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Mathematical Modeling For The Estimation Of Dielectric Constant Of Dry And Moist Soil At C And X Band Microwave Frequencies

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Abstract: In the present paper an attempt is made to form a mathematical model that enables to estimate the value of dielectric constant of dry and moist soil at C and X band microwave frequencies (5.3 GHz and 12 GHz). The soil samples are collected from different locations of Haryana (India) and variations of their dielectric constants are studied at different moisture content. The value of dielectric constant is estimated in terms of texture of samples collected and moisture content added in these samples. The model is then tested for the sample collected from different regions of Haryana with different texture of soil and compared with Hallikainen et al. model. The results obtained from the proposed model are accurate and have good practicality.
Keywords: **Dielectric, Soil, Microwave, Moisture, Modeling**

I. INTRODUCTION

Microwave remote sensing now a day is a major tool to study natural resources including soil. The soil has Physical properties-porosity, bulk density, texture, grain size, color etc; Chemical properties - pH, organic matter, nutrients available, inorganic matter etc; Electrical properties – permeability, dielectric constant, dielectric loss, electrical conductivity etc. In microwave remote sensing of soil, its electrical parameters play important role as it depends on soil moisture, texture of soil and frequency at which measurements are made. Dielectric constant is a function that depends on texture of soil, moisture content and frequency at which observations are made.[1-5]

Wang and Schmugge[6] presented an empirical model for the calculation of complex dielectric constant of soil-water mixture. The equation has an adjustable parameter that can be chosen to best fit the value of dielectric constant. The soil dielectric constant according to this model is linear combination of permittivities of its component parts-bound water, free water, air and soil material. Hallikainen et al.[7] presented a quadratic polynomial fitting model for the calculation of dielectric constant of soil as a function of sand and clay present in sample and volumetric moisture content at frequencies-1.4, 4, 6, 8, 10, 12, 14, 16 and 18 GHz. Dobson et al.[8] presented semi-empirical model for the calculation of dielectric constant of soil which can be expressed in terms of bulk density of soil, density of soil solids, soil texture, volumetric moisture content, dielectric constant of soil solids and complex permittivity of free and bound water. It also has a constant factor α, the value of which is 0.65. Neil R Peplinski et al.[9,10] expanded the model in the frequency range 0.3-1.3 GHz, allowing model in wider frequency range i.e. 0.3-18GHz

Calla OPN et al.[1,11] presented a model for the estimation of dielectric constant of dry soil in relation to the physical constituents at X-Band microwave frequency. They used three coefficients a, b, c. the values of these three coefficients are not made fixed, but different for different frequencies.

Boyarskii D A et al.[12] developed a model to calculate the effective permittivity of wet soil based on dielectric properties of free and bound water in soil and texture of soil. They used the fact that water in soil remains bound when soil wetness increases from zero to a certain value. Change in volume of bound water in soil leads to the change in its dielectric properties as bound water molecule relaxation time Changes, at a certain wetness of soil, dielectric properties of bound water in it become similar to dielectric properties of free water. Further increase of wetness has no impact on soil bound water dielectric constant which remains equal to free water dielectric constant.

Gadani et al.[13-14] presented a model for estimation of complex permittivity of wet soil at C and X-Band microwave frequency. In this model permittivity of dry soil is considered as initial parameter at frequency of measurement. One more parameter GV is used in this model which is dependent on soil texture.

Quan C el al.[19] measures the value of dielectric constant of soil of different regions using Hallikainen et al.[7] model at 5.3 GHz and compare the results with Dobson et al.[8] model. Rajeev Kumar and Anupamdeep Sharma[15] measured complex dielectric constant of dry and moist soil of indo-Gangetic region of Haryana at C-Band microwave frequency. In the present study, a mathematical model is formed to estimate the value of dielectric constant of dry and moist soil at C-Band microwave frequency. For this model we need to have physical constituents of soil and volumetric moisture content.

