INTRODUCTION

Over last decades, Microwave remote sensing became the emerging field for the study of natural resources. It emphasis the interaction of electromagnetic waves with the materials under study. The study of dielectric properties of different earth constituents at microwave frequencies plays vital role as they provides interpretation of various remote sensing data. Dielectric properties are primarily a function of frequency, water saturation, porosity, texture, component geometry and electrochemical interactions. Dielectric dispersion in low frequency region is helpful to understand the behaviors of induced polarization in the materials, while high frequency dielectric measurements are useful in planning ground penetrating radar survey (Sengwa, 2005). Many researchers working with this aspect, studied dielectric properties of different materials with various methods. Study of dielectric properties of different soil textures collected from Bidar region of Karnataka state, at X-band microwave frequency using Infinite sample method has been studied (Chaudhari et al., 2007). The dielectric properties of soil collected from different regions of Uttarakhand has been studied at X-band microwave frequency using Infinite sample method. (Srivastava et al., 2004). Dielectric constant of soil is function of moisture content is studied. (Narasimha Rao et al.,1990). Microwave emission depends upon the dielectric constant of the soil (Calla et al., 2004). The dielectric constant of red soil in frequency range 12 GHz to 18 GHz has been studied.(Puri et al., 2004). Microwave transmission and reflection of moisture-laden brown and black soil using Ku-Band is also reported (Puri et al., 2005). Laboratory measured dielectric property data and related electromagnetic wave propagation parameters (Curtis J.O., 1998, 2001) for a broad range of soil texture and the variation of

Dielectric properties of dry and wet soils at X-band microwave frequency

H.C. CHAUDHARI*, V.J. SHINDE and J.P. KULKARNI

Microwave Research Center, P.G. Department of Physics, J.E.S. College, Jalna - 431 203 (India)

(Received: March 10, 2008; Accepted: April 27, 2008)

ABSTRACT

Interaction of electromagnetic waves with the materials of planet earth provides the information for microwave remote sensing. From the reflected wave it is possible to reveal the information, which is useful for the measurement of dielectric properties. The dielectric properties of material are function of its chemical constituents and physical properties. Measurements of real (\(\varepsilon'\)) and imaginary (\(\varepsilon''\)) parts of the complex dielectric constant (\(\varepsilon^*\)) of soil with varied moisture content were made at 9.85 GHz. The X-band microwave setup in the TE\(_{10}\) mode with slotted section and a crystal detector is used for measurements. Infinite sample method is found suitable for measurement of these soils. The measurements are made at room temperature. The dielectric properties of dry soil samples are in good agreement with the earlier work. The value of \(\varepsilon'\) and \(\varepsilon''\) first increases slowly and then increase rapidly with moisture content. From this data, the a.c. conductivity and relaxation time are also reported. The result shows the change in electrical properties of dry and moisture-laden soils. These results provide a basis for using high-frequency electromagnetic sensors in the detection of soil moisture content or in ground-penetrating radar.

Key words: Dielectric constant, dielectric loss, conductivity, relaxation time.
dielectric permittivity and conductivity as functions of moisture content is studied. The dielectric constant of soil samples from Uttar Pradesh and Kashmir are measured at different frequencies in the range 8 GHz -10 GHz using waveguide cell method and variation of dielectric constant with frequency is reported (Calia et al., 2005) Also a model for estimation of dielectric constant is developed. The variation of dielectric constant of dry soil with its physical constituents is reported by Calia et al. (Calia et al., 2005) for this study number of soil samples were collected from northern India. The measurements done using waveguide cell method at X-band microwave frequency are used to develop a model named as CVCG model. This can be used to compute the dielectric constant from known soil texture. Measurements of dielectric constant and conductivity of soil samples contaminated by diesel oil in the frequency range 2-250 MHz were reported (Darayan et al., 1998).

The measurement of dielectric constant and tangent loss of some Indian clay minerals (Mahan et al., 1980) at microwave frequency are reported. Conductivity and relaxation time for metal powders collected from mines of Chattisgarh are determined from the parameters measured using X-band microwave frequency (Srivastava et al., 2004). The vector network analyzer is used for the measurement of dielectric constant (Logsdon et al., 2005). On this basis, the present study has been undertaken to have an idea of electrical properties of different soil texture of the Bidar region of Karnataka State. In this paper, the experimentally determined values of the real and imaginary parts of the complex dielectric constant have been shown for red and black soils under study at different moisture content. These parameters are used to determine the a.c.electrical conductivity and relaxation time.

