Analysis On Fringing Electric Field Sensor Sensitivity Based On It Geometry Shape and Sizing

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Abstract-**This project purpose is to analyze the 'Fringe Electric Field (FEF) Sensor' sensitivity by varying it geometry shape and electrode size. Fringing electric field (FEF) sensors are commonly used to determine the properties that cannot be directly measure for example electrostatic, temperature, hardness and many others. In this project, the FEF sensor was used to determined the moisture level in soil by measuring its capacitance values. This project will start with simulation using Finite Element Method Magnetic (FEMM) to simulate the FEF sensor. The process then continues with fabricating the FEF sensor using Printed Circuit Board (PCB) technology. The FEF sensor will be tested using LCR meter to measure the capacitance values and the data obtained are varies by the geometry shape, electrode width and number of electrode of the FEF sensor. The data obtained will be tabulated then compare with the simulation data.**

Keywords: fringing electric field (FEF); geometry shape; electrode sizing; volumetric water content (VWC); Finite Element Method Magnetic (FEMM); LCR meter;

I. INTRODUCTION

A material properties such as moisture, temperature and hardness cannot be directly measured, so a sensor such as fringing electric field is always used to measure the types of properties. Fringing electric field can be used to determine soil moisture level[1,5]. This FEF sensor using the capacitor principle operation which is electrode width × electrode length is represent area of conductor in electrode. While the gaps between electrodes represent distance, d between two plates in capacitor structure and the permittivity of water.

The formula of capacitance is

$$C = \frac{\varepsilon A}{d} \tag{1}$$

where C is the capacitance (farads); ε, the permittivity of dielectric (absolute, not relative); A is the area of plate in square meters and d is the distance between plates in meters.

Capacitance is the capability of a material to store a charge. Physically, capacitor consist of two parallel area plate with a gap between them. If a voltage is apply between both plate, an electric charges will occurs on the plates thus an electrical field will exist which in this case the fringing electric field is exist between the space.

The method to conduct the FEF sensor is by applying AC voltages at the drive and sense electrodes while the guard (ground) will be grounded. A fringing electric field will be produced and the overlapping between fringing electric field of drive and sense will result in capacitance characteristic. The permittivity of soil is effecting the capacitance based on the volumetric water content (VWC) contain in the soil. The change on the permittivity will effect electric field and the change is detected by sense electrodes then sends the signal to LCR meter to calculate the value of capacitance. The higher capacitance values have, the better sensitivity for the FEF sensor will turn out to be.

VWC describes how much water is in a material for example soil, silt and clay. The content consist on the basis of material and water mass or its volume. Soil samples made for this project is by using method ratio of water volume to dried soil volume for instance 50% of moisture is made up from 200ml of water and add to 400ml of dried soil volume[7]. The permittivity for pure water at room temperature (20°C) is 80 and any intrusion in the pure water such as impurity substance or changes in temperature could disturb the pure water permittivity.

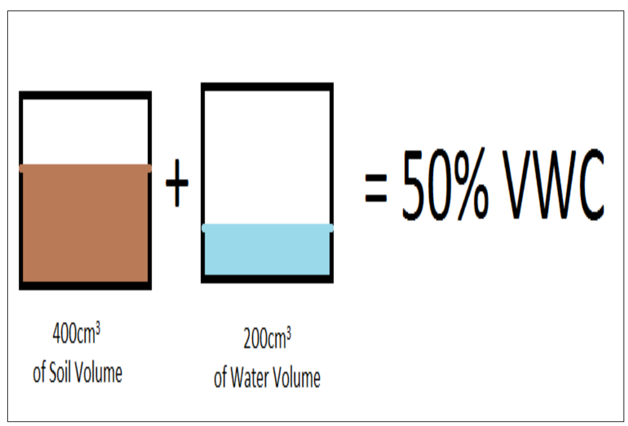

Figure 1: Ratio between water volume and soil volume

LCR meter is usually used to measure an Inductance(L), Capacitance(C), and lastly Resistance(R) of a device. It not measured the values directly but from it impedance where the calculation is done by instrument circuitry.