II. EXPERIMENTAL DETAILS

A. Sample preparation

Haryana State lies between 27°39' -30° 55' N latitude and 74°28' -77°36' E longitudes[16]. Samples of soil are collected from six different locations of Haryana – Hisar, Ramgarh, Rohtak, Siswal, Balsmand and Naraingarh. The samples of soil collected first sieved and coarse particles are removed. The texture structure of six samples are presented in Table 1 for which measurements are made. The fine particles obtained are then oven dried for several hours to remove moisture completely and make it dry. Now to prepare moist soil samples measured quantity of distilled water is added to dried soil. The gravimetric soil moisture content in percentage term is calculated using the following relation[17] :

$$w_c(\%) = \frac{w_w - w_d}{w_d} \times 100$$

where w_w is the weight of wet soil and w_d is the weight of dry soil.
Volumetric moisture content (w_v) of samples are abtained using formula:

$$w_v = w_c \times \rho_d$$

Where ρ_d is dry density of soil.

Table 1. Texture of Soil Samples Collected

Location	Sand (%)	Silt(%)	Clay(%)	Dry density of Soil	Texture
Naraingarh	60	26	18	1.38	Sandy Loam
Hisar	81	12	7	1.62	Loamy Sand
Rohtak	65	19	16	1.41	Sandy Loam
Siswal	90	4	6	1.68	Sand
Balsmand	82	8	10	1.57	Loamy Sand
Ramgarh	15	59	26	1.11	Silt Loam

B. Measurement of dielectric constant of soil

In the present work, technique used for the measurement constant is waveguide cell technique[18]. A microwave bench operating at C-Band is used at 5.3 GHz in TE_{10} mode with Gunn source at room temperature and another microwave bench operating at X-Band is used at 12 GHz in TE_{10} mode with reflex Klystron as microwave source were used for measurements. The microwaves are allowed to be incident on the sample. A part of incident signal reflects and superimpose with incident signal to give rise to standing wave pattern. The dielectric constant is measured by using the shift in minima of standing wave pattern that takes place due to the change in guide wavelength on the introduction of sample in the waveguide. Dielectric constant can be calculated using the following relation.

$$\epsilon' = \frac{g_\epsilon + \left[\frac{\lambda_{gs}}{2a}\right]^2}{1 + \left[\frac{\lambda_{gs}}{2a}\right]^2}$$

where g_ϵ is real part of admittance, λ_{gs} is wavelength in air filled guide,
a = inner width of rectangular waveguide.

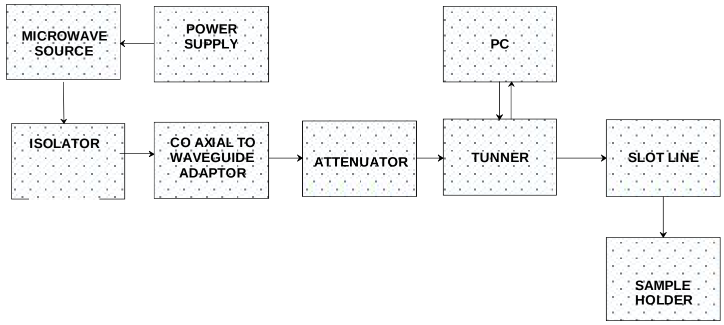

Fig 1. Block Diagram of Experimental Set up of Microwave Bench

III. GENERATION OF MODEL

The generation of the model is based on the experimental results on soil samples collected from different regions of Haryana, the texture and constituents of samples are shown in Table 1.

As the dielectric behavior of dry soil and wet soil are different[12]. To ensure accuracy in model two different models are generated one to estimate value of dielectric constant of dry soil (ϵ'_{dry}) and other to estimate increase in dielectric constant ($\Delta\epsilon'_{moist}$) on the addition of water in it, such that effective dielectric constant of moist soil can be estimated by adding results from both models i.e.

$$\epsilon' = \epsilon'_{dry} + \Delta\epsilon'_{moist}$$

Modeling for $\boldsymbol{\epsilon'_{dry}}$**:**

As ϵ'_{dry} is independent of volumetric moisture content (w_v) and considered only dependent of texture, so one can estimate its value using relation:

$$\epsilon'_{dry} = \frac{a_0(\%Sand)^{b_o}}{(\%Clay)^{c_0}}$$

. Where a_0, b_o and c_0 are constants

To find the values of a_0, b_o and c_0 using the observed values of dielectric constant of dry soil , we get six equations for each frequency i.e for C band and X band. From these six equations, values of a_0, b_o and c_0 are obtained by least square regression method to fit a power function. From this one can estimate the value of dielectric constant of dry soil of known texture.