**MATERIAL AND METHODS**

The infinite sample method described by Altshuler is used for the measurements of dielectric properties. An X-band microwave bench operating at 9.85 GHz in the TE10 mode with slotted section and a crystal detector used for measurement of VSWR and the shift of minima is needed in this technique. The complex dielectric constant is calculated using the relation

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

Where \(\lambda_c\), \(\lambda_g\) and \(k\) 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 sample respectively. The samples were filled and pressed manually in 40 cm long wave-guide, which was terminated with matched load. The measurements of \(D\), \(D_r\) and \(\lambda_g\) were made using a slotted line. The VSWR was determined using double minimum power method. The soil sample taken for present study belongs to the Nanded region of Karnataka state. Samples were collected from both irrigated and non-irrigated areas of the state. The Physical & Chemical properties of the soil were measured at Soil analysis laboratory; Department of Agriculture, Govt. of Maharastra situated at Parbhani. Eight samples of various soil textures having different physical and chemical properties are used for study. The gravimetric soil moisture content in percentage \(W_c\) is calculated using wet (\(W_1\)) and dry (\(W_2\)) soil masses using the following relation.

$$
W_c(\%) = \frac{W_1 - W_2}{W_2} \times 100
$$

Measurements have been carried out at 9.85 GHz. The experimental set-up consist of a 2K25 reflex klystron as the microwave source, with maximum output power of 25 mW and frequency range 8.2-12.4 GHz. To avoid the interference between source and reflected signals, the source was connected with a broadband isolator with maximum isolation of 30 dB and insertion loss of 1.25 dB. To control the power at desired level, a variable attenuator is connected after the isolator. A resonance type frequency meter was used to measure frequency of the signal. The slotted line was employed to measure VSWR and distance. For accurate measurements of minima and VSWR, the
probe carriage was mounted with a dial gauge having least count one micron.

From the measurement of dielectric constant and dielectric loss, other electrical parameters can be obtained. (Srivastava (2004), Barathan, (2006)).

\[ \sigma = \omega \varepsilon_0 \varepsilon'' \] ... (3)

And

\[ \varepsilon' = \omega \varepsilon_0 \] ... (4)

where

\( \omega \) is angular frequency, \( f = 9.85 \) GHz

\( \varepsilon_0 \) is permittivity of free space

**RESULTS AND DISCUSSION**

The Texture, Physical and Chemical properties of the samples under study are reported in table 1. The variations in the values of dielectric constant and dielectric loss with percentage moisture content are measured and plotted in figures 1 and 2 for soil sample I and II respectively. Similarly, the a.c. electrical conductivity and relaxation time with variation of percentage moisture content are plotted in figure 3 and 4. It is obvious that the relative permittivity of the soils increase slowly with moisture content initially, this may be due to bi-phase dielectric behavior of water molecule in soil that have smaller permittivity values as compared to free water molecules below transition point and after reaching a transition point they increase rapidly.

From this study, it is observed that the relation between the dielectric constant and the gravimetric water content is almost non-linear. This is because, for a composite material such as moist soil, the dielectric constant is not a simple function of the values for the individual components. The value of dielectric loss for sandy loam soil is more than that of loam soil, this may be due to higher value of particle density and higher percentage of organic carbon in sandy loam soil. The a.c. electrical conductivity (\( \sigma \)) and relaxation time (\( \tau \)) shows a

