compare. The results show the electrode width effect the sensor sensitivity. The sensor sensitivity is high when the electrode width is small.**

Keywords- fringing electric filed (FEF), volumetric water content (VWC)

I. INTRODUCTION

Soil moisture sensor provides the valuable information for agriculture such as growers and monitoring a plant [1, 6]. Monitoring a plant is important to an agriculture sector. This sensor is one of tools that can help to monitor the plant by detect the level of moisture. The level of moisture is detected by sensor using volumetric water contents measurement. The volumetric water content is ratio between water volume and soil volume. To measure the volumetric water content of soils two methods has been applied which indirect and direct [7]. Direct method is method that applies for drying and weighing of soil sample. For indirect method, the measurement is based on correlation of physical properties of soil samples.

Fringing electric filed (FEF) can be used to determine the moisture contents of soil. FEF sensor has been used for non-invasive measurement of material of properties such as temperature and hardness [1, 8]. The performance of FEF sensors depends on their signal strength, penetration depth, linearity and measurement sensitivity [1, 8]. There are many factors geometry that can affect the FEF sensor such as electrode material, electrode width, number of electrode and gap between electrodes [2]. This paper focuses on factor dimension and width of electrode affect performance of soil sensor. This paper also study effect of different drive and sense electrode to the sensitivity of sensor.

FEF sensor is been designed using Printed circuit board (PCB). PCB is used to support the electrode by connected electrically using a pathways or track from cooper [3]. PCB is not complicated to design and a low cost. Manufacturing a sensor is expensive because the complexity of the circuit. More complex circuit means higher cost needed for manufacturing the sensor. PCB gives a low cost of fabricating to overcome this problem.

The soil moisture sensor is expected give a better reading and result for land activities especially for agriculture sector [1]. The sensor also has good resolution and high sensitivity which allow trends in moisture changed to be tracked. The main objective is to make a low cost sensor with accurate detection by study width electrode factor. It can be used for small or big agriculture sector and farmer.

II. THEORY

The moisture content can be measured using capacitor formula where FEF acts as capacitor plate and moisture as a dielectric constant [1, 2]. It measures the capacitance value via effect of dielectric constants. Through the capacitance value, the VWC in soil can be determined. In theory the capacitance is:

$$C = \varepsilon_r \varepsilon_0 \frac{A}{d}$$

Equation 1

Where *C* is for capacitance, *A* is the area of the two plates, ε is the dielectric constant and *d* is the gap between the plates.

The summary of FEF sensor operation is ac voltage will be applied through drive electrode of sensor. It will create fringing electric field and cause the soil permittivity change. When there are changing in permittivity, the electric field is will change and not static. The sense electrode will transmit output signal and the moisture level can be determined [1, 2]. The FEF configuration is show as figure 1 below.

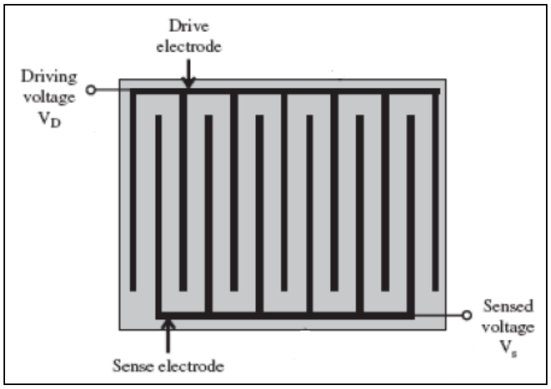

Figure 1. FEF sensor configuration

III. METHODOLOGY

To achieve the objective the several methods has been done such as finding the information about the topic. These projects required to design and simulate the sensor to get the relationship of width and capacitance value before design the actual FEF sensor. The simulation is using Finite Element Method Magnetic (FEMM). Then, design FEF sensor is using PCB Proteus software. After design the sensor, the testing need to conducted to show the actual relationship of design width and capacitance value. All process is shown in design simulation, PCB design and testing the sensor sections.

A. DESIGN SIMULATION

The simulation was done using Finite Element Method Magnetic (FEMM). FEMM is a solution for low frequency electromagnetic of two-dimensional planar and axisymmetric domains [4]. The geometry design is drawn on the software template before run the simulation. The length of electrode and PCB dielectric constant is set first before start drawn the electrode. The PCB dielectric constant is 4 and length electrode is depending on each design. Then, by referring to the width and gap the drive and sense electrode is draw on software. The drive and sense electrode should placed side by side each other. The thickness of electrode is 0.1mm and for PCB thickness is 1.6mm. The complete design is shown in figure 2.