Modeling for $\Delta\epsilon'_{moist}$:

As $\Delta\epsilon'_{moist}$ is increase in dielectric constant on addition of water in dry soil, its value is zero for zero volumetric content for all samples. The equation of $\Delta\epsilon'_{moist}$ with w_v is a polynomial of degree 2 therefore one can define

$$\Delta\epsilon'_{moist} = f_1 . w_v + f_2 . w_v^2$$

Where f_1 and f_2 are functions of constituents of samples.

To determine the values of f_1 and f_2, one can use:

$$f_1 = \frac{a_1(\%Sand)^{b_1}}{(\%Clay)^{c_1}} \quad \text{and} \quad f_2 = \frac{a_2(\%Sand)^{b_2}}{(\%Clay)^{c_2}}$$

Where a_1, b_1, c_1, a_2, b_2 and c_2 are constants.

To find values of a_1, b_1, c_1, a_2, b_2 and c_2 using the observed values of increase in dielectric constant of moist soil shown in Table 2, we get 70 equations for each frequency. From these 70 equations, values of a_1, b_1, c_1, a_2, b_2 and c_2 are obtained by least square regression method to fit a power function. From this one can estimate the value of increase in dielectric constant of moist soil of known texture and volumetric moisture.

Therefore $$\epsilon' = \epsilon'_{dry} + f_1 . w_v + f_2 . w_v^2$$

IV. RESULT AND DISCUSSION

76 observations are made to for dielectric constant of soil collected from different locations of Haryana for each frequency, out of which 6 observations at each frequency are for dry soil and remaining 70 for moist soil. Different analysis is done on dry and moist sample observations.

Regression analysis is done on dry soil results to obtain values of a_0, b_o and c_0 . The values of other constants are determined using 70 observations to fit 2 power functions i.e. f_1 and f_2. Table 2 represents values of various constants

Table 2. Values of various constants

Frequency	a_0	b_0	c_0	a_1	b_1	c_1	a_2	b_2	c_2
5.3 GHz	2.3106	0.0424	0.0199	21.2062	0.2624	0.0854	3.3631	0.2678	-0.4095
12 GHz	2.6412	0.0262	0.0533	-5.0041	-0.202	-0.0046	151.9445	0.0012	0.0014

The experimental results are shown in Fig 2 and Fig 3 for 5.3 GHz and 12 GHz respectively for different samples collected. The plots also show the variations of dielectric constant with moisture content for Hallikainen *et al*[7]. model and proposed model. The plots reflects that values obtained from proposed model are in good agreement with observed values and and values from *Hallikainen et al.*[7] model and proposed model

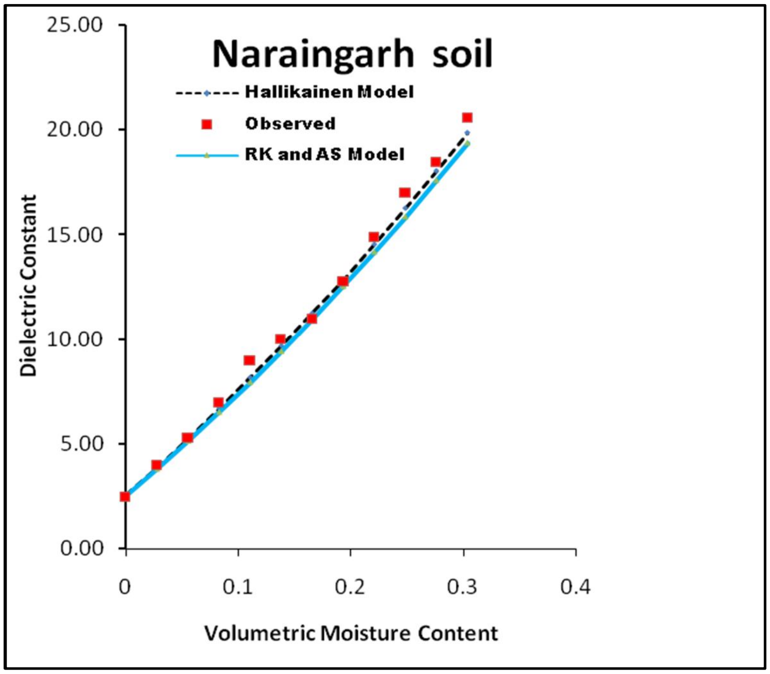

Fig 2.1 Variation of Dielectric Constant of Soil from Naraingarh with Volumetric Moisture Content at C-Band