| Soil Sample | Texture         | Sand % | Silt % | Clay % | W.H.C. % | Particle Density | Porosity |
|-------------|-----------------|--------|--------|--------|-----------|------------------|----------|
| I           | Sandy Loam      | 54.80  | 28.40  | 16.77  | 51.1      | 2.0              | 45.4     |
| II          | Loam            | 50.43  | 32.15  | 17.41  | 61.7      | 1.8              | 50.5     |
| III         | Clay Loam       | 27.68  | 33.59  | 38.73  | 45.6      | 2.2              | 45.9     |
| IV          | Clay Loam       | 22.08  | 44.38  | 33.94  | 58.0      | 2.0              | 45.9     |
| V           | Clay            | 13.69  | 39.78  | 46.60  | 55.3      | 2.3              | 53.1     |
| VI          | Clay            | 12.28  | 39.98  | 47.74  | 67.3      | 1.8              | 51.0     |
| VII         | Silty Clay Loam | 16.66  | 52.09  | 31.25  | 57.5      | 1.9              | 50.0     |
| VIII        | Silty Clay      | 2.95   | 45.28  | 51.17  | 51.3      | 2.2              | 50.0     |

| Soil Sample | pH    | E.C. mS/cm | Organic Carbon % | Ca % | Mg % | Na % | CaCO₃ % |
|-------------|-------|------------|------------------|------|------|------|---------|
| I           | 8.4600| 0.2700     | 0.6400           | 37.5300 | 36.1000 | 0.5300 | 5.0000 |
| II          | 8.6200| 0.2700     | 0.5000           | 43.3800 | 31.2400 | 0.9700 | 8.1200 |
| III         | 8.9300| 0.1600     | 0.6300           | 33.3600 | 34.6600 | 0.4000 | 5.5000 |
| IV          | 8.7100| 0.2800     | 0.5100           | 33.3600 | 23.0000 | 0.8100 | 6.6200 |
| V           | 8.5100| 0.2200     | 0.5500           | 43.8700 | 32.8900 | 0.5100 | 6.2500 |
| VI          | 7.9200| 0.2600     | 1.1500           | 31.2700 | 23.0000 | 3.3300 | 11.7500 |
| VII         | 7.1200| 1.6000     | 0.5300           | 29.8900 | 19.7300 | 0.4900 | 3.2500 |
| VIII        | 8.6000| 0.1900     | 0.4800           | 25.0200 | 16.4400 | 0.6600 | 3.6200 |
systematic change with increase in moisture content. According to Debye, when polar molecules are very large, then under the influence of electromagnetic field of high frequency, the rotary motion of the polar molecules of a system is not sufficiently rapid to attain an equilibrium with the field. The polarization then acquires a component out of phase with the field and the displacement current acquires conductance dissipation energy. Thus, the dielectric loss is proportional to the a.c. conductivity. The increase in relaxation time due to increase in moisture content is due to increasing hindrance to the process of polarization. The increase in dielectric loss with moisture for loam soil is more than of sandy loam soil, this may be due to higher percentage of Na in loam soil. These results are in good agreement with the earlier reported work.

CONCLUSIONS

Moisture in soil significantly affects the dielectric properties of soil. Physical and chemical properties show remarkable variation in dielectric properties. This is because, for a composite material such as moist soil, the dielectric constant is not a
simple function of the values for the individual components. The value of dielectric loss for sandy loam soil is more than that of loam soil, this may be due to higher value of partical density and higher percentage of organic carbon in sandy loam soil. The laboratory studies of dielectric properties of soils with varied moisture as well as other physical and chemical properties with actual field conditions are very useful in correlating the data recorded by remote sensing technique. The a. c. electrical conductivity and relaxation time depend upon the dielectric loss, which represents attenuation and dispersion. The increase in relaxation time due to increase in moisture content is due to increasing hindrance to the process of polarization. The increase in dielectric loss with moisture for loam soil is more than of sandy loam soil, this may be due to higher percentage of Na in loam soil. Since a dielectric property of soil determines the properties like emissivity, scattering coefficient etc. The correlation between dielectric properties and the radar detected properties provide the basis for remote sensing. Also these values can be used for passive and active sensors in microwave remote sensing. The soil health and soil fertility can be predicted from more database.

ACKNOWLEDGMENT

Authors thank Prof. P.B. Patil and Prof. S.C. Mehrotra, Dr. Babasaheb Ambedkar Marathwada University Aurangabad for fruitful discussion and suggestions. The authors also thank Mr. Jawale Anantrao, soil analysis laboratory, Parbhani for providing facilities to measure the soil physical and chemical properties.

