DIELECTRIC PROPERTIES OF SOILS WITH ORGANIC AND INORGANIC MATTER AT J-BAND MICROWAVE FREQUENCY

Harish C. Chaudhari.
Physics Research Centre, Department of Physics, J.E.S. College, Jalna, 431 203, India.

Abstract

The real (ε') and imaginary (ε'') parts of the complex dielectric constant (ε*) of four soils with increasing percentage of humus and calcium carbonate seperatly are measured. The J-band microwave bench tunned to 7.0 GHz is used for measurements. The two point method is used for these measurements. The value of ε' and ε'' increases with increase in organic as well as with inorganic matter of soils. These values are used to estimate relaxation time. The result shows the variation in dielectric properties with addition of humus and calcium carbonate for same soils. These results are useful for researchers working in field of microwave remote sensing and agriculture.

Keywords: Humus, Calcium carbonate, Dielectric constant, Dielectric loss.

Introduction

The interaction of electromagnetic waves with the geological material depends upon the complex dielectric permittivity, relative to the free space. The dielectric properties of soil are function of its physical properties such as sand, silt, clay and the chemical properties such as nitrogen, sodium, potassium, iron, magnesium also on the available micronutrients**.** Being a non-homogeneous medium dielectric constant of soil is combination of individual dielectric constant of its physical properties, chemical properties, macronutrients, micronutrients, minerals, organic and inorganic matter content. Researchers working on dielectric properties of soils studied dielectric parameter of different materials with various methods [1-12]. The effect of cow manure on dielectric properties of clay loam soil at microwave frequency have been measured using a vector network analyzer with varied moisture contents in the frequency range 150 MHz to 2.2 GHz. Measurements of complex dielectric permittivity in this frequency range were also carried out for different concentration of cow manure in soil [1]. Dielectric properties of soil–organic matter mixtures using coaxial impedance dielectric reflectometry are measured [2]. Dielectric response of a variable saturated soil contaminated by non-aqueous phase liquids (NAPLs) hydrocarbon contamination in soils and groundwater by means of the time domain reflectometry (TDR) technique is observed [3]. The dielectric constant and dielectric loss of black soil collected from Karmad area of Marathwada region of Maharashtra state with organic and inorganic matter at four different frequencies 8 GHz, 9 GHz, 10 GHz, 11 GHz and at 27 ^{0}C using microwave X-band are reported [4]. The dielectric properties of soil with varied calcium carbonate at 3.0 GHz frequency with microwave S-band using infinite sample method are reported [5]. The dielectric properties of soil with increasing percentage of humus at S-band microwave frequency are reported [6]. Dielectric properties of different soil textures collected from Karnataka state, at X-band microwave frequency using infinite sample method has been studied [7]. Variation in dielectric properties with increase in saline water are reported. The effect of saline water on the emmisitivity of soils is also studied [8]. The dielectric constant of dry soils with their physical constituents and naturally available nutrients at C-band microwave frequency 4.5 GHz are presented. The results are analyzed statistically to find correlation coefficients between dielectric constant and different soil properties [9]. Measurements of the a.c. electrical conductivity and relative dielectric permittivity, are conducted on 40 air-dried soil samples that were subsequently analyzed for pH, total organic matter in soil P_2O_5, Fe_2O_3 and heavy metal concentrations [10]. The dielectric properties of some fertilizers in aqueous solution at different temperatures at microwave frequency are reported [11]. The dielectric properties of the soil samples collected from Chhattisgarh state at X- band frequency are studied using infine sample method [12]. Dielectric parameters of dry and wet soils at 14.89 GHz are reported [13]. The effect of organic matter content of soil with different organic matter level and at a given moisture level on the microwave emissivity is observed [14]. The nature of soil varies with location, contamination. The present study has been undertaken to have an idea of variation in dielectric properties of soils with increase in varied percentage of humus or calcium carbonate at J-band microwave frequency.

