Design of the Probe Sensor for the TDR Soil Moisture Sensor System

Prashant Thapliyal[1], Gambheer Singh Kathait[2], Vishal Rohilla[3]
[1,2,3] Assistant Professor, HNB Garhwal University, Srinagar Garhwal, Uttarakhand, India

***Abstract*: The probe sensor is of two parallel plates type which is used to determine the moisture content of the soil. The probe sensor is connected to a resistance to time period converter circuit of the TDR soil moisture sensor system whose output time period depends upon the resistance of the soil which in turn depends upon the moisture content of the soil acting as medium between the plates of the probe sensor. The TDR probe sensor is designed and simulated using the Integrated Electro software in order to determine the effects of the parameters like length, thickness and gap between the plates on electric field and energy density. The simulation results are used to predict and determine the geometry of the probe sensor, the materials that should be used in making the plates of the probe sensor and coating the plates of the probe sensor for reducing the effects of the fringing field and noise in the environment.**

***Keywords*— TDR probe sensor, Simulation, Parameters effects**

I. INTRODUCTION

The sensing probe is an important part of the TDR soil moisture sensor system. The parameter used for the measurement of the soil moisture is the resistance of the soil. The time period of the reflected signal from the soil depends upon the resistance of the soil in between the parallel plates probe sensor. Thus the soil moisture content can be measured by measuring the time period of the reflected signal from the soil. The parallel plates probe act as a waveguide for the signal transmission and reflection. Thus the various possible geometries of the probe sensor are simulated in the Integrated Electro software and the effects of the changes in the geometries in the parameters like electric field are studied. The Integrated Electro software is a powerful simulation tool in which the different 3-D geometries of the probe sensor can be designed in equivalent 2-D geometries and the parameters like the length and thickness can be varied to study the changes in the electric field and energy density between the parallel plates of the probe sensor.

II. BASIC THEORY OF PROBE SENSOR

The sensing probe is the primary sensing element, which senses the dielectric properties of the soil sample. The aims of optimal probe design are to obtain a representative sampling volume with a robust, practical design while minimizing the effects of Electrical conductivity across the probe. These factors are not complementary, and some compromises must be made in design. For instance, spacing plates further apart increases the ease with which they can be inserted into the soil and increases the magnitude of the resistance measured across the plates. However, it leads to more energy storage closer to the surface of the plates, where, due to compaction effects, the soil might be less representative than undisturbed soil[1].

A. Two-Rod vs. Three-Rod Probes

Two-rod and three-rod probes are most commonly used for routine field work. As a result, many studies have examined the attributes of these probes[2][6] conducted a theoretical study comparing the sampling volume of balanced two and three rod probes in some detail. It is found that given an increase in rod diameter for the same centre spacing a marginal improvement in the uniformity of the distribution of the sensitivity within the sample area was achieved. In comparison, the three rod probe had a reduced sample area and more energy around the central rod. Therefore it would suggest that the two-rod probes are perhaps preferable for fieldwork.

B. Comparison between Probes Using Plates or Rods

One of the main aims of TDR probe design is to try to obtain a relatively uniform energy distribution in the sampling volume. Achieving this aim reduces the bias of the measurement for areas close to the surface of the rods where disturbance of the porous medium will be maximal.

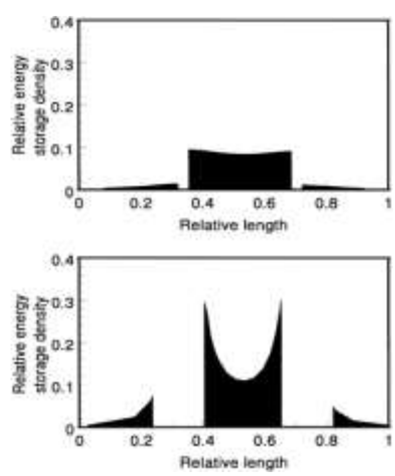

Fig. 1. The relative energy storage distribution cross sections comparison between (a) parallel plates and (b) twin rods. The graphs indicate that there is

a more even distribution of energy in the sample between plates than between rods.

Fig.1 compares the relative energy storage density between two balanced parallel rods and two balanced parallel plates. The diagrams illustrate that more of the energy is closer to the conductor using rods than using plates. First suggested the use of TDR probes with plate geometry[7]. More recently plates acting as blades have been proposed for both static[8] and mobile[9] TDR measurements. It is conducted a comparison of four different probe geometries, comparing plates vs. rods with two and three conductor geometries. These included two parallel rods, three parallel rods, two parallel plates and three parallel plates. The three rods were constructed from 4-mm-diameter stainless steel, 0.15 m long, with a centre spacing of 24 mm between outer and inner conductors. The plates were made from 2-mm-thick stainless steel, 20 mm high and 0.15 m long, with centres spaced 22 mm apart[10][12].