REFERENCES

1. Altshuler, H.M, The hand book of microwavemeasurements, M Suchler & J Fox, Third Edition, Vol.II,John Wiley and sons, N.Y. 511 (1963).
2. Barathan S, Govindrajan D, Sivakumar G & Raghu K, icrowave study of hydration of cement with different waters, Indian Journal of Pure & Applied Physics, 44: 334-338 (2006).
3. Calla O P N, Vivek Ranjan, Chetan Bohra & Gangadhar L. Naik V, Estimation of dielectric constant of soil from the given texture at microwave frequency, Indian Journal of Radio & Space Physics, 33: 196-200 (2004).
4. Calla O P N, Baruah A, Das B , Mishra K P, Kalita M, Haque S S, Variability of dielectric constant of dry soil with its physical constituents at microwave frequencies and validation of the CVCG model, Indian Journal of Radio & Space Physics, 33: 125-129 (2004).
5. Calla O P N, Baruah A, Das B, Mishra K P, Kalita M, Haque S.S, Emission and scattering behaviour of dry soils from north east India, Indian Journal of Radio and Space Physics, 33: 321-328 (2004).
6. Calla O P N, Kalita S H, Estimation of scattering coefficient of saline soil for slightly rough surface and undulating surface at microwave frequencies, Indian Journal of Radio and Space Physics, 33: 405-410 (2004).
7. Calla O P N, Rai A R, Mathur P, Mathur D, Bohra D, Waseem H, Bali H S, Estimation of emissivity and scattering co-efficient of the constituents of vegetarian at microwave frequencies, Indian Journal of Radio and Space Physics, 34: 67-70 (2005).
8. Calla O P N, Ranjan V, Bohra C, Naik G L, Waseem H, Bali H S, Estimation of Dielectric constant of soil from the given texture at microwave frequency, Indian Journal of Radio and Space Physics, 33: 196-200 (2004).
9. Curtis J, Narayanan R, Effect of laboratory procedures on soil electrical property measurements, IEEE Transactions on Instrumentation and Measurement, 47-6: 1474-1482 (1998).
10. Curtis J, Moisture effects on the dielectric properties of soils index terms - Conductivity dielectric properties, permittivity, soil
moisture, *IEEE Trans. Geo. Remote Sensing* **39-1**: 125-132 (2001).

11. Chaudhari H C, Shinde V.J, Moisture dependent dielectric study of different soil textures at X-band microwave frequency, *Bulletin of Pure and Applied Sciences*, **26**: 13-18 (2007).

12. Darayan S, Liu C, Shen L C, Shattuck D, Measurement of electrical properties of contaminated soil, *Geophysical prospecting*, **46**: 477-488 (1998).

13. Logsdon S D, Soil dielectric spectra from vector network analyzer data, *Soil Sci. Soc. Am. J.* **69**: 983-989 (2005).

14. Mahan M K, Jha B L, Chetal A R, Dielectric properties of Indian clay minerals: Bentonite & Pyropillilite, *Indian Journal of Pure & Applied Physics*, **18**: 401-403 (1980).

15. Narasimha Rao P V C, Suresh Raju, Rao K.S, Microwave remote sensing of soil moisture: Elimination of texture effect, *IEEE Transactions on Geoscience and Remote Sensing*, **28**: 148-155 (1990).

16. Puri Vijaya, Darshane S, Shaikh S, Moisture dependent Ku band microwave characteristics of red soil, *Indian Journal of Radio & Space Physics*, **33**: 399-404 (2004).

17. Puri Vijaya, Darshane S, Shaikh S, (2005), Ku band microwave transmission and reflection of moisture-laden brown and black soil, *Indian Journal of Physics*, **79(12)**: 1419-1422.

18. Sengwa R J, Soni A, Dielectric dispersion and microwave dielectric study of marbles in support of radar investigations, *Indian Journal of Pure & Applied Physics*, **43**: 777-782 (2005).

19. Srivastava S K, Mishra G P, Study of the characteristics of the soil of Chhattisgarh at X-band frequency, *Sadhana*, **29**(4): 343-348 (2004).

20. Srivastava S K, Vishwakarma B R, Study of dielectric parameters of aluminium ore bauxite of Manipat area of Chhattisgarh at X-band frequency, *Sadhana*, **29**(4): 349-354 (2004).