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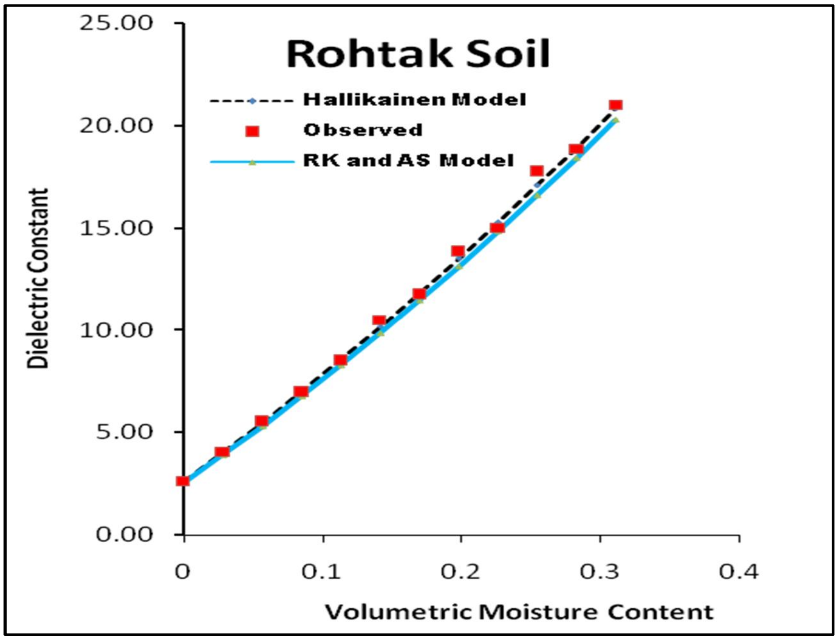

Fig 2.2 Variation of Dielectric Constant of Soil from Rohtak with Volumetric Moisture content at C-Band

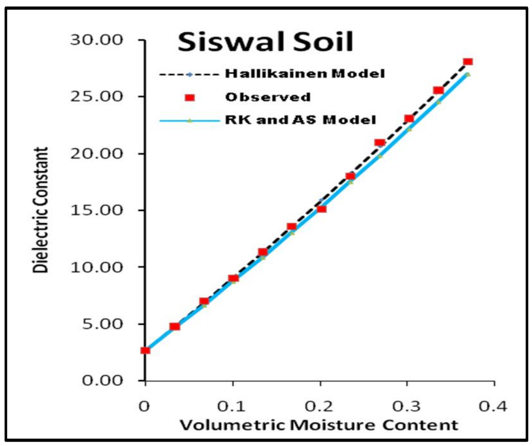

Fig 2.3 Variation of Dielectric Constant of Soil from Siswal with Volumetric Moisture Content at C- Band