On the basis of previous study and discussion about the probe sensor, it is decided that two parallel plates configuration is better than two rods configuration. It can be simulated in the **Integrated ELECTRO** software and also clear from the fig.1. The relative energy distribution is uniform and even for two plate configuration than the two rod configuration.

III. DESIGN CONSIDERATIONS OF THE PARALLEL PLATES PROBE SENSOR

The proposed dimensions of the parallel plate electrodes according to previous discussion may be:

1. Length of the electrodes = 120mm. to 180mm.
2. Width of the electrodes = 20mm.
3. Thickness of the electrodes = 1mm. to 2mm.
4. Gap between the electrodes = 25mm. to 40mm.
5. Thickness at the tip = 0.5mm.
6. Plates are tapered for the length = 10mm.

In the above dimensions the length and thickness can be simulated with the **Integrated ELECTRO** software.

A. EFFECT OF LENGTH VARIATIONS ON ELECTRIC FIELD

The electric field in two regions has been taken into consideration.

For Length=120mm

- *Electric Field in the Region between Electrodes*

The electric field per unit length of the electrode in the region between the electrodes is stable, constant and high 1.5 kV/m up to 80mm.of entire length (fig.2).

- *Electric Field in the Region Outside and Near to the Edge of the Electrodes*

The electric field outside and near to edge of the electrodes is the fringing electric field. This fringing electric field acts as environmental noise interfering with the connection cables and wires and other components of the sensor and producing a distortion in the output signal and thus producing error in the readings. The fringing field varies in the range of 1.5 kV/m to 0.0486 kV/m when the distance is varied in x-axis between 160 mm. to 0 mm. So the rate of change of fringing field is 9.07125V/m-mm. Thus the fringing electric field decreases to zero at less distance and the other components are less interfered (fig.2).

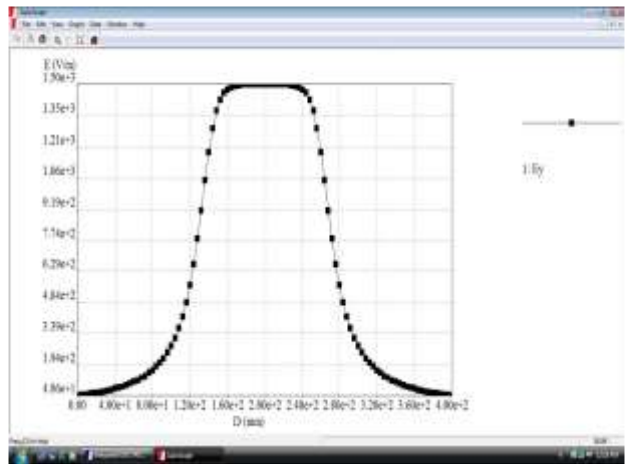

Fig. 2. Electric Field vs Length for L=120mm

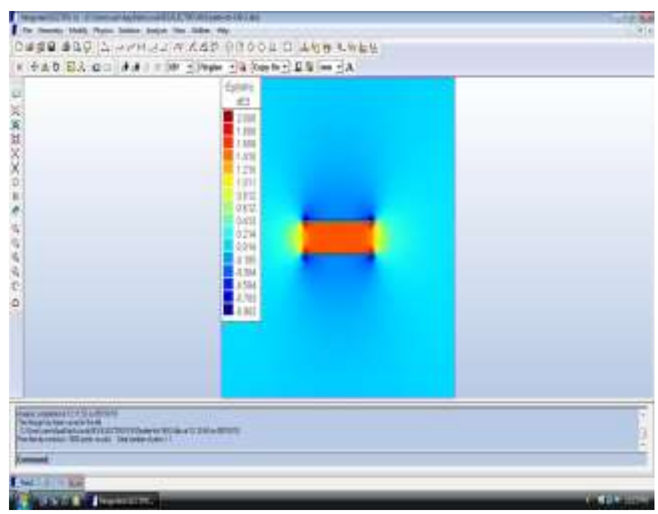

Fig. 3. Simulation Contour of Electric Field for L=120mm

For Length=140mm

- *Electric Field in the Region between Electrodes*

The electric field per unit length of the electrode in the region between the electrodes is stable, constant and high 1.5 kV/m up to 95mm. of entire length (fig.4).