Materials and Methods

The soil samples are collected from marathwada region of Maharastra state. Soil are collected from both irrigated and non-irrigated areas. The locations are recorded using Garmin make GPS 60. The Physical and chemical properties of the soil are measured at soil analysis laboratory. Number of soil samples of different physical and chemical properties are used for study. Out of these physico-chemical and dielectric properties of four soils are presented in this paper. The field capacity (FC) can be approximated by the empirical formula on soil composition [15].

FC= 25.1 - 0.21 (% Sand) + 0.22 (% Clay)

Wilting coefficient (Wp) is calculated by using the Wang and Schmugge model [16].

Wp=0.06774 –0.00064 (%Sand)+0.00478 (%Clay)

The complex dielectric constant is calculated using the relation

$$\varepsilon^* = \varepsilon' - j\varepsilon''$$

The two point method described by Altschuler [17] is used for the measurement of dielectric constant (ε') and dielectric loss (ε'').

Theory

The theory for Two point method is based on consideration of Figure 1(a) shows an empty short-circuited waveguide (sample holder) with a probe located at a voltage minimum D_R . Figure 1 (b) shows the same waveguide, now containing a sample of length l_ε with the probe located at a new voltage minimum D. The sample is adjacent to the short circuit. Looking from $T_{\varepsilon 1}$, towards the right and the left, one can write the impedance equation

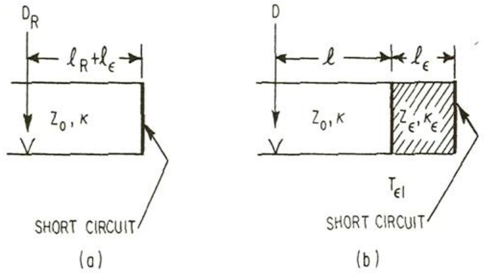

Figure 1. Dielectric Constant Measurement with Short-Circuited Waveguide.

$$Z_0 \tan k.l = -Z_\varepsilon \tan k_\varepsilon l_\varepsilon \quad (1)$$

Likewise, in Figure 1(a), looking toward the right, one has

$$Z_0 \tan K\,(l_R + l_\varepsilon) = 0 \quad (2)$$

Now, consider

$$\tan k\,(D_R - D + l_\varepsilon) = \tan k\,[(l_R + l_\varepsilon) - (l + l_\varepsilon) + l_\varepsilon]$$

$$= \tan k\,[(l_R + l_\varepsilon) - R]$$

Expanding the tangent and making use of equation (2) , substitution into equation (1) yields

$$Z_0 \tan k\,(D_R - D + l_\varepsilon) = Z_\varepsilon \tan k_\varepsilon\, l_\varepsilon \quad (3)$$

When it is recalled that $Z_0/Z_\varepsilon = k_\varepsilon/k$, one can rewrite equation (3) in the form,

$$\frac{\tan k\,(D_R - D + l_\varepsilon)}{k\, l\varepsilon} = \frac{\tan k_\varepsilon l_\varepsilon}{k_\varepsilon l_\varepsilon} \quad (4)$$

All the quantities associated with the left-hand member are measurable, while the right-hand member is of the form tan Z / Z, so that once the measurement has been performed, the complex number, Z $=k_\varepsilon l_\varepsilon$ can be found by the solution of transcendal equation. The basic arrangement of equipment for this measurement technique is shown in Figure (2). In view of the periodic nature of the tangent function, there exists an infinity of solutions for ε_r. Perform a second identical experiment with a sample of different length l_ε. The solution is the one common to the two sets of solutions.

Experimental Details

Without sample dielectric in the short circuited line, find D_R, the position of the minimum in the slotted line with respect to an arbitrarily chosen reference plane (D=0). Measure the guide wavelength, λ_g, by measuring the distance between alternate minima in the slotted line.