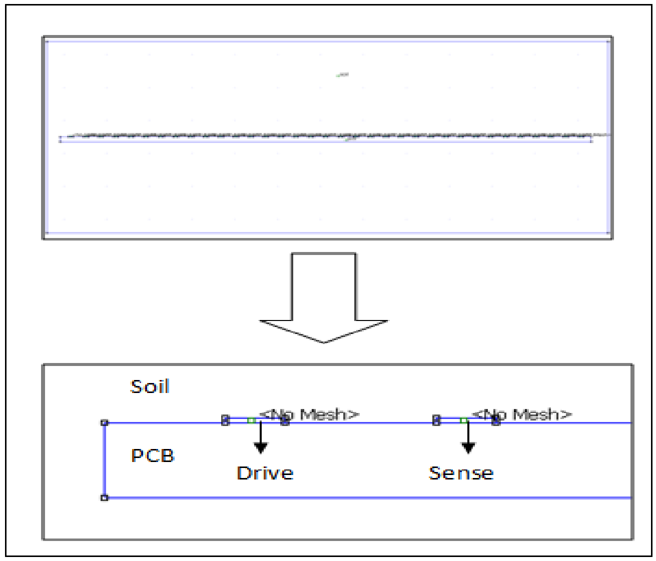

Figure 2. Design Simulation

After done with drawing, the mesh generation can be generated to get the capacitance value as shown figure 3. The percentage of dielectric constant (moisture) is simulate from 1% (Ɛr1), 20 %(Ɛr16), 40 %(Ɛr32), 60 %(Ɛr48), 80 %(Ɛr64) of moisture. Each plate will be set with percentage of dielectric constant and the result is record.

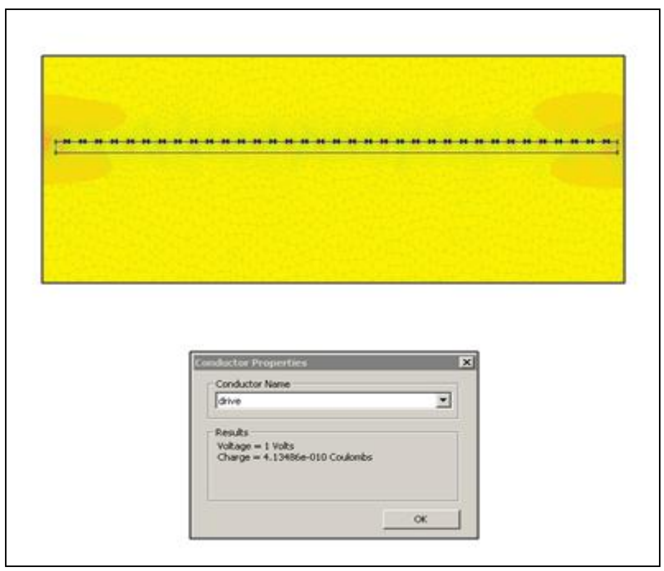

Figure 3. Mesh generation and result

B. PCB DESIGN

The PCB design in figure 4 is draw with Proteus software. Proteus is design PCB software combine the schematic capture and PCB layout. It is been programmed to provide the easy tool for education and professional workers [5]. Start the design by set the design geometry and characteristics of each design. The design geometry used in this paper is vertical geometry and without ground. The choice of this geometry is to characterize the sensor with these specifications. The board was set to be 100mmx100mm work area or size. The objective is to add the number of electrode and to increase length of electrode. The characteristics of design are shown below.

TABLE 1. DESIGN CHARACTERISTIC DUE TO DIFFERENT WIDTH

	Electrode Width (mm)	Gap Between Electrode (mm)	Number of Electrode
Plate 1	1.0	2.5	18
Plate 2	2.0	3.0	9
Plate 3	3.0	2.0	9
Plate 4	4.0	3.5	5

Table 1 shows characteristic design of FEF sensor. The four plates are created using different of widths, gaps and numbers of electrode. The width is set from 1.0mm to 4.0mm. These characteristics are made to differentiate and to find the best of FEF sensor with high sensitivity between the designs.