- *Electric Field in the Region Outside and Near to the Edge of the Electrodes*

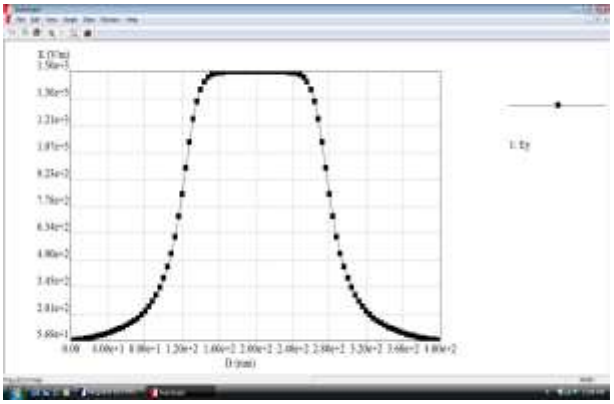

Fig. 4. Electric Field vs Length for L=140mm

The fringing field varies in the range of 1.5 kV/m to 0.0569 kV/m when the distance is varied in x-axis between 155 mm. to 0 mm. So the rate of change of fringing field is 9.31V/m-mm (fig.4).

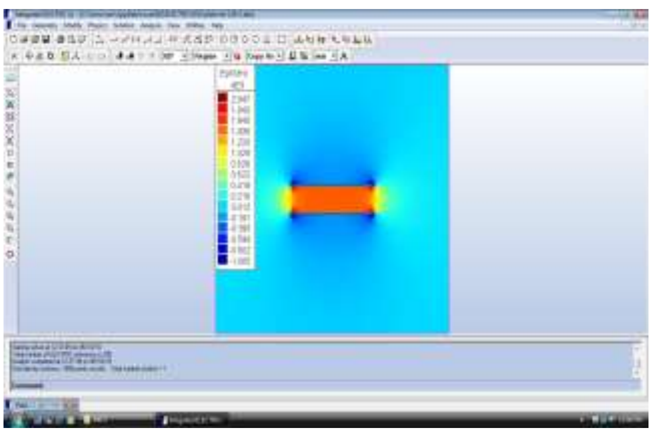

Fig. 5. Simulation Contour of Electric Field for L=140mm

For Length=160mm

- *Electric Field in the Region between Electrodes*

The electric field per unit length of the electrode in the region between the electrodes is stable, constant and high 1.5 kV/m up to 105mm. of entire length (fig.6).

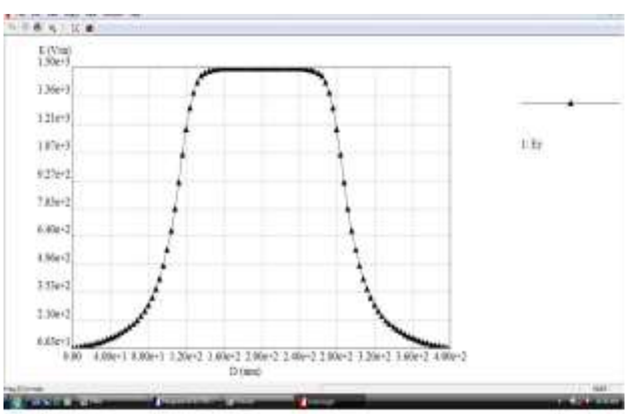

Fig. 6. Electric Field vs Length for L=160mm

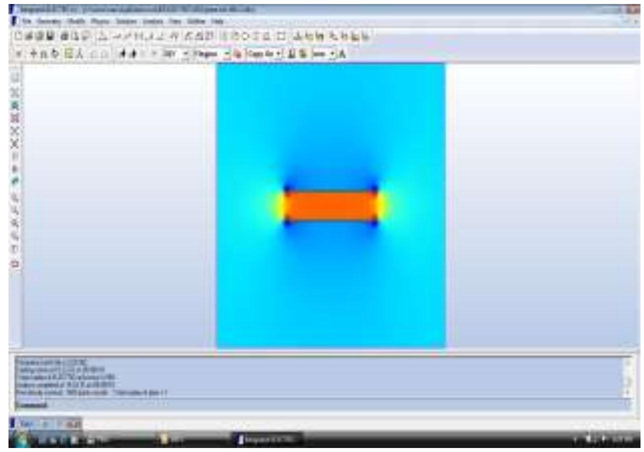

Fig. 7. Simulation Contour of Electric Field for L=160mm

- *Electric Field in the Region Outside and Near to the Edge of the Electrodes*

The fringing field varies in the range of 1.5 kV/m to 0.0663 kV/m when the distance is varied in x-axis between 150 mm. to 0 mm. So the rate of change of fringing field is 9.558V/m-mm (fig.6).