II. METHODOLOGY

A. Concept design

The plate design for both hardware and software in this project contain a several different plate designs which is varies according to their respective parameter for the analysis. The varied parameters are electrode length, electrode width, electrode gap and number of electrode. Each plates are named based on their parameter which is varied for comparison. All the plates have ground (full copper layer) at the back plane to avoid interference from external electromagnetic fields. To keep away from cross-talk between sensors a guard electrodes are used[2].

There are five plate designs for this project and they are reference plate, electrode plate, width plate, gap plate and lastly length plate. The other values that have been varied is the VWC level.

All the parameters are selected so they can be studied whether they will have effect to the sensitivity of the FEF sensor or not.

i. *Reference plate*

The reference plate used as the reference for the other plate which contains the fix parameter that used to compare the result with the other plate.

No. of electrode	Electrode width	Gap between electrode	Electrode length
40	1.0mm	1.0mm	34.0mm

Table 1: Specifications for Reference plate

ii. *Electrode plate*

The electrode plate have the same parameter as reference plate except for the number of electrode on the plate that *reduced* to 50%. The plate have 10 drive electrodes and 10 sense electrodes which is different from reference plate that contain 20 drive electrodes and 20 sense electrodes.

No. of electrode	Electrode width	Gap between electrode	Electrode length
20	1.0mm	1.0mm	34.0mm

Table 2: Specifications for Electrode plate

iii. *Width plate*

As for the width plate the only different it has with reference plate is the size of electrode width which *increased* to 2.0mm.

No. of electrode	Electrode width	Gap between electrode	Electrode length
40	2.0mm	1.0mm	34.0mm

Table 3: Specifications for Width plate

iv. *Gap plate*

The gap plate has the change in the gap or distance between drive electrodes and sense electrodes which is *decrease* from 1.0mm on the reference plate to 0.5mm on the gap plate.

No. of electrode	Electrode width	Gap between electrode	Electrode length
40	1.0mm	0.5mm	34.0mm

Table 4: Specifications for Gap plate

v. *Length plate*

The length plate has the change in electrode length for both drive and sense electrode where from reference plate the length is 34mm and for length plate the length is *increased* to as 68mm.

No. of electrode	Electrode width	Gap between electrode	Electrode length
40	1.0mm	1.0mm	68.0mm

Table 5: Specifications for Length plate

B. Software design

Software used for the simulation of this project is Finite Element Method Magnetics (FEMM) which is a finite element package for solving 2D planar and ax-symmetric problems in electrostatics and in low frequency magnetic[4]. For this problem, the 2D planar is used to simulate the FEF sensor.

All five plates are simulated using FEMM software to find the value of capacitance based on each specification that have been setup. The percentage of permittivity of the soil is varied by 1% ($\varepsilon r1$), 20 %($\varepsilon r16$), 40 %($\varepsilon r32$), 60 %($\varepsilon r48$), 80 %($\varepsilon r64$) and 100 %($\varepsilon r80$) of moisture.

