Study of the characteristics of the soil of Chhattisgarh at X-band frequency

S K SRIVASTAVA and G P MISHRA

Department of Physics, Govt. P. G. College, Ambikapur 497 001, India e-mail: sk_srivastava@yahoo.com

Abstract. The real and imaginary parts (ε_1 and ε_2) of the complex dielectric constant (ε) of sand, silt and clay with varied moisture content have been determined experimentally under laboratory conditions at 9.967 GHz. using infinite sample method. The values of (ε_1) and (ε_2) first increase slowly with moisture content upto a certain transition point and then increase rapidly with moisture content.

Keywords. Soil characteristics; complex dielectric constant; Chhattisgarh region; X-band frequency

1. Introduction

Ground-based studies of the dielectric properties of different earth constituents at microwave frequencies are important as they provide a successful interpretation of various remote sensoring data. The dielectric constant of soil is found to be strongly dependent on moisture content (Calla et al 1999, 2000). The measurement of dielectric constant of soil as a function of moisture content has been carried out over a wide frequency range in the past several years using soils of widely different texture structures (Wang & Schmugge 1980). Calla et al (1999) have predicted that microwave emission will depend upon the dielectric constant of the soil. Further, Calla et al (2000) have measured the dielectric constant of dry and wet soil in frequency range 2 GHz to 20 GHz. Yadav & Gandhi (1992) suggested a simple microwave technique to measure the dielectric property of the solids and their powder. Dube (1984) suggested a new method to determine the dielectric parameter for films at microwave frequency. On this basis, the authors have attempted to measure the dielectric constant of soil at microwave frequency. The present study have been undertaken to have a comprehensive idea of dielectric properties of different soils of the Chhattisgarh region. In this paper, the experimentally determined values of the real and imaginary parts of the complex dielectric constant have been shown for sand, silt and clay samples with varied moisture content.

2. Materials and methods

The technique used in this measurement is the infinite sample method described by Altshuler (1981). An X-band microwave bench operating at 9.967 GHz in the TE₁₀ mode with a slotted

section and a crystal detecter used for measurements of VSWR and the shift of minima are needed in this technique. The complex dielectric constant calculated using the relation

$$\varepsilon = \varepsilon_1 - j\varepsilon_2 = [\{1/1 + (\lambda_c/\lambda_a)^2\} + \{1/1 + (\lambda_g/\lambda_c)^2\}] \times [R - j \tan\{k(D - D_R)\}/1 - jR \tan\{k(D - D_R)\}],$$
 (1)

where λ_c , λ_g and k are cut-off wavelength, guide wavelength and wave vector respectively, R is voltage standing wave ratio (VSWR) and D and D_R are the positions of first minima with and without the sample connected. The samples were filled and pressed manually in a 50 cm long waveguide, which was terminated in a matched load. The values of D, D_R and λ_g were determined using a dial indicator on the slotted line section. The VSWR was determined using double minimum power method. The soil sample taken for present study belongs to the Surajpur area of the Chhattisgarh region. Samples are taken from both irrigated and non-irrigated areas. The characteristics of the soil were measured in the soil mechanics lab at the Govt. Polytechnic, Ambikapur and the dielectric constants were measured at the Department, Govt. P. G. College, Ambikapur. The moisture content in percentage by dry weight, Wc(%) is calculated using the following relation

$$Wc(\%) = [(wt. of wet soil - wt. of dry soil)/wt. of dry soil] \times 100.$$
 (2)

Measurements have been carried out at 9.967 GHz. This experimental set-up consists of a 2 K 25 reflex klystron as the microwave source, with maximum output power of 25 mW and frequency range 8.2–12.4 GHz. The source is connected with a broadband isolator with maximum isolation of 30 dB and insertion loss of 1.25 dB. This is used to avoid interference between the source and reflected signals. After isolator a variable attenuator is used to control the power at the desired level. This is followed by a 20 dB multihole directional coupler which is used to monitor the power level flowing through the system. A direct reading absorption type frequency meter with high Q-factor ($Q \sim 1000$) and 2.5 MHz resolution with dip ≥ 1 dB is used to measure the frequency of the signal. The detector was of square law characteristics with VSWR better than 2:1. A precession slotted line section was employed to measure the VSWR and distance. The accuracy of the distance measurement is within 0.004 cm.