B. EFFECT OF LENGTH VARIATIONS ON ENERGY DENSITY

For Length=120mm

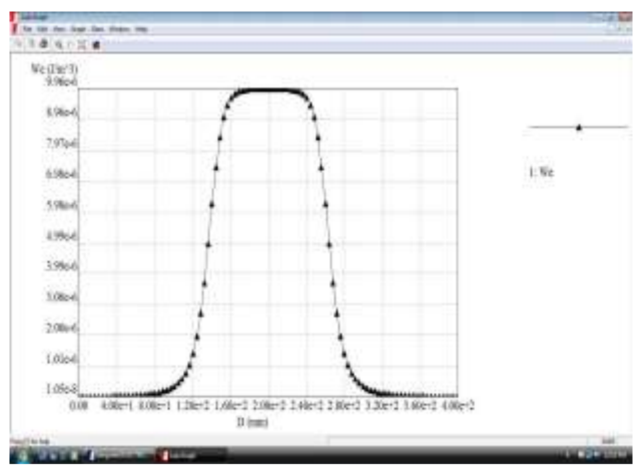

Fig. 8. Energy Density vs Length for L=120mm

The energy density in the region between the electrodes is stable, constant and high 9.96µJm^{-3} up to 40mm.of entire length (fig.8).

The graph plotted below (fig.9) shows the energy density variations when the spacing between the two electrodes is varied.

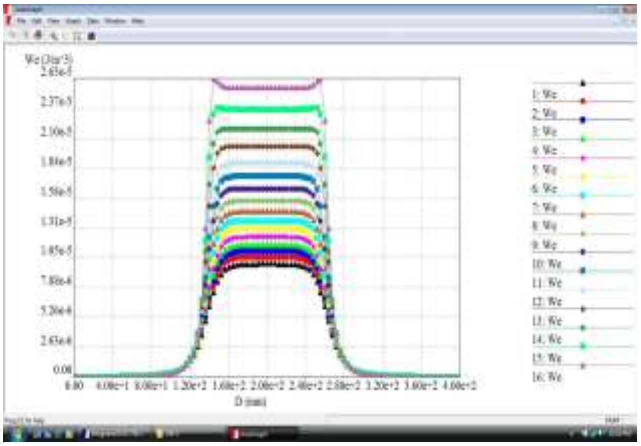

Fig. 9. Energy Density vs Spacing between Electrodes for L=120mm

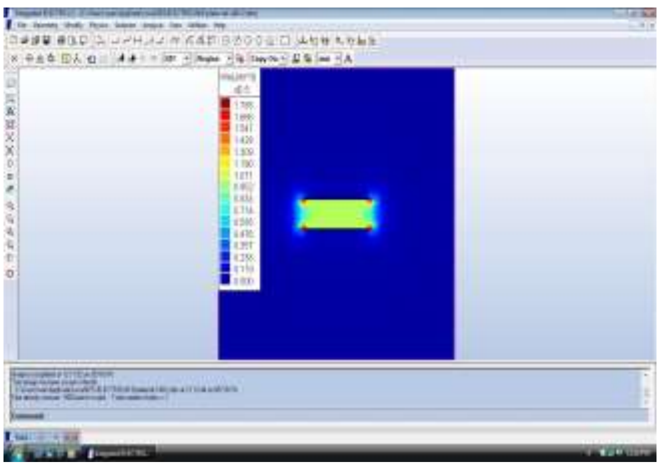

Fig. 10. Simulation Contour of Energy Density for L=120mm

For Length=140mm

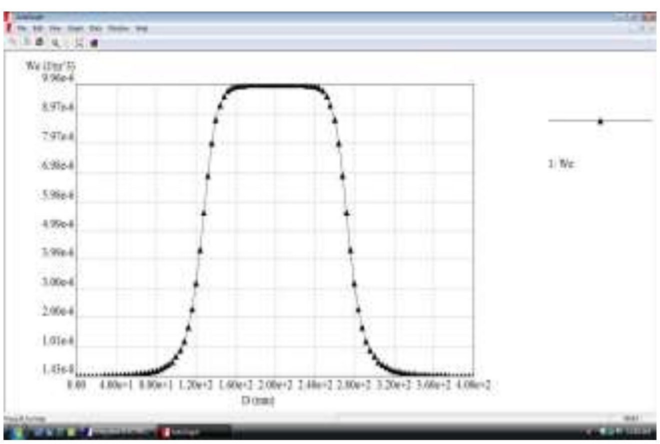

Fig. 11. Energy Density vs Length for L=140mm

The energy density in the region between the electrodes is stable, constant and high 9.96µJm^{-3} up to 80mm.of entire length (fig.11). The graph plotted below shows the energy density variations when the spacing between the two electrodes is varied (fig.12).

