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Dynamic Nature of Electric Field Variations with Changing Dielectric Constant of Propagating Medium

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***Abstract* – The properties of electric field depend on the medium through which the ray is propagating. Depending upon the dielectric characteristics of the medium, the nature of the field changes. In microwave measurements and also in their application areas, it is very important to select the propagating dielectric medium based on the requirements otherwise the desirable output cannot be achieved. The influence of noise due to dielectric mismatch can produce erroneous results that further affect the experiment under consideration. In this paper an analysis has been made to show the deviation of received field depending on different dielectric media. Some specific dielectric materials have been placed inside the propagating medium, horn antennas are used both as transmitter and receiver and power meter is used to calculate the received power of the field. The power variations at the receiving section have been observed and a graphical representation has been made based on the received power variations with the frequencies of operation. Based on this analysis a clear understanding can be made on how the field depends on medium dielectric. This analysis is also helpful in various microwave measurements and designing of microwave devices.**

Keywords- ***Dielectric constant; Dielectric deviations; Electric field propagation; Microwave measurements.***

I. INTRODUCTION

In today's world, it is impossible to survive without the fundamental laws that governs the main properties behind electromagnetic wave propagation [1,2,3]. Likewise, there are enumerable number of technologies, industries, organizations, devices, instruments, and many more whose core operating principal depends upon the electromagnetic field propagation through various mediums [4,5]. Every now and then new researches are coming up and new technologies are developed based on some basic principles of EM (Electromagnetic) wave propagations. One of them is the behavior of electric field while propagating through different dielectric mediums.

Electric field propagations follow the fundamental laws those are derived from Maxwell's equations [6-9]. There the dependencies of electric field with medium dielectric permittivity have been shown clearly [10].

Based on that fact our following experiment has been proposed. Selecting suitable medium is extremely necessary for various microwave measurements, for developing microwave devices and to conduct experiments related to antenna theory. Due to its medium dependency electric field varies and produces erroneous results. Through this work an analysis has been made to show the logic behind the deviations and how to adjust them correctly to avoid inaccurate outputs.

Dielectric mediums with different dielectric constant have been chosen and fields are passed through from transmitter section to the receiver section. The power measurements are done of the received fields at the receiver section. It is seen that the received power varies for varying dielectric media. For a range of frequencies inside the microwave frequency range, this experiment has been conducted. A graphical analysis has also been made based on the received power and changing frequency for distinct dielectric mediums. Considerable amount of difference has been achieved. In the case of very high frequency, the medium dielectric dependency on operating frequency comes [11, 12]. So, the experiment has been restricted within feasible frequency range. The output analysis clearly shows that due to the changing behavior of propagating field through various dielectric medium, it is very much essential to choose suitable media. This experiment will be very much helpful for all who are related in the field of microwave engineering or conducting experiments based on EM propagation.

The chapters flow like, in second section the fundamental concepts of medium dependency of EM field have been explained with required mathematical formulation. Third section elaborates the making of the experimental model. Fourth section describes the formation of the experimental setup and placement of the model inside the setup. Fifth section evaluates the output results and gives suitable table and graphical representation of the outputs. It also proves the necessary outcomes that have been expected from this entire experiment. Finally, the last section concludes the experiment with some future aspects and proposals that can be conducted with the help of the idea discussed through this work.

II. RELATION BETWEEN FIELD PROPAGATION WITH MEDIUM DIELECTRIC

Considering a medium with uniform dielectric distribution and having a dielectric constant **ε.** The applied filed in the medium is **E**. The dipole moment per unit volume induced in the medium is given by,

$$\mathbf{P} = \epsilon_0 (\epsilon - 1)\mathbf{E} \quad \text{........ (1)}$$

Where,
P is the dipole moment in the medium,
ϵ is the dielectric constant of the medium,
ϵ_0 is the dielectric constant in free space.

The medium considered here is uniform in nature. So, free charges and free currents are absolutely absent. Closed charge density is absent as well. The medium is non-magnetic hence; it is free from magnetization current density. Time varying induced dipole moment causes polarization current in the medium. That can be given by the equation below:

$$\mathrm{j} = \frac{\partial \mathbf{P}}{\partial t} \quad \text{.......... (2)}$$

Using equations (1) and (2) the Maxwell's equations can be rearranged & expressed as:

$$\nabla \times \mathbf{B} = \epsilon_0 \mu_0 (\epsilon - 1)\frac{\partial \mathbf{E}}{\partial t} + \epsilon_0 \mu_0 \frac{\partial \mathbf{E}}{\partial t} = \frac{\epsilon}{c^2}\frac{\partial \mathbf{E}}{\partial t} \quad \text{.. (3)}$$

Where,

B is the Electric flux density in the medium,

c is velocity of light in free space ($\approx 3 \times 10^8$ m/sec.),

μ_0 is magnetic permeability of free space.