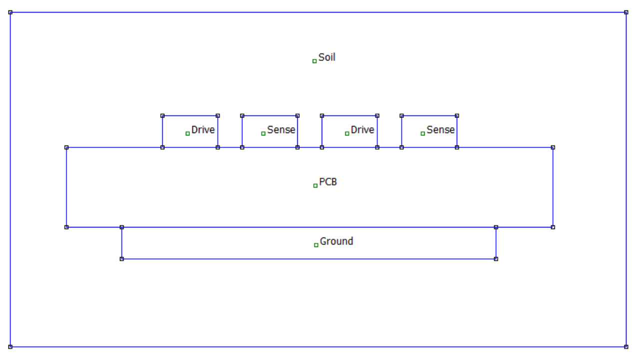

Figure 2: Example of design layout on simulation

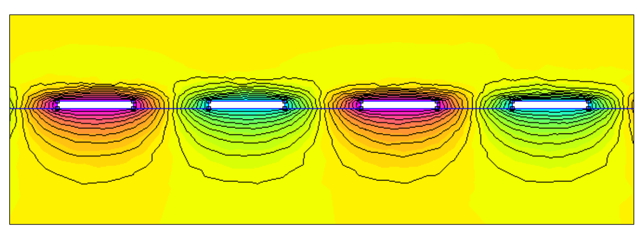

Figure 3: Output on simulation

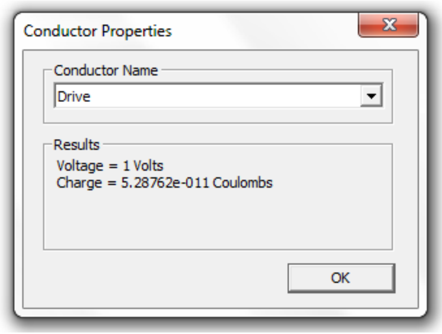

Figure 4: Capacitance value

C. Hardware design

The fabrication process for the hardware start by drawing the design in a software. Ultiboard (PCB Design Software) from National Instrument is used for the PCB design layout and after the drawing had finished the design files then send to a technician at Fabrication Laboratory level 4 UiTM Shah Alam for PCB fabrication process.

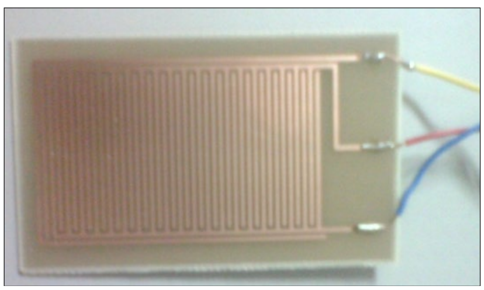

Figure 5: Plate design

After the fabrication process finish, testing process for the FEF sensor plates are performed to find the value of the capacitance. The test used LCR meter AT 10kHz of frequency to measured the capacitance of each plates in a several samples of soil that have a different level of VWC in percentages. The soil samples was prepared by using volumetric method. All the soil samples have same volume which is 800ml and the soil samples was prepared 24-hours before running the test to make sure that the water is absorbed properly.

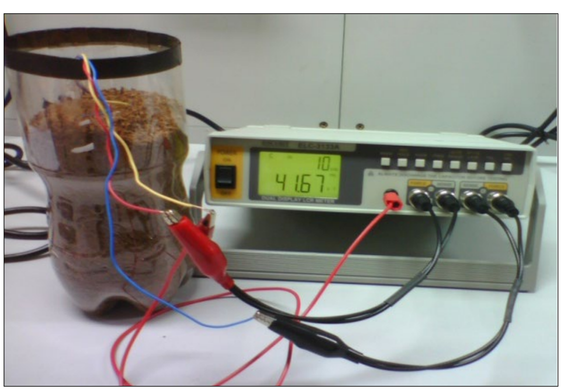

Figure 6: Test setup

III. RESULT AND DISCUSSION

A. Simulation test

The result for simulation test have been obtained and recorded in the table below:

Plates	Capacitance (pF) based on moisture level					
	1%	20%	40%	60%	80%	100%
Reference	39.23	118.40	185.80	250.07	313.20	374.90
Electrode	19.80	58.75	92.00	123.83	155.11	186.10
Width	50.25	140.10	215.40	287.30	357.90	427.90
Gap	52.88	178.22	291.10	400.55	508.68	616.17
Length	79.81	236.80	370.70	489.90	624.92	749.80

Table 6: Result for simulation test

The result plotted into a chart as shown in the figure below:

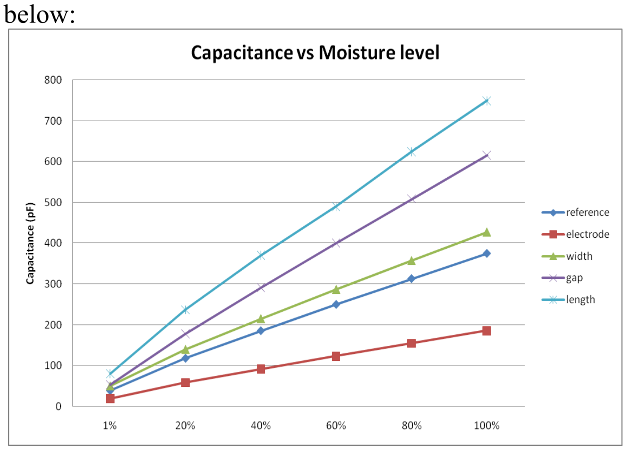

Figure 7: Chart of simulation result

The chart from the simulation result shows an increment linear line for the capacitance values of all plates due to the increases of the moisture level. The chart shows that sensitivity (capacitance) for length, gap and width plate are above the reference plate. While the electrode plate have less sensitivity than the reference plate which also the lowest values of sensitivity from all other plates in all moisture level. The highest sensitivity belong to the different in length of the electrodes (length plate) followed by the different in distance between two electrodes (gap plate) and then the width size of the electrodes (width plate).