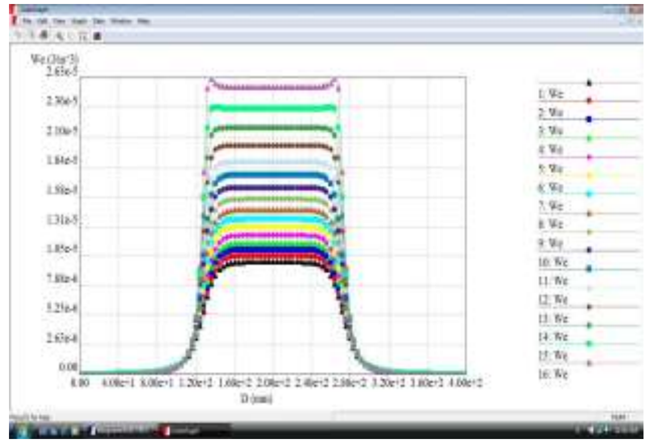

Fig. 12. Energy Density vs Spacing between Electrodes for L=140mm

In fig.12 as the spacing decreases between two electrodes the energy density is uniform for the less length of the electrodes.

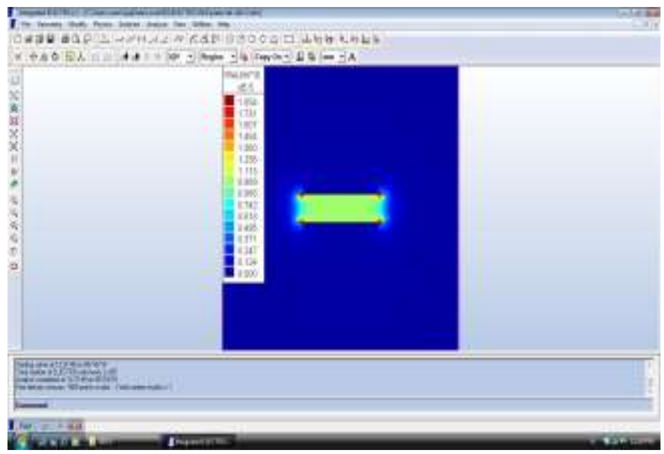

Fig. 13. Simulation Contour of Energy Density for L=140mm

For Length=160mm

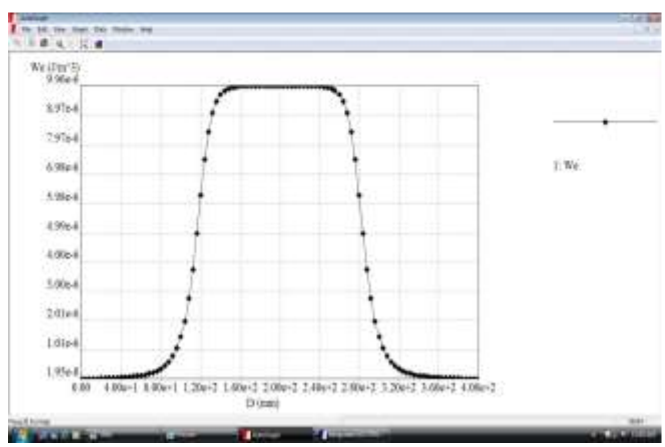

Fig. 14. Energy Density vs Length for L=160mm

The energy density in the region between the electrodes is stable, constant and high 9.96µJm^{-3} up to

95mm.of entire length (fig.14). The graph plotted below shows the energy density variations when the spacing between the two electrodes is varied (fig.15).