TABLE 2. DESIGN CHARACTERISTIC DUE TO DIFFERENT WIDTH OF DRIVE AND SENSE ELECTRODE

	Drive Electrode Width (mm)	Sense Electrode Width (mm)	Gap Between Electrode (mm)	Number of Electrode
Plate 1	1.5	1.0	1.5	18
Plate 2	3.0	2.0	2.5	9
Plate 3	3.5	3.0	1.5	9
Plate 4	5.0	4.0	3.0	5

Table 2 shows characteristic FEF sensor design with different dimensions of drive and sense electrode, number of electrode and gap between plates. Each plate dimension was selected from 1.5mm drive and 1.0mm sense to 5.0mm drive to 4.0mm sense. The objective from this finding was to characterize FEF sensor whether better with or without different width of drive and sense electrode.

The PCB design can be start after all design geometry and characteristics is set and find out. Firstly by using track mode in software the track vertically is draw using top copper as an electrode. The size of trace width is set to match the design characteristics above. The complete figure drawing of design was show below.

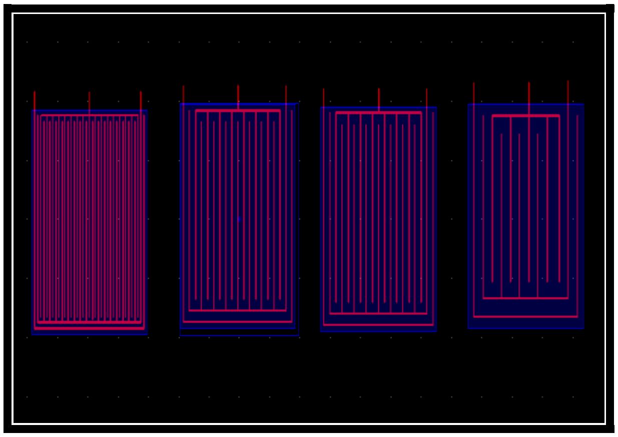

Figure 4. Vertical PCB design

After done with sensor design, next step is to fabricating the sensor. All work was done in Fabrication Laboratory at UITM. The complete sensor was shown in figure 5 below.

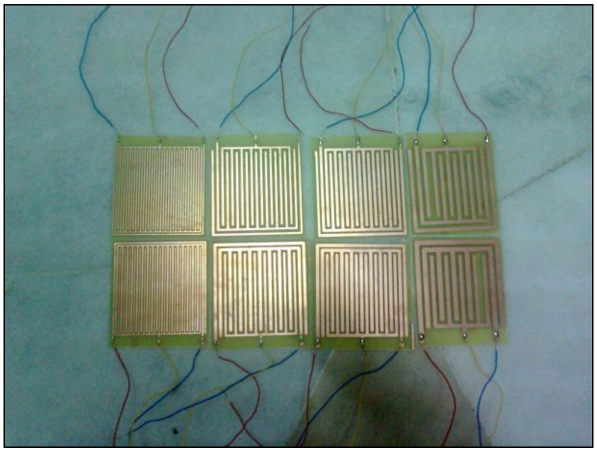

Figure 5. Completed PCB design

C. TESTING THE SENSOR

After fabrication of PCB is done next step is to testing the sensor. The testing of FEF sensor is to measure and analyzed the performance of sensor. The sensor is test using LCR meter with 10 KHz of frequency [2]. The AC voltage was applied through device under test (DUT). The LCR meter will measure the ratio of voltage and current to determine the magnitude of impedance and capacitance value. The soil sample with different volumetric water contents (VWC) is prepared for this testing. The sample is from coconut pit which is containing 1%, 20%, 40% 60% and 80%. The sample needs to be ready 24 hours before doing the testing to give better measurement. Each plate tested with different soil sample as in figure 6 and the reading was record.

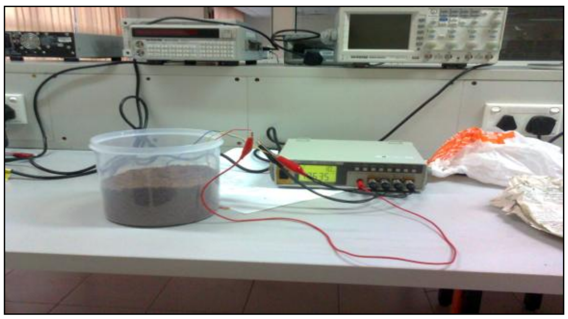

Figure 6. Test for FEF sensor

IV. RESULT AND DISCUSSION

The results simulation and testing was analyzed and the graph was plotted to show relationship between each sensors. The result of the finding is shows below.