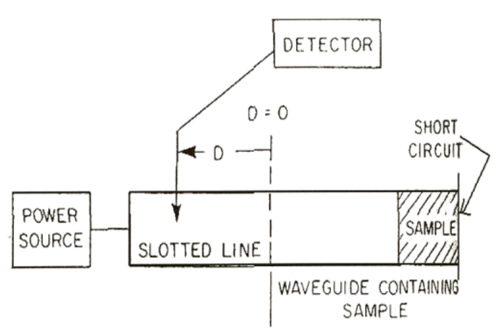

Figure 2. Two Point Method of Measuring Dielectric Constant.

Remove the short circuit, insert the soil sample and replace the short circuit in such a manner that the short circuit touches the end of the sample. Measure D, the position of the minimum in the slotted line, with respect to the reference plane (D=0) as shown in Figure (2). Note r, the VSWR in the slotted line. Repeat the same procedure for soil sample of different length sample lengths $l_{1\varepsilon}$ and $l_{2\varepsilon}$.

Propagation constant (in the empty waveguide) is calculated as

$$k = \frac{2\pi}{\lambda_g}$$

The complex number $c\angle\psi$ can be obtained from the equation

$$c\angle-\psi = \frac{1}{jkl_\varepsilon}\frac{1-|\Gamma|e^{-j\phi}}{1+|\Gamma|e^{j\phi}}$$

where $\phi = 2k\,(D - D_R - l_\varepsilon)$

and $|\Gamma| = \frac{r-1}{r+1}$

solve the complex transcendental equation for T and τ to get conductance($G\varepsilon$) and susceptance($B\varepsilon$)

$$c\angle-\psi = \frac{\tanh(T\angle\tau)}{(T\angle\tau)}$$

The dielectric constant (ε') and dielectric loss (ε'') of the soil sample can be calculated with the equations

$$\varepsilon' = \frac{G_\varepsilon + \left[\frac{\lambda_g}{2a}\right]^2}{1+\left[\frac{\lambda_g}{2a}\right]^2} \quad \text{and} \quad \varepsilon'' = \frac{-B_\varepsilon}{1+\left[\frac{\lambda_g}{2a}\right]^2}$$

The block diagram of microwave experimental setup for measurement of dielectric properties is shown in Figure 3. The experimental set-up consist of a KPS151 reflex klystron as the microwave source having frequency range 5.85 GHz - 8.2 GHz. To avoid the interference between source and reflected signals, the source is connected with a broadband isolator with minimum isolation and minimum insertion loss. To control the power at desired level, a variable attenuator is connected after the isolator. A frequency meter is used to measure frequency of the signal. The diode detector with square law characteristics with VSWR is used. The detected power is feed to an micro ammeter. The slotted line is employed to measure VSWR and distance. A 9 cm long wave-guide is used as sample holder. For accurate measurements, the probe carriage is mounted with a dial gauge having least count of one micron.

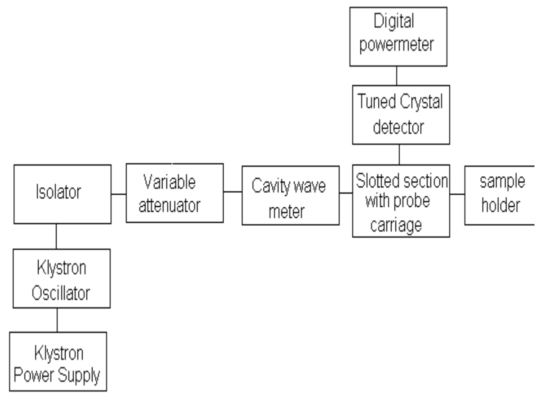

Figure 3. Block Diagram of Experimental setup for Measurement of Dielectric Properties.