The result shows that when the electrodes gain more length it will improve the sensitivity of the FEF sensor which is consistent with the equation of capacitance where more length in electrode will expand the area of conductor thus increased the capacitance value. Same goes to the thicker width of electrodes which increase the sensitivity of the FEF sensor. The principle also applied for the gap plate where the reduction in gap between two electrodes will raise the sensitivity value of the FEF sensor. As for the electrode plate, the reduction amount of electrodes causing directly in decreasing of the total area of conductor which cause the sensitivity of the FEF sensor the be decreasing.

B. Actual test

The result for actual test have been obtained and recorded in the table below:

Plates	Capacitance (pF) based on moisture level				
	1%	20%	40%	60%	80%
Reference	41.67	2752	17448	46200	76590
Electrode	20.37	1847.4	11753	27640	46130
Width	58.04	2864	56150	66490	77200
Gap	54.15	1948.6	39110	79450	104890
Length	117.05	12586	73090	109240	145760

Table 7: Result for actual test

The result plotted into a chart as shown in the figure below:

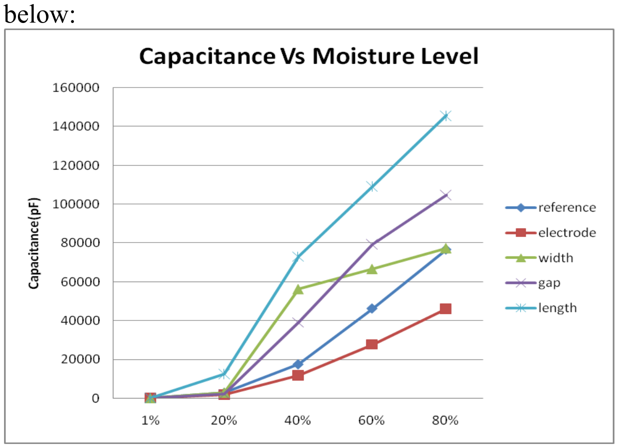

Figure 8: Chart of actual result

The chart from the actual result shows an increment of nearly linear line for the capacitance values of all plates due to the increasing of the moisture level. The result shows that the capacitance value for length, width and gap plate are higher than the reference plate while the electrode plate have lower capacitance than the reference plate. The highest value of capacitance is from length plate while electrode plate have the lowest capacitance value.

The width plate have the most not consistent line due to some environmental effects while the other plates only have slightest change in consistency but still can be consider as linear line. The non-linear line could be caused by human error while preparing the soil samples and also while conducting the test with LCR meter. The value of very high capacitance could be cause by materials used or the value of voltage supply used in conducting the test using LCR meter.

C. Comparison of simulation and actual test

The simulation test and actual test have the same characteristics where the value of capacitance for length, width and gap are above reference plate while the electrode plate is below the reference plate in all moisture level range.

IV. CONCLUSION AND RECOMMENDATION

The analysis from both simulation and actual test can be used to proved that the geometry shape and sizing can affect the values of capacitance or the sensitivity of FEF sensor. The size of electrodes length effect the sensitivity of FEF sensor. The FEF sensor sensitivity can be raised by lengthen up the length size of electrode. Widen the width of electrodes can improve the sensitivity of FEF sensor and adding up the number of electrodes also can enhance the sensitivity of FEF sensor. Narrowing the gap between electrodes as well can increase the sensitivity of FEF sensor and therefore decreasing the size of the FEF sensor. The increasing in the area of conductor as well as narrowing the gap between electrodes will cause the sensitivity of FEF sensor to be more sensitive. It can be concluded that, increasing the width, length, number of electrodes and reducing the gap between electrodes will improve the sensitivity of FEF sensor.

It is recommended for future research to use more suitable soil material to get better result. It is also encouraged to dry the soil first before adding moisture into it. The water used for sampling should be pure water to make sure that no impurity will change the permittivity of the water and hence interfere with the outcome result. The numerical calculation should be done when picking the sizing for the geometry size.

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