Since $c = (\epsilon_0 \mu_0)^{-1/2}$.Thus, the fundamentals equations of Maxwell's are same for the propagation of electromagnetic waves through dielectric medium and through vacuum except that c $\longrightarrow$ c/n where $n = \sqrt{\epsilon}$ is called the *refractive index* of the medium. So, this is concluded that the speed of electromagnetic waves through a dielectric medium is slower (by **n** times) with respect to vacuum [13, 14].

III. EXPERIMENTAL SETUP

From the fundamental concept of Electromagnetic theory, it is known that if the dielectric constant of a medium increases from 1 (ϵ >1), then its electric affinity increases and more numbers of electric lines of forces converge towards it [15,16]. That will cause an increment in field intensity and power at the receiving end. This statement has been also justified by our experiment.

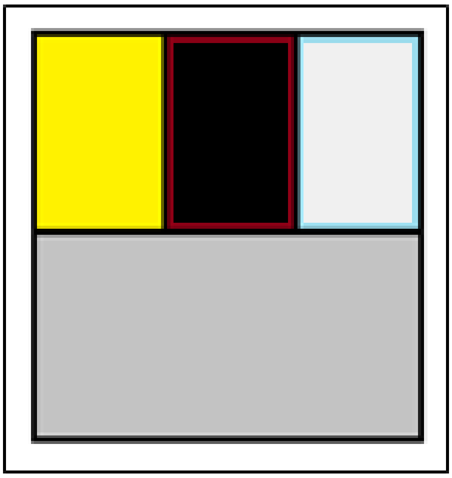

Fig. 1 (a): The experimental model

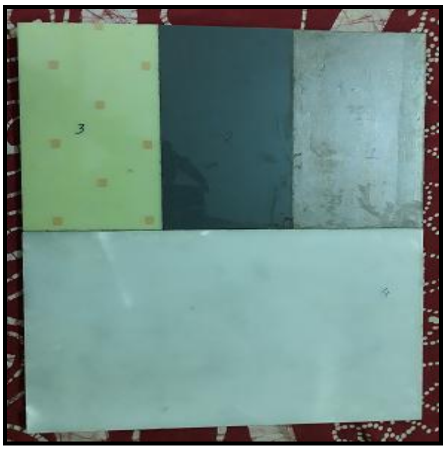

Fig. 1 (b): The hardware counterpart of the Model

The dimension of the entire model is 14 inch x 12 inch

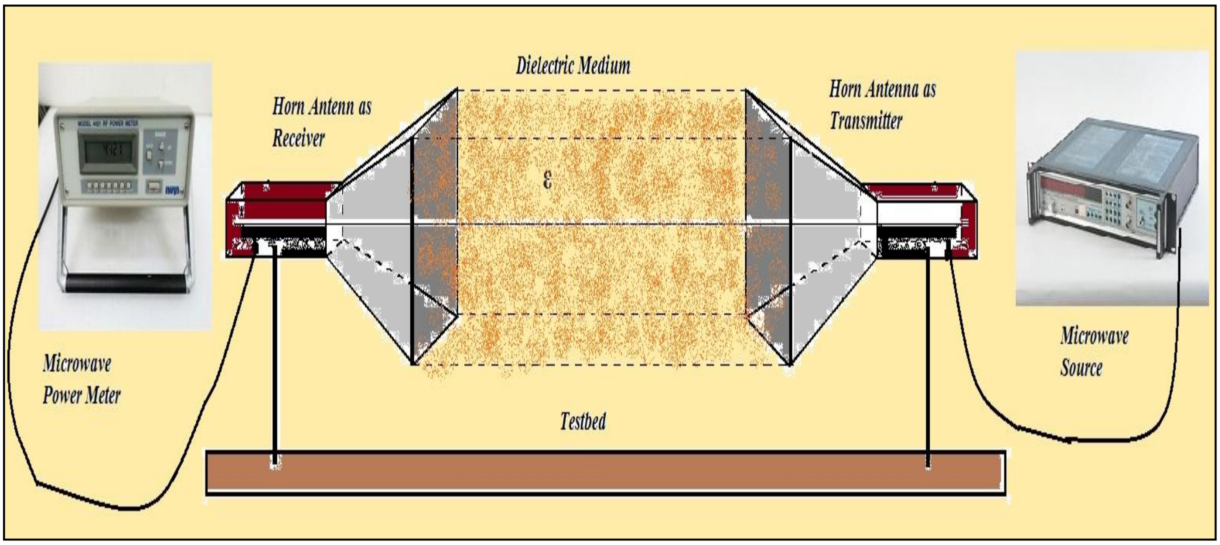

Fig. 2: The entire experimental setup with proper antenna arrangements

TABLE1
Model Description

Region Specification	***Dimension of the Region***	***Dielectric Constant (ε)***	***Material Name***
	4 inch x 7 inch	2.2	Plastic Type
	4 inch x 7 inch	8.2	Plastic Type
	4 inch x 7 inch	2.8	Glass Type
	12 inch x 7 inch	4.2	Plastic Type

● *Placement of the Model inside Setup*

This model has been placed in between two horn antennas. One is acting as a transmitter and another is the receiver. The model and the receiver are in the near field region of the transmitter. At first the received power has been measured from horn to horn without the model and next with the model.

In these two measurements the variations in received power has been shown in a tabular fashion. The frequency range that has been considered here is from **2 GHz** to **4 GHz**. The variation in received power supports the changing field at the receiver.