The values of dielectric constant and dielectric loss are used to estimate relaxation time (τ), in picoseconds, using the relation

$$\tau = \frac{\varepsilon''}{\omega\varepsilon'}$$

where, ω is angular frequency,
($\omega = 2\pi f$; f = 7.0 GHz)

Result and Discussion

The physical properties of soil samples are listed in Table 1. The physical parameters and locations of soils are reported in Table 2. Chemical properties of these four soils are given in Table 3. The variation in the values of dielectric constant with percentage humus and calcium carbonate are plotted in Figure 4(a) and 4(b) respectively. Non-linear relationship between the dielectric constant with humus as well as calcium carbonate can be observed. Dielectic loss for these four soils with percentage variation of humus and also with calcium carbonate are plotted in Figure 5 (a) and 5 (b) respectively. The non-linear and abrupt behavior is observed. It is obvious that the dielectric constant of the soils increases slowly with humus while increases suddenly at 4%, then increases slowly. The variation of dielectric loss is less with calcium carbonate as compare to the humus. The variations in relaxation time with percentage increase in humus and calcium carbonate are plotted in Figures 6 (a) and 6 (b) respectively.

Table 1. Physical Properties of Soil Samples.

Soil	Texture	Sand %	Silt %	Clay %
I	Silty Clay Loam	16.67	52.83	30.50
II	Clay	12.28	39.99	47.73
III	Clay	21.02	34.96	44.02
IV	Silty Clay Loam	54.82	28.39	16.79

Table 2. Location and Physical Parameters of Soils.

Soil	Location		FC	Wp
	Latitude	Longitude		
I	$20^0$00'12.5N	$73^0$47'40.1''E	28.31	0.20
II	$19^0$37'17.2N	$75^0$1'26''E	33.02	0.29
III	$19^0$46'35.5N	$74^0$37'03.6''E	30.37	0.27
IV	$19^0$21'20.7N	$75^0$42'33.3''E	17.28	0.11

Table 3. Chemical Properties of Soil Samples

Soil	Carbon %	Ca %	Mg %	Na %	$CaCO_3$ %
I	0.53	29.19	19.73	0.49	3.25
II	1.15	31.27	23.00	3.33	11.75
III	0.37	29.19	21.37	1.48	6.00
IV	0.51	33.36	23.00	0.81	6.62

The relaxation time (τ) is proportional to dielectric loss. Soil texture has remarkable effect on the dielectric properties. All these parameters are useful for researchers working in the field of agriculture and microwave remote sensing. The physico-chemical properties, physical parameters are useful to prepare soil health card which may be further used to predict the soil fertility. These results are in good agreement with earlier reported work.

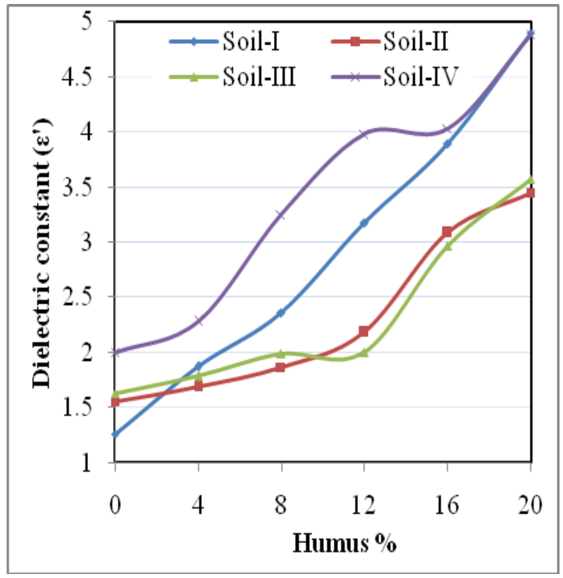

Figure 4 (a). Variation in Dielectric Constant with Percentage Humus Content for Soils.