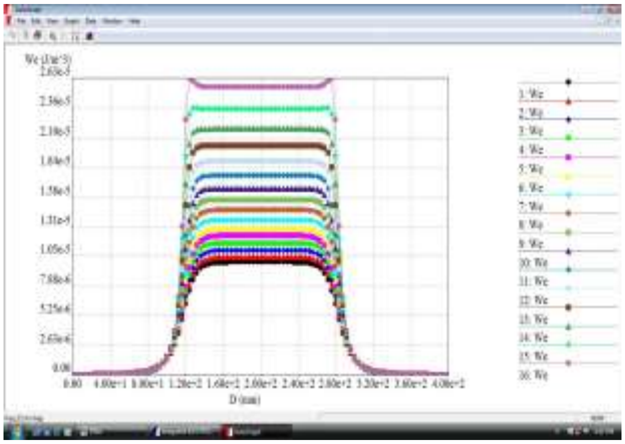

Fig. 15. Energy Density vs Spacing between Electrodes for L=160mm

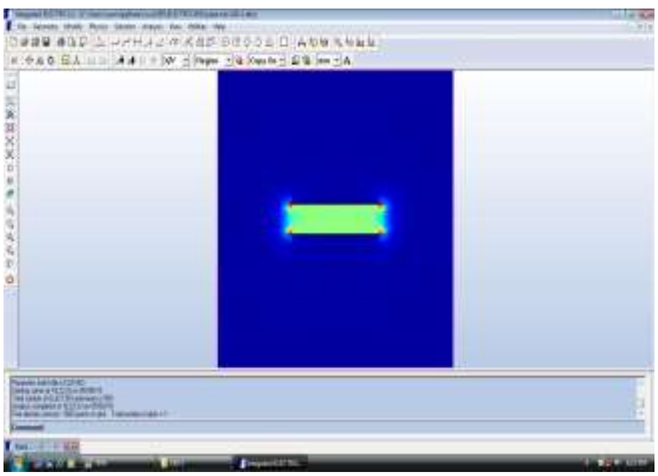

Fig. 16. Simulation Contour of Energy Density for L=160mm

C. *EFFECT OF THICKNESS VARIATIONS ON FRINGING ELECTRIC FIELD*

For Length=120mm and thickness t=2mm

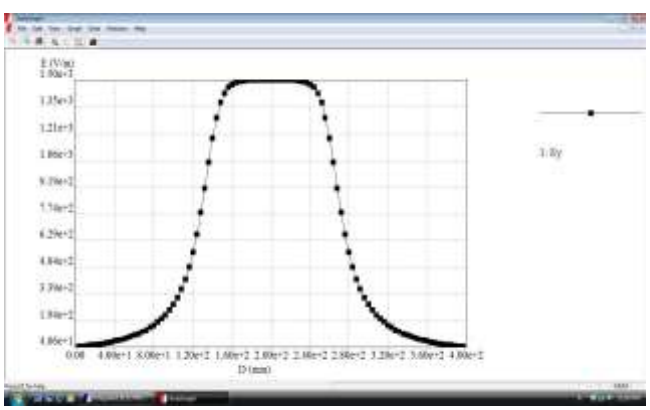

Fig. 17. Electric Field vs Length for t=2mm

For Length=120mm and thickness t=1.5mm

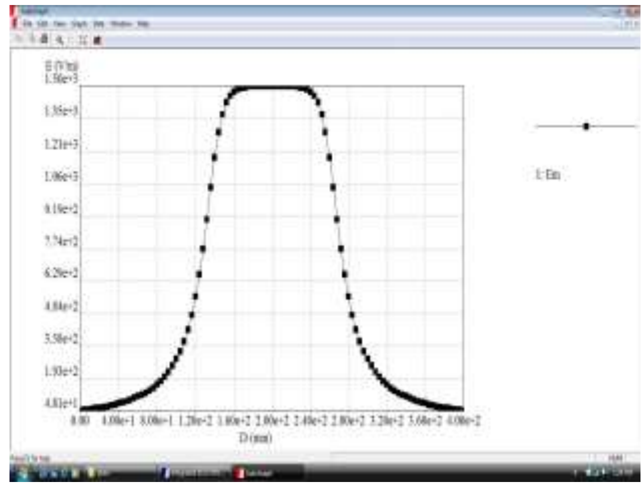

Fig. 18. Electric Field vs Length for t=1.5mm

As it is shown in fig.17 and fig.18 that fringing field is decreasing more rapidly when the thickness is reduced. In fig.17 the fringing field varies in the range of 1.5 kV/m to 0.0486 kV/m when the distance is varied in x-axis between 160 mm. to 0 mm. So the rate of change of fringing field is 9.07125V/m-mm. In fig.18 the fringing field varies in the range of 1.5 kV/m to 0.0481 kV/m when the distance is varied in x-axis between 160 mm. to 0 mm. So the rate of change of fringing field is 9.0743V/m-mm.