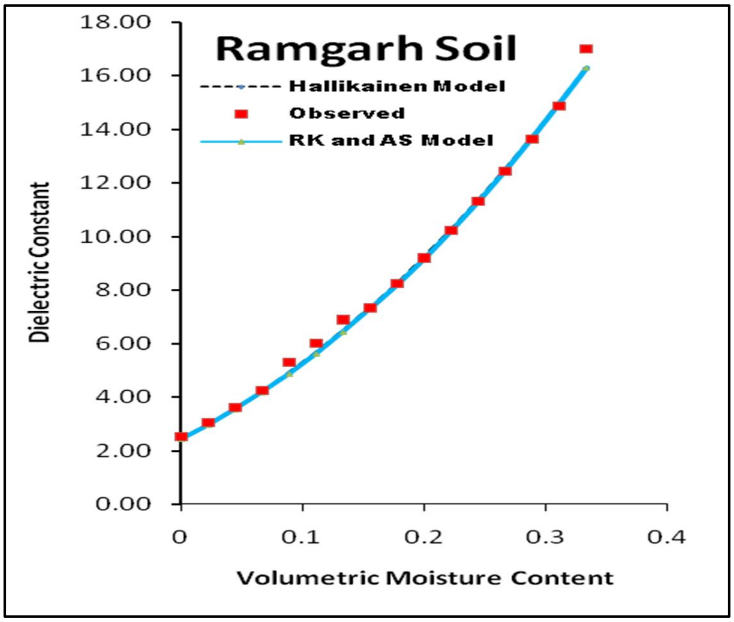

Fig 2.4 Variation of Dielectric Constant of Soil from Ramgarh with Volumetric Moisture Content at C-Band

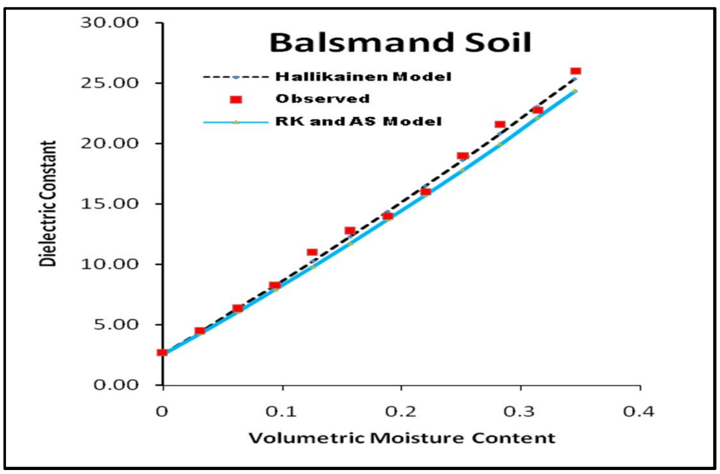

Fig 2.5 Variation of Dielectric Constant of Soil from Balsmand with Volumetric Moisture Content at C-Band

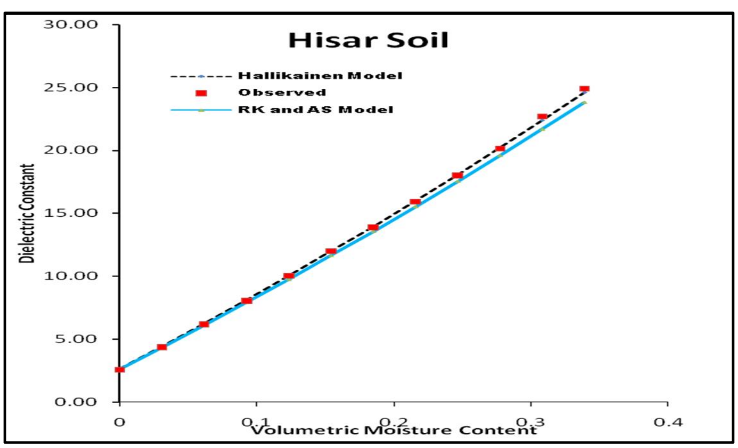

Fig 2.6 Variation of Dielectric Constant of Soil from Hisar with Volumetric Moisture Content at C-Band