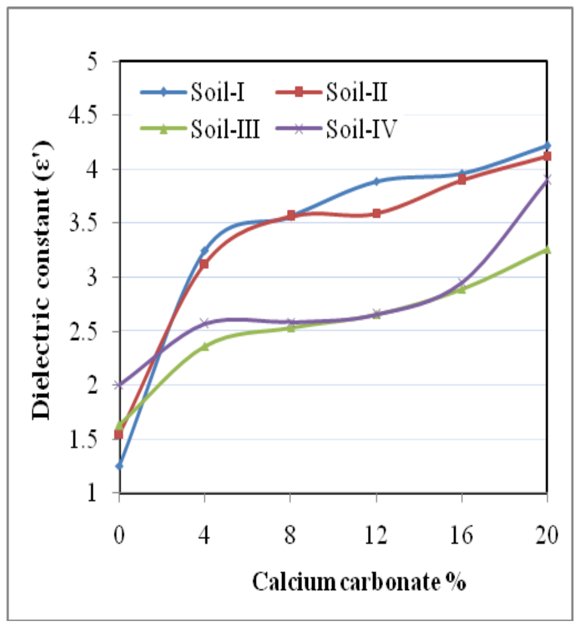

Figure 4 (b). Variation in Dielectric Constant with Percentage Calcium Carbonate for Soils.

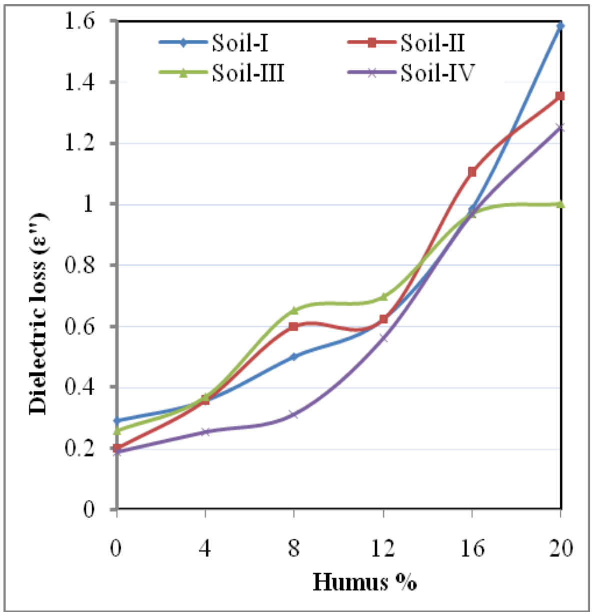

Figure 5 (a). Variation in Dielectric Loss with Percentage Humus Content for Soils.

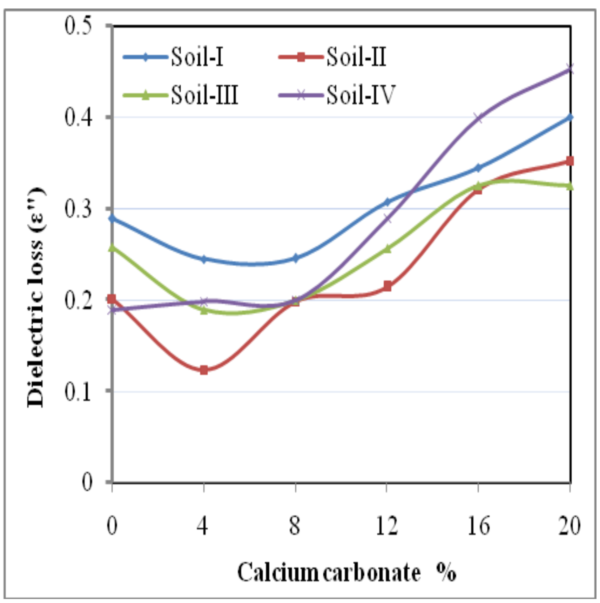

Figure 5 (b). Variation in Dielectric Loss with Percentage Calcium Carbonate for Soils.