D. *EFFECT OF THICKNESS VARIATIONS ON ENERGY DENSITY*

For Length=160mm and thickness t=2mm

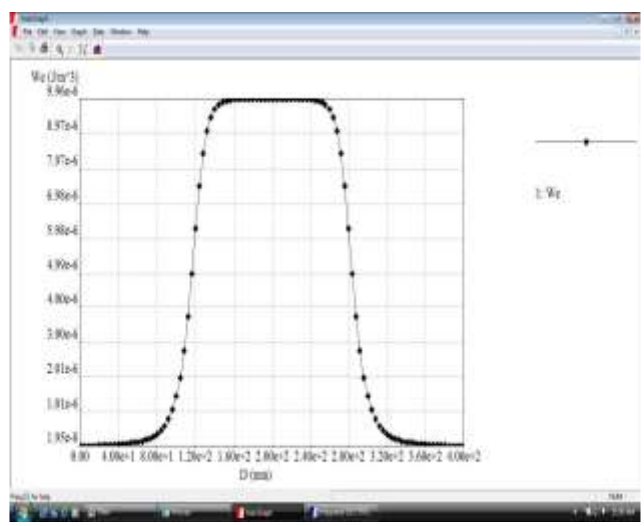

Fig. 19. Energy Density vs Length for t=2mm

For Length=160mm and thickness t=1.5mm

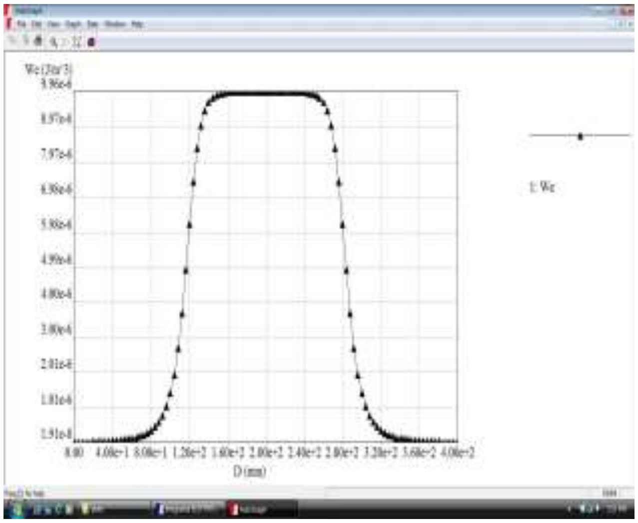

Fig. 20. Energy Density vs Length for t=1.5mm

Again it is observed from the graphs (fig.19 and fig.20) that reducing the thickness of the plates for same length the effect are only on the fringing field, while the energy density is nearly constant between the electrodes

III. MATERIALS AND METHODS

A plastic housing is used to hold the electrodes. The electrodes are attached to it. The connection cables from the electrodes are connected to the data logging system for further processing of the data. The outer surface and the edges of the plates are coated with an insulating material with low dielectric constant in order to reduce the effects of the fringing electric field due to the edges of the plates, electric field due to the charge accumulated on the outer surface of the plates, the electric field in the environment. This fringing electric field is reduced by the Teflon or Epoxy coating due to its low dielectric constant. The electric field due to the charge present on the outer surface of the plates causes interference in other nearby components of the sensor. This electric field is reduced by the Teflon coating due to its low dielectric constant.

A. *PROPERTIES OF THE TEFLON*

The following properties of Teflon make it to be used for coating the outer surface of the plates of the parallel plate TDR sensor.

1. *RESISITANT TO MANY MATERIALS*

This includes ozone, chlorine, acetic acid, ammonia, sulfuric acid and hydrochloric acid. The only chemicals known to affect these coatings are molten alkali metals and highly reactive fluorinating agents. Thus Teflon will be affected less by the chemicals and ionic solutions present in the soil.

2. *WEATHER AND UV RESISTANCE*

The Teflon coated plates will more resistant to weather. Thus the Teflon coated plates have long endurance and durability.

3. *NON STICK*

Very few solid substances will permanently adhere to a Teflon coating. While tacky materials may show some adhesion, almost all substances release easily. Thus the soil and other chemicals will not be able to adhere to Teflon coated plates.

4. *OUTSTANDING PERFORMANCE AT THE HIGHER TEMPERATURES*

It can temporarily withstand temperatures of 260C and cryogenic temperatures of -240C and still have the same chemical properties. It has an initial melting point of 342C (+- 10C) and a secondary melting point of 327C (+- 10C). Thus Teflon coated plates will be able to operate at higher temperatures.

5. *LOW COEFFICIENT OF FRICTION*

It is the ratio of the force required to make two surfaces slide over each other. A low number equals low resistance and smooth operation. This indicates the difficulty in sliding one surface against another. The coefficient of friction is generally in the range of 0.05 to 0.20, depending on the load, sliding speed, and type of Teflon coating used. Thus the Teflon coated plates can be penetrated easily into the soil.

6. *NON WETTING*

Teflon finishes are both hydrophobic and oleophobic, cleanup is easier and more thorough. Thus the error in the capacitance due to moisture will be less.

IV. RESULTS

From the above discussion it can be concluded that the length of the electrodes should not be very less, but at the same time it should not be very long. Because as we increases the length of the electrodes, the fringing field also increases, but for a suitable length the electric field and energy density is uniform and high for maximum length of the electrodes. The thickness of the plates should be less, because for less thickness the fringing field decreases rapidly to zero. The last important thing is that spacing between electrodes should not be very less. It should be vary between 25mm. to 40mm. Because reducing the spacing very much the energy density is reduced. The material for the parallel plates probe sensor is chosen Stainless steel-316, due to its good conducting property and its ruggedness.

So from above conclusion we have chosen following dimensions of the electrodes shown in fig..21.

