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*Full Length Research Paper*

# Dielectric study of moisture laden soils at X-band microwave frequency

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**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 (ε') and imaginary (ε'') parts of the complex dielectric constant (ε*) of soil with varied moisture content were made at 9.65 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 ε' and ε'' 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. Also precise microwave dielectric measurements of soils and recognition of their dependence on physical and chemical composition are interesting and can be used in support of radar investigations of the Earth's geology.**

**Keywords:** Dielectric constant, dielectric loss, conductivity, relaxation time.

## 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 frequentcies plays vital roll 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 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 Uttarpradesh 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 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, 1998, 2001) for a broad range of soil texture and the variation of dielectric permittivity and conductivity as functions of moisture content are studied. The dielectric constant of soil samples from Uttar Pradesh and Kashmir are measured at different frequencies in the range 8 - 10 GHz using waveguide cell method and variation of dielec-

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tric constant with frequency is reported (Calla 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 Calla et al. (Calla 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 experimenttally 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.

## MATERIALS AND METHODS

The infinite sample method described by Altshuler is used for the measurements of dielectric properties. An X-band microwave bench operating at 9.65 GHz in the $TE_{10}$ 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

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

$$\varepsilon^* = \frac{1}{1+\left[\frac{\lambda_c}{\lambda_g}\right]^2} + \frac{1}{1+\left[\frac{\lambda_g}{\lambda_c}\right]^2}\left[\frac{r - j\tan[k(D-D_R)]}{1 - jr\tan[k(D-D_R)]}\right]^2 \quad (1)$$

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 & $D_R$ 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 Bidar region of Karnataka state. Samples were collected from both irrigated and non-irrigated areas of the state. The Physical and 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

$$W_c\,(\%) = \frac{W_1 - W_2}{W_2} \times 100 \quad (2)$$

Measurements have been carried out at 9.65 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 (Srivastawa, 2004; Barathan, 2006).

$$\sigma = \omega\varepsilon_0\varepsilon'' \quad (3)$$

And

$$\tau = \frac{\varepsilon''}{\omega\varepsilon'} \quad (4)$$

where

$\omega$ is angular frequency, f = 9.65 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 Tables 1a and b. 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 VII and VIII 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 organic carbon, Na and $CaCO_3$ percentage in sandy loam

**Table 1a.** The texture, physical and chemical properties of soil.

| Sample | Texture | Sand % | Silt % | Clay % | W.H.C. % | Particle Density | Porosity |
|---|---|---|---|---|---|---|---|
| I | Silty Clay | 2.34 | 35.15 | 62.51 | 81.0 | 1.4 | 52 |
| II | Clay | 6.80 | 37.5 | 55.70 | 57.8 | 2.0 | 51.5 |
| III | Clay | 8.90 | 49.45 | 41.65 | 77.7 | 1.9 | 60.7 |
| IV | Clay | 21.00 | 35.00 | 44.00 | 87.9 | 1.5 | 53.6 |
| V | Clay | 02.60 | 36.3 | 61.10 | 49.0 | 2.1 | 48.5 |
| VI | Sandy Loam | 55.45 | 26.55 | 15.30 | 70.2 | 2.2 | 55.1 |
| VII | Loam | 27.68 | 33.57 | 38.73 | 45.6 | 2.2 | 45.9 |
| VIII | Sandy Loam | 54.84 | 28.39 | 16.77 | 51.1 | 2.0 | 45.4 |

**Table 1b.** Chemical properties of soil

| | Chemical Properties | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sample | pH | E.C. mS/cm | Organic Carbon % | $P_2O_5$ % | $K_2O$ % | Ca % | Mg % | Na % | $CaCO_3$ % |
| I | 7.690 | 10.600 | 0.870 | 0.001 | 0.148 | 37.530 | 27.950 | 1.260 | 2.620 |
| II | 6.110 | 0.400 | 0.220 | 0.001 | 0.015 | 25.020 | 18.000 | 0.470 | 4.750 |
| III | 8.470 | 0.470 | 0.920 | 0.001 | 0.020 | 29.190 | 19.730 | 0.600 | 6.620 |
| IV | 7.920 | 0.420 | 0.460 | 0.001 | 0.025 | 33.360 | 24.660 | 0.260 | 2.750 |
| V | 7.410 | 0.350 | 0.600 | 0.001 | 0.028 | 41.700 | 35.010 | 0.360 | 3.750 |
| VI | 8.240 | 0.340 | 0.790 | 0.001 | 0.032 | 27.100 | 19.730 | 0.820 | 9.120 |
| VII | 8.530 | 0.160 | 0.630 | 0.001 | 0.015 | 33.360 | 24.660 | 0.400 | 3.426 |
| VIII | 8.240 | 0.340 | 0.790 | 0.001 | 0.032 | 27.100 | 19.730 | 0.820 | 5.253 |

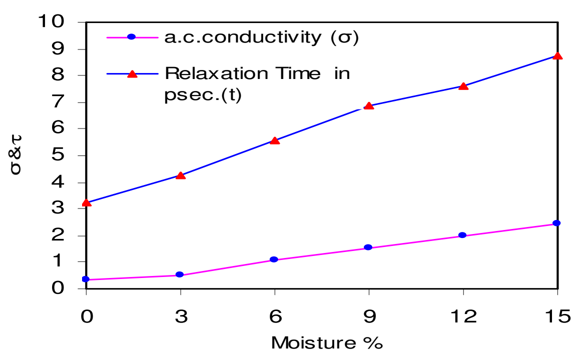


**Figure 1.** Variation of dielectric constant and dielectric loss with moisture content for sandy loam sample.

soil. The a.c. electrical conductivity (σ) and relaxation time (τ) shows a 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. 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 organic carbon, Na and $CaCO_3$ percentage 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. Since a dielectric property of soil determines the properties like emissivity, scattering coefficient etc.

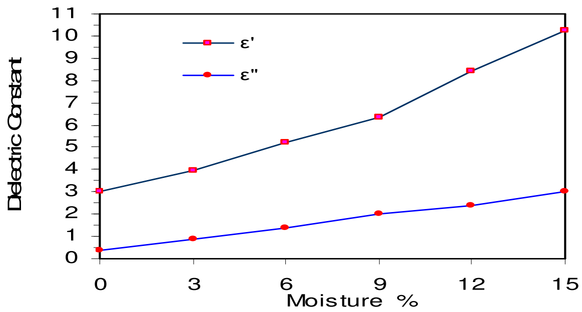


**Figure 