3. Emprical model

Wang & Schmugge (1980) applying the regression analysis related the values of wt and with the wilting point (WP) of the soils by the relation

$$wt = 0.49 \times WP + 0.165,$$
 (3)

$$\gamma = -0.57 \times WP + 0.481,\tag{4}$$

where wt and γ both have the dimensions of WP, which is a volume ratio (cm³/cm³). The WP can be calculated from the texture of the soils using the following relation

$$WP = 0.06774 - 0.00064 \times \text{sand (\%)} + 0.00478 \times \text{clay (\%)}, \tag{5}$$

where, clay and sand are the clay and sand contents in percent by dry weight of the soil. The values of WP, wt and γ ; porosities along with the texture information of the soils used in this study are shown in table 1. The porosity of soil can be calculated using the relations

$$\eta = (G \times \gamma_w - \gamma_d)/G \times \gamma_w, \tag{6}$$

where G is 2.65, and λ_w is density of water, and γ_d is density of sample.

Sand (%)	Silt (%)	Clay (%)	WP	Wt	γ	Density	Porosity
67.4	27.8	4.7	0.067	0.197	0.368	1.72	0.351
66.7	29.1	4.2	0.045	0.187	0.374	1.82	0.313
50.3	34.7	10.1	0.083	0.205	0.364	1.79	0.325
47.9	13.6	35.6	0.207	0.264	0.329	2.00	0.246
47.0	31.5	10.5	0.087	0.204	0.363	2.01	0.242
46.7	39.5	13.3	0.101	0.214	0.359	1.91	0.273
40.80	39.3	22.5	0.148	0.237	0.345	1.93	0.273
40.00	40.5	12.2	0.100	0.214	0.359	1.97	0.257
28.90	53.4	17.1	0.138	0.232	0.348	2.02	0.238
19.30	63.7	17.0	0.136	0.231	0.349	2.00	0.246

Table 1. Physical characteristics of soil used for dielectric measurements at 9.967 GHz.

4. Results and discussion

Variations in values of the dielectric constant, both ε_1 and ε_2 , with percentage moisture content have been measured and are plotted in figures 1 and 2. The constituents of the soils have been listed in table 1. It is found that the relative permittivities of the soils increase only slowly with moisture content initially and after reaching a transition point they increase rapidily. This observation is qualitatively in good agreement with the results of others (Vyas 1982). The first feature obtained in this study can be explained using the bi-phase dielectric behaviour of water molecules in soils that have much smaller permittivity values (comparable with the permittivity of ice) as compared to free water molecules (Wang & Schmugge 1980). At moisture contents below the transition point due to the presence of only a few free water molecules, the mixture dielectric permittivities increase only slowly whereas at moisture contents above the transition point the number of free water molecules increases rapidly and hence a steep rise in permittivity is observed. The second observation can be attributed to much smaller noncapillary pore space, less drainage, less aeration and thus high water capacity of high clay content soils as compared to sandy soils. The experimental results obtained are clearly matched with earlier reported results.

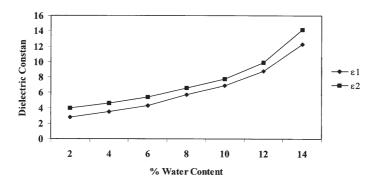


Figure 1. Variation of dielectric constant with percentage water content for moist sandy sample.

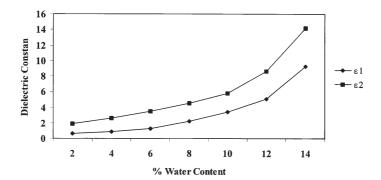


Figure 2. Variation of dielectric constant with percentage water content for moist silty sample.

5. Conclusion

The conclusions obtained from this study are as follows

- (i) The dielectric constants of soils are strongly dependent on soil moisture and soil texture.
- (ii) Wang & Schmugge (1980) model describes well the dielectric behaviour of wet soils.
- (iii) Laboratory studies of dielectric properties of soils with varied moisture, texture, temperature density, as well as other chemical and physical properties of soils are very important in correlating remotely sensed data with actual field conditions and in distinguishing targets having identical dielectric properties.
- (iv) Dielectric constants of solid particles, like sand, silt and clay present in storms are essential in the estimation of the total attenuation due to sand and dust storms in microwave communications.
- (v) The fertility of soils can be predicted with the help of permeabilities, dielectric constant and porosities. Dielectric constants of irrigated and non-irrigated soils differ in their characteristics.

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