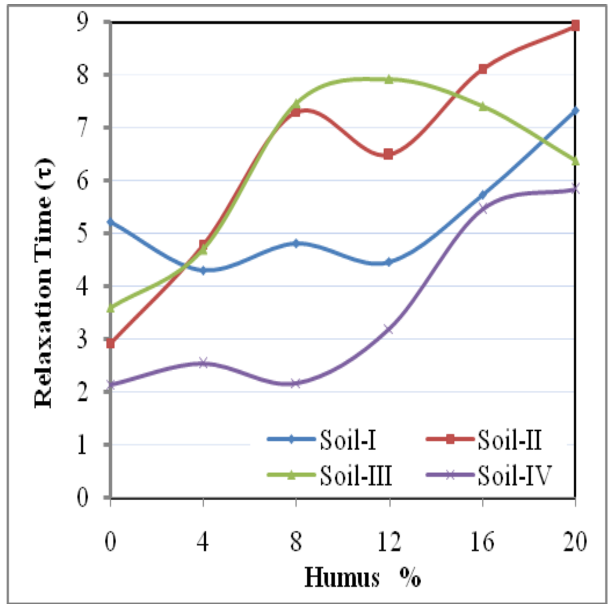

Figure 6 (a). Variation in Relaxation time with Percentage Humus Content for Soils.

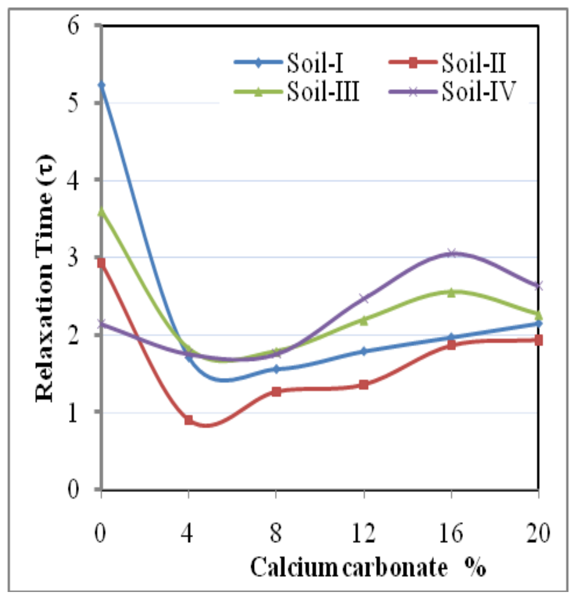

Figure 6 (b). Variation in Relaxation Time with Percentage Calcium Carbonate for Soils.

Conclusions

Study of physical properties, chemical properties, dielectric properties of soils with varied organic and inorganic matter is useful in agriculture to predict quality and fertility of soil. Also it is useful for the researchers working in the field of microwave remote sensing. The results from such studies are important to understand the fundamental nature of the response of particular soil to high frequency electromagnetic field.

Acknowledgment

Author thanks University Grant Commission for providing financial assistance under minor research project (47-2160/11(WRO)).

References

[1] Asha Buliya, K. C. Pancholi, R. K. Paliwal, "Effect of Cow Manure on Dielectric Properties of Clay Loam Soil at Microwave Frequency", International Journal of Scientific Research, 2013, 2(2), 374- 375.

[2] Franco M. Francisca,, Marcos A. ontoro, "Measuring the Dielectric Properties of Soil–Organic Mixtures using Coaxial Impedance Dielectric Reflectometry", Journal of Applied Geophysics, Vol. 80, May 2012, 101–109.

[3] A. Comegna , A. Coppola, G. Dragonetti, A. Sommella, "Dielectric Response of a Variable Saturated Soil Contaminated by Non-Aqueous Phase Liquids (NAPLs)" Procedia Envionmental Sciences, 19, 2013, 701-710.

[4] Navarkhele V V, Shaikh A A, Ramshetti R S, "Dielectric Properties of black soil with Organic and Inorganic Matters at Microwave Frequency", Indian Journal of Radio and Space Physics, 2009, 38,112-115.