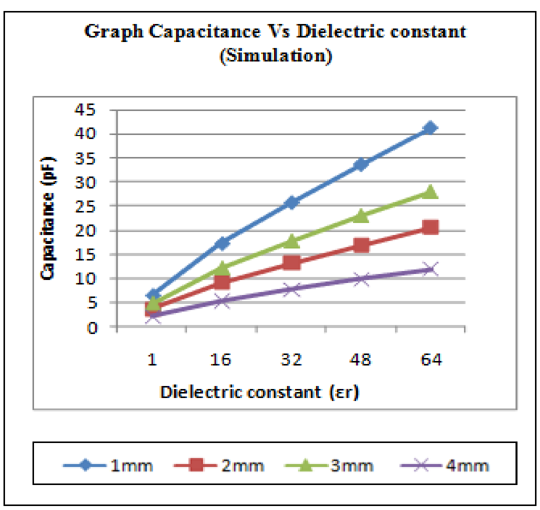

Figure 7. Graph Simulation Graph Simulation of different width electrode

Graph in figure 7 show the result simulation of different electrode width. From the graph the capacitance is increasing when dielectric constant increases. The capacitance also increases when electrode width decreases. The electrode width 1.0mm has the higher capacitance value compare to other at each dielectric constant percentage. The lower capacitance value is at 4.0mm electrode width for each dielectric constant. The result shows that the performance and sensitivity of the sensor is high when the sensor is design with small electrode.

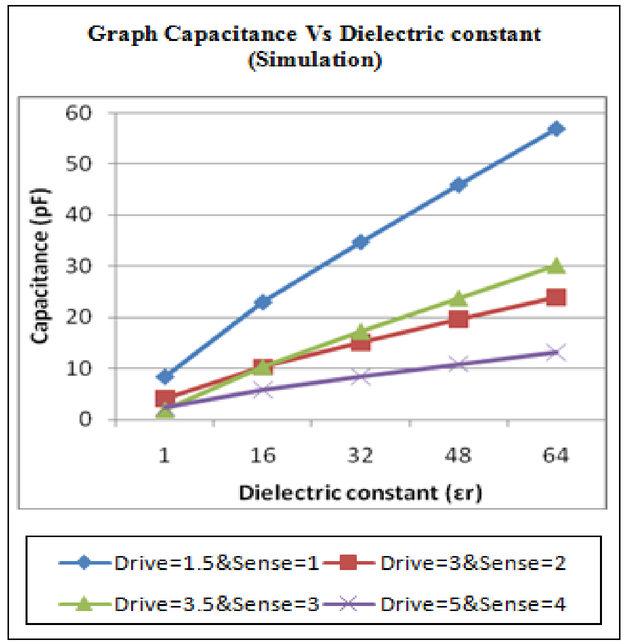

Figure 8. Graph Simulation of different drive and sense width electrode

Graph in figure 8 show the characteristics the sensor due to the different dimension of drive and sense electrode width. Based on graph above drive 1.5mm and sense 1mm has a high capacitance value than other at each dielectric constant percentage. The lower capacitance value is drive 5mm and sense 4mm which is the bigger width between the sensors. The value of capacitance is slightly increases than the previous one. The result shows that the different width affects the capacitance value which is sensor more accurate and high sensitivity.