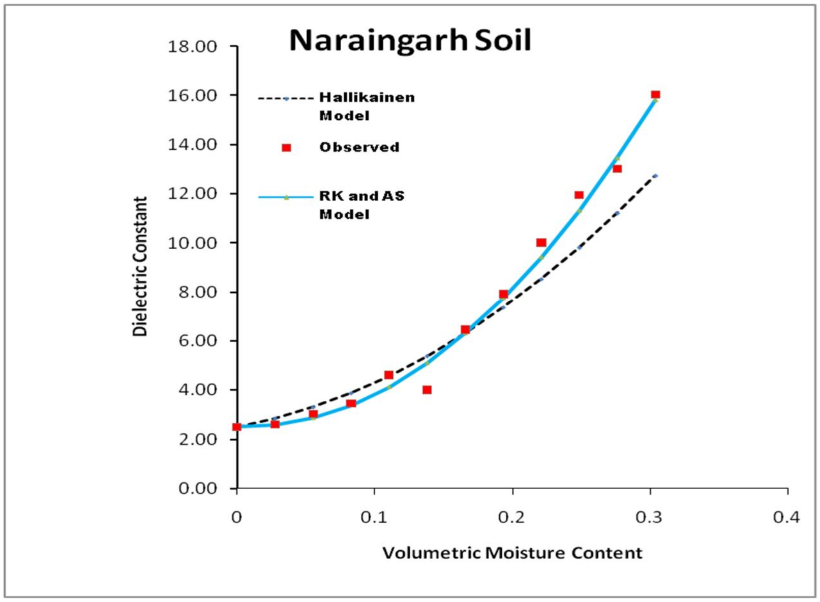

Fig 2.7 Variation of Dielectric Constant of Soil from Naraingarh with Volumetric Moisture Content at X-Band

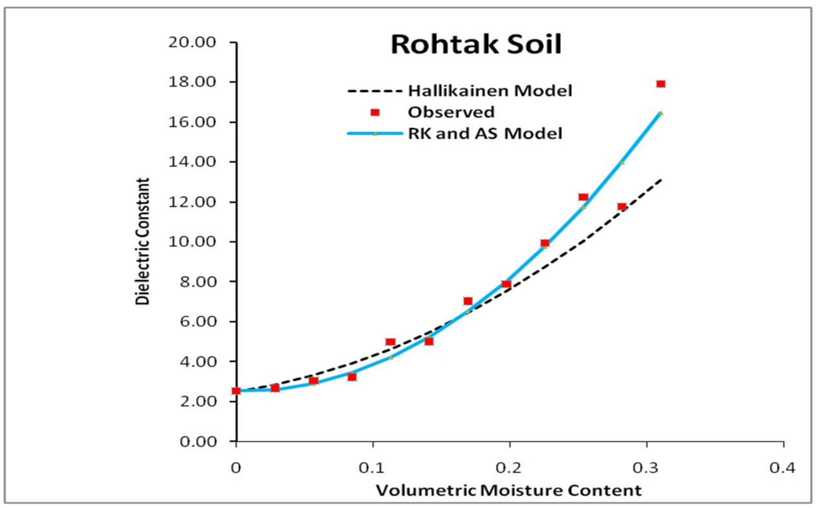

Fig 2.8 Variation of Dielectric Constant of Soil from Rohtak with Volumetric Moisture Content at X-Band

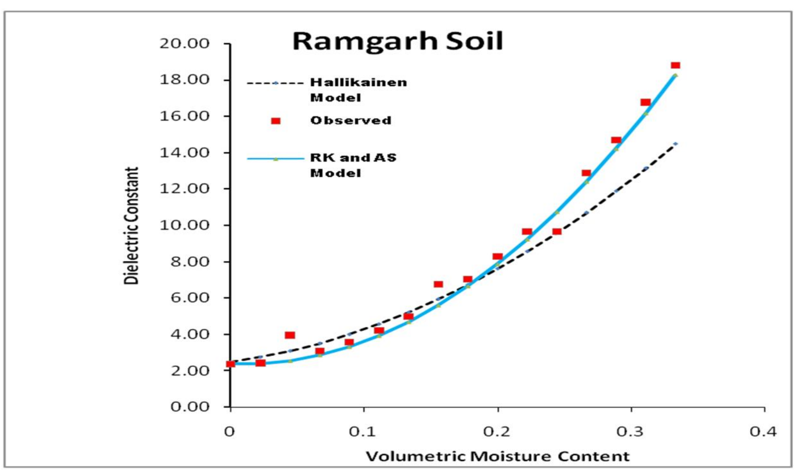

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Fig 2.9 Variation of Dielectric Constant of Soil from Ramgarh with Volumetric Moisture Content at X-Band