IV. RESULT ANALYSIS

In this section the received power readings for two different conditions are taken and the same is drafted in tabular form below. The resultant dielectric of the entire model has been considered when the model is placed between the antennas. The placement of the model changes medium dielectric and that further varies the properties of the travelling wave through that medium.

A. Received power Measurement with and without Model

TABLE 2

Variations of Received power with changing frequencies for Different dielectric mediums

Frequency in GHz	***Received power in dB in absence of model***	***Received power in dB in presence of model***
2.0	-66.72	-62.54
2.1	-64.25	-58.47
2.2	-55.39	-45.21
2.3	-32.42	-27.54
2.4	-25.32	-23.20
2.5	-20.12	-20.65
2.6	-17.80	-15.32
2.7	-14.70	-13.65
2.8	-12.54	-12.57
2.9	-12.70	-13.25
3.0	-13.10	-12.50
3.1	-12.80	-11.59
3.2	-14.08	-12.25
3.3	-13.09	-11.96
3.4	-15.57	-13.40
3.5	-16.40	-13.89
3.6	-17.80	-15.35
3.7	-18.96	-16.87
3.8	-17.20	-17.31
3.9	-18.93	-17.59
4.0	-18.58	-17.90

From the above data it is found that for a particular frequency the received power increases in presence of the model with respect to power in the absence of the model. Suppose, if a frequency has been considered say 2 GHz, the received power in absence of model is -66.72 dB and that increases to -62.54 dB in presence of the model. A graphical representation has been made of received power with respect to the frequency for two cases.

of low dielectric values inside it. Due to practical non availability of high dielectric material in market the model is formed with low dielectric materials. Though the result is quite satisfactory and also holds the statement but if proper materials are used then this same experiment will show some more accurate deviations that can make the idea much clear. That will be done in near future as an improvement within this experiment.