1. Length of the electrodes (L) = 160mm.
2. Width of the electrodes (W) = 20mm.
3. Thickness of the electrodes (t) = 1.5mm.
4. Gap between the electrodes (S) = 40mm.
5. Thickness at the tip (t') = 0.5mm.
6. Plate is tapper for the length (P) = 10mm.

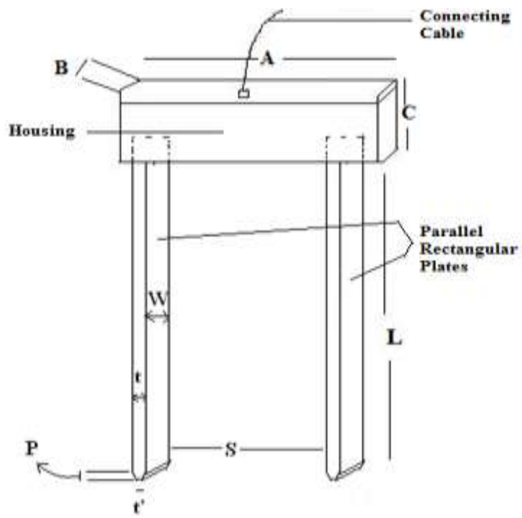

Fig. 21. Proposed Rectangular Parallel Plate Probe Sensor

V. CONCLUSIONS AND DISCUSSION

The parallel plate probe sensor forms an important part of the TDR soil moisture sensor system and thus parameters of the TDR probe sensors are also important. The practical results are improved with improved parameters of the TDR probe sensor. The parameters of the developed TDR probe sensor are improved through simulation in the Integrated Electro software. The design of the TDR probe can be further improved through simulation in more powerful software tools and other parametric variations of frequency selectivity, extracting moisture selective electrical variations, effect of ionic conductivity existing in the soil moisture and the input electrical stimulus tunning can be further investigated to develop precise soil moisture predictive models. Thus, a pre-processing such as software simulations to extract selective parameter of interest out of a whole spectrum of electrical variations in the signal because of real world complex parametric events such as investigation of exact volume of water content in a piece of soil under measurement, becomes an easy and preferable solution. The overall exercise and specific parametric analysis resulted in to producing, an improved practical results of the developed TDR probe sensor.

REFERENCES

[1]. Rothe, A., W. Weis, K. Kreutzer, D. Matthies, U. Hess, and B. Ansorge. 1997. Changes in soil structure caused by the installation of time domain reflectometry probes and their influence on the measurement of soil moisture. Water Resour. Res. 33:1585–1593.

[2]. Dalton, F.N., and M.Th. van Genuchten. 1986. The time-domain reflectometry method for measuring soil water content and salinity. Geoderma 38:237–250.

[3]. Zegelin, S.J., I. White, and D.R. Jenkins. 1989. Improved field probes for soil water content and electrical conductivity measurement using time domain reflectometry. Water Resour. Res. 25:2367–2376.

[4]. Knight, J.H. 1992. Sensitivity of time domain reflectometry measurements to lateral variations in soil water content. Water Resour. Res. 28:2345–2352.

[5]. Ferre, P.A., D.L. Rudolph, and R.G. Kachanoski. 1996. Spatial averaging of water content by time domain reflectometry: Implications for twin rod probes with and without dielectric coatings. Water Resour. Res. 32:271–279.

[6]. Ferre, P.A., J.H. Knight, D.L. Rudolph, and R.G. Kachanoski. 1998. The sample areas of conventional and alternative time domain reflectometry probes. Water Resour. Res. 34:2971–2979.

[7]. Chudobiak, W.J.B., B.A. Syrett, and H.M. Hafez. 1979. Recent advances in broad band VHF and UHF transmission line methods for moisture content and dielectric constant measurement. IEEE Trans. Instrum. Meas. 28:284–289.

[8]. Robinson, D.A., and S.P. Friedman. 2000. Parallel plates compared to conventional rods as TDR waveguides for sensing soil moisture. Subsurface Sens. Technol. Appl. 1:497–511.

[9]. Inoue, Y., T. Watanabe and K. Kitamura. 2001. Prototype time-domain reflectometry probes for measurement of moisture content near the soil surface for applications to 'on the move' measurements. Agric. Water Manage. 50:41–52.

[10]. D. A. Robinson, S. B. Jones, J. M. Wraith, D. Or and S. P. Friedman, "A Review of Advances in Dielectric and Electrical Conductivity Measurement in Soils Using Time Domain Reflectometry".

[11]. Skaling W. 1992. TRASE: A product history. p. 187–207. *In* G.C. Topp (ed.) Advances in measurement of soil physical properties: Bringing theory into practice. SSSA Spec. Publ. 30. SSSA, Madison, WI.

[12]. Kraus J.D. 1984. Electromagnetics. 3rd ed. McGraw Hill, London.