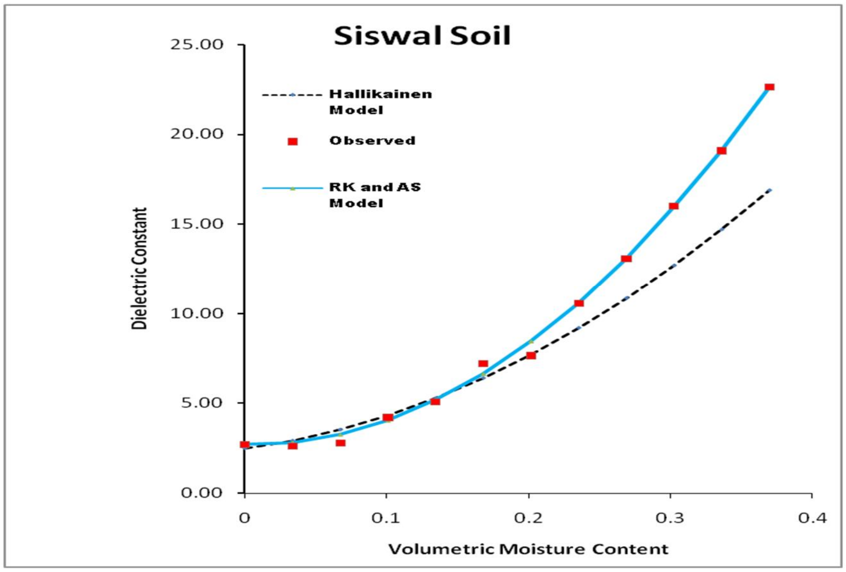

Fig 2.10 Variation of Dielectric Constant of Soil from Siswal with Volumetric Moisture Content at X-Band

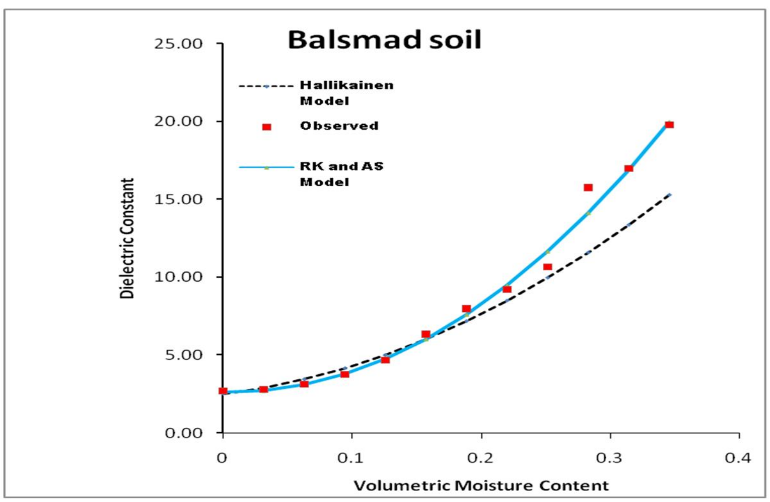

Fig 2.11 Variation of Dielectric Constant of Soil from Balsmand with Volumetric Moisture Content at X-Band

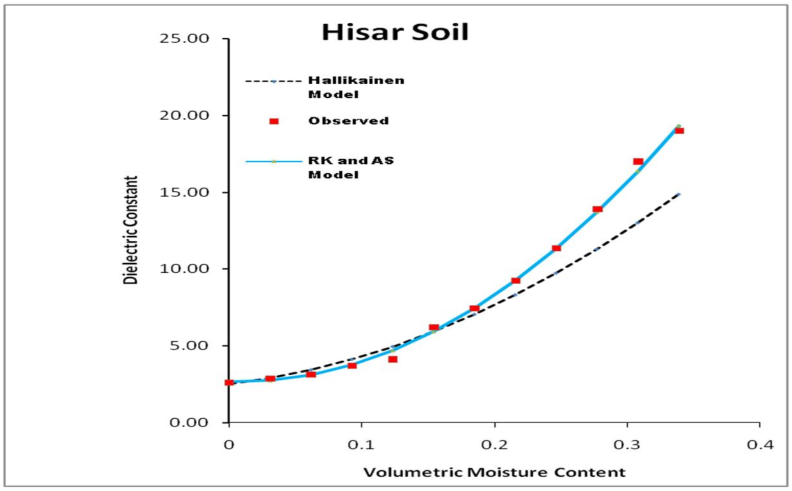

Fig 2.12 Variation of Dielectric Constant of Soil from Hhisar with Volumetric Moisture Content at X-Band

V. CONCLUSION

The proposed model is found to be accurate and have good practicality for the soil samples of different texture. The plots showing the variations dielectric constant of these soil samples with volumetric moisture content show that values obtained from proposed model are in good agreement with Hallikainen et al.[7] model.