[5] Chaudhari H C, " Dielectric Properties of Soils with Inorganic Matter at S-band Microwave Frequency" ,International Journal of Chemical and Physical Sciences, 2014,3(6), 59-66.

[6] Chaudhari H C, Shinde V J, Zingare R P,Jadhav B U, "Dielectric Properties of Soils with Organic Matter at S-band Microwave Frequency ", Journal ofDeccun Current Science, 2013, 8, 137-142.

[7] Chaudhari H C, Shinde V J, "Dielectric Properties of Soils at X-band Microwave Frequency", Indian Journal of Pure and Applied Physics, 50, 2012, 64-67.

[8] Gadani D H, Rana V A, Vyas A D, Bhatnagar S P, "Effect of Saline Soils on Emissivity of Soil ", Indian Journal of Radio and Space Physics, 2011, 40, 218-225.

[9] Chaudhari P R, Ahire D V, Ahire V D, "Variation of Dielectric Constant of Dry Soils with their Physical Constituents and Available Nutrients at C-Band Microwave Frequency", Journal of Chemical, Biological and Physical Sciences, 2012, 2(2), 1001-1009.

[10] L. K. Dospatliev, I. T. Ivanov, B. K. Paarvanova, N. T. Katrandzhiev R. T. Popova , "Determining the Relationship between the Dielectric Properties and the Basic Physical and Chemical Parameters of the Air-Dry Soil", International Journal of Scientific and Research Publications, 2014, 4(7), 1-7.

[11] Vivek Yadav, Anil Kumar, Sudeep Sharan, A.K.Sinha, "Analyses of Dielectric Properties of Fertilizers (urea and diammonium phosphate) in Aqueous Solution at Different Temperatures in Microwave Frequency", Internationaljournal of the physical sciences, 2010,5(16), 2466-2470.

[12] Srivastava S. K. and Mishra G P, "Study of the Characteristics of the Soil of Chhattisgarh at X-band Frequency"Sadhana, 29(4), 2004, 343-347.

[13] Ghosh A., Behari J. and Pyne S.,"Dielectric parameters of Dry and Wet Soils at 14.89 GHz", Indian Journal of Radio and Space Physics, 27, 1998, 130-136.

[14] P.E.O'Neill, T.J.Jackson, " Observed Effects of Soil Organic Content on the Microwave Emissivity of Soils" Remote Sensing Environ, 31 , 1990, 175-182.

[15] Schmugge T, " Effect of Soil Texture on Microwave Emission of Soils", NASA Technical memorendom, 80632, January 1980, 8.

[16] Wang J R , Schmugge T J, "An empirical Model for Complex DielectricPermittivity of Soils as a Function of Water Content", IEEE transactions on Geoscience and Remote Sensing, 1980, GE-18, 288-298.

[17] Sucher M & Fox J, Handbook of Microwave Measurements, III edition, John Wiley and Son Inc, New York, 1963,511.

Biography

H.C.Chaudhari. received the M.Sc. degree in Physics, with specialization in Advanced Electronics which includes Microwaves, from the Marathwada University, Aurangabad, Maharashtra. He has received Ph.D in Physics from the Dr. Babasaheb Ambedkar Marathwada University, Aurangabad, Maharashtra. Currently, He is an assistant Professor of Physics at J.E.S. College Jalna, Maharashtra. His teaching area includes Electronics, Mechanics etc. and research areas include dielectric study of geological materials and chemicals etc. He has co-authored two textbooks, PHYSICS For B.Sc. Second Year (Semester III) and PHYSICS For B.Sc. Second Year (Semester IV), Himalaya Publishing House, 2014. He has completed two projects sanctioned by UGC, New Delhi, India. Dr. H.C.Chaudhari may be reached at

hcchaudhari@rediffmail.com
Phone No: +91 9423730843