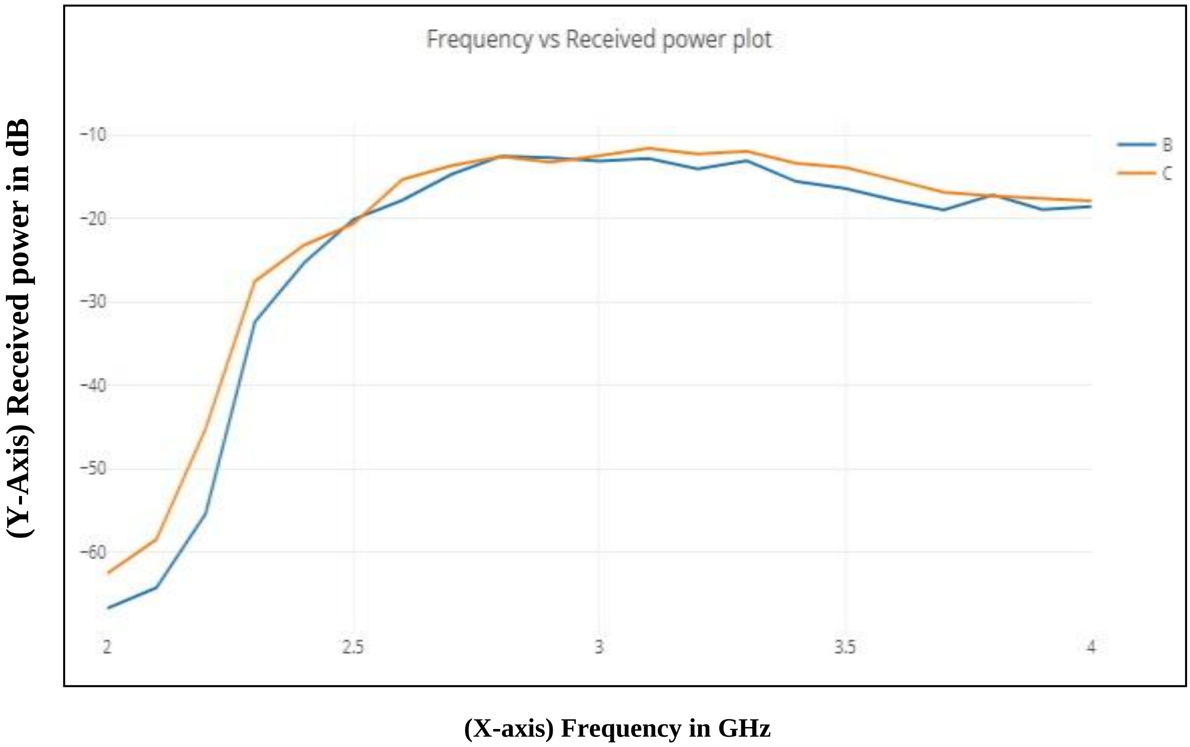

Fig.3. Frequency vs. received power plot for two different conditions

In above figure (figure 3) line B represents the received power without model and line C represents received power with model. From these two graphs also, it is cleared that, there is a variation in received power and hence in received field for different dielectric medium at a certain frequency range.

V. RESULT EVALUATION

From the above analysis it has been made clear that the received power and field both varies if the dielectric of the medium changes and this practical realization gives this integrated theoretical and practical approach a solid base. The combined dielectric effect has been taken under consideration here. Apart from taking individual one the entire model with combinations in dielectric has been placed inside the setup. So, the graph that has been plotted is the combined dielectric effect of the model. The two graphs are close to each other as because the presence

VI. EDUCATIONAL ASPECT OF THE EXPERIMENT

To understand the fundamental behavior of the propagating EM field through various dielectric medium this experimental approach is very much helpful. The air gaps in between the transmitter and receiver create signal power degradation at the receiver section. So, designing of the intermediate section is a challenging task and to improve the power level this can be re-designed. All the instruments used throughout our experiment worked perfectly without any instrumental failure. Unavailability of proper dielectric materials in the market is one of the major reasons of small difference between two plots in figure 3, but replacing them with suitable dielectric material surely improve the output result. One can further extend this work by incorporating a greater number of dielectric mediums with sufficient difference in cumulative dielectric constant.

Frequency dependency on dielectric medium is an area of argument. Here the frequency range has been selected such a way that the cumulative dielectric field should not get affected by the frequency. The range of frequency selectivity is something everyone must keep in mind while conducting this experiment. The presence of lossy dielectric mediums inside the experimental chamber disrupts the power reception. We have also taken this fact under consideration. In future any kind of extension must include all possible kinds of facts to get the optimum and error free result. Finally, the lessons one can get out of this experiment are extremely important. The fundamental characteristics of a propagating EM Field through a changing dielectric medium has been proved practically. The nature of receiving filed and how it changes have also been clarified. This experiment gives a basic idea to students and researchers whoever wants to work in this field. Knowing the basic necessity of a beginner this experiment has been conducted and the results are sufficient enough to give high motivation to explore the world of EM wave propagation.

VII. CONCLUSION

Microwave measurement techniques are used in various aspects in the development of research, in the construction of devices and many other fields related to Microwave & Antenna Theory. This experiment will be helpful for all students in this field who want to start doing research or projects in this field. Through this simple experiment the filed propagation dependency on medium dielectric has been shown. Antenna designing, microwave device handling, measurements using various instruments etc. are the works required to be done for the development of microwave engineering. Through this work a basic property of Electromagnetic field propagation has been shown through a methodical and practical experiment. Hope this experiment will play a vital role for the beginners to gain interest in this field. Basic C-programming software are used to calculate the data and to plot the graph from the data output C-plot graphical developer has been used.

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