The values of dielectric constant can be easily estimated using proposed model by knowing its constituents. These values can be used to calculate various other values used in remote sensing applications in agriculture etc.

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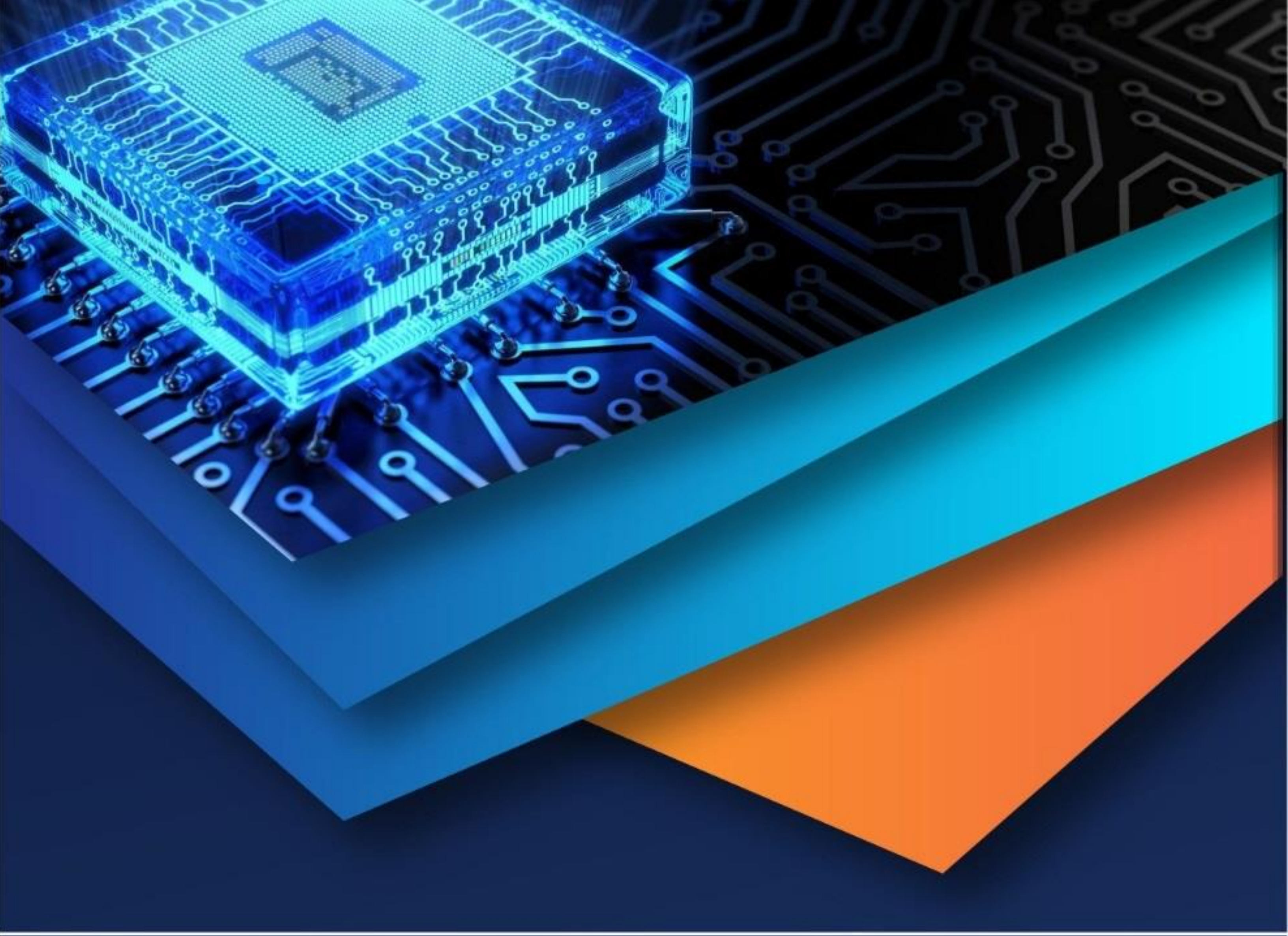

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