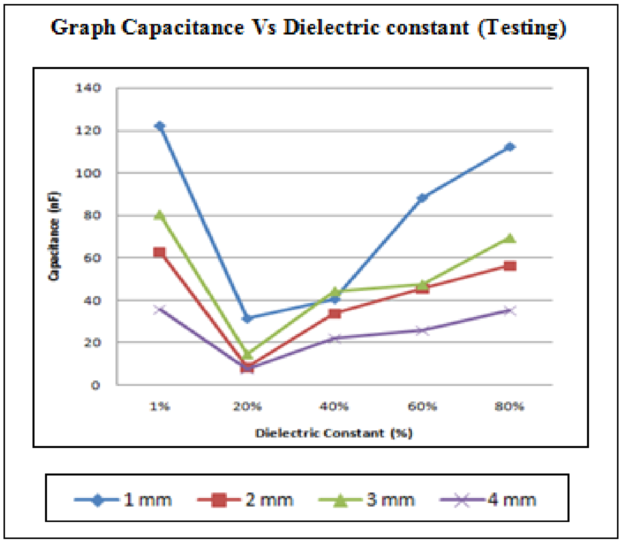

Figure 9. Graph Testing of different width electrode

The graph in figure 9 shows result of different electrode width**.** From the graph the capacitance is increase when dielectric constant increases although graph not linear. The value not stable and linear because effect of sensor without ground. It also happens because environmental effect and sample of soil that been prepared [9]. The smaller width 0.1 mm has a higher capacitance value compare to others. It shows that the capacitance value increase when the electrode width decrease (smaller). This means the smaller electrode has a higher sensitivity other than bigger electrode. This result and simulation result was prove that the FEF sensor affected by electrode width.

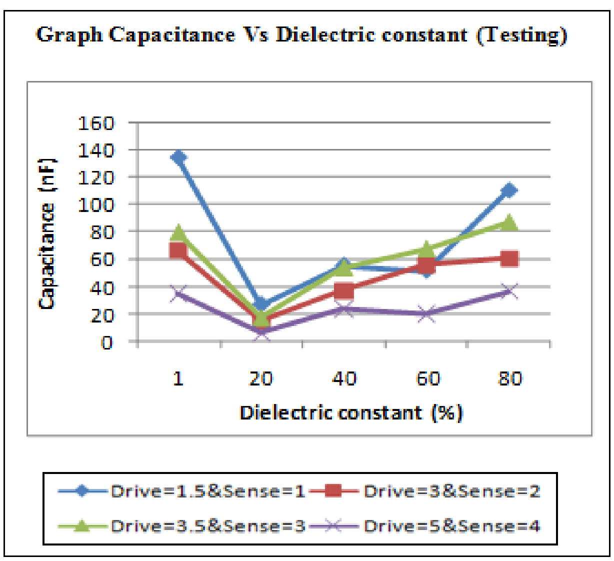

Figure 10. Graph Testing of different drive and sense width electrode

The graph in figure 10 shows the results of different drive and sense electrode width. The result is similar with previous one but slightly increases the capacitance value. That means the different of width drive and sense electrode not rapidly changing the sensitivity of sensor. The graph is also the same with the different width which is not linear due to environmental effect. The testing result show the similar pattern with the simulation except not linear.

TABLE 3. CAPACITANCE VALUE WITH GEOMETRY DESIGN AT 20% SOIL SAMPLE

Electrode Width (mm)	Gap (mm)	Number of Electrode (drive)	Capacitance Value (nF)
1.0	2.5	18	31.45
2.0	3.0	9	8.40
3.0	2.0	9	14.51
4.0	3.5	5	7.5

Drive Width (mm)	Sense Width (mm)	Gap (mm)	Number of Electrode (drive)	Capacitance (nF)
1.5	1.0	1.5	18	26.58
3.0	2.0	2.5	9	14.48
3.5	3.0	1.5	9	17.7
5.0	4.0	3.0	5	6.4

Table 3 shows the reading for 20% soil sample of moisture contents. The results show that design with electrode width 1mm is high sensitivity compare with other designs. Based from this finding, the sensor is high sensitivity when electrode width is smaller. The number of electrode also influence the performance of sensor with the more electrode can increase the capacitance value. This can be seen from table when electrode number is 18 the capacitance value is high. From the table, when the gap between the electrode increase the value of capacitance is decreased. When gap between electrodes is 3.5mm and 3mm the capacitance is 7.5nF and 6.4nF respectively.

V. CONCLUSION AND RECOMMENDATION

This paper presented the effect of dimension and electrode width to performance of FEF sensors. Based from results, the width of electrode is influence the performance of FEF soil moisture sensor. Besides that, the number electrode and gap between each electrode also affect the sensitivity of sensor. The results also show that, the capacitance value of drive and sense different width is slightly bigger than with different width electrode. The FEF sensor can be designed using the smaller width, increase the number of electrode and decrease the gap. The size of sensor in this project is 100mmx100mm also can be modified to increase the number of electrode. The simulation and testing show a different because environmental effect and human error during prepared soil sample. The testing should be doing in covered oven to reduce the effect. The design should have a ground electrode to control the interference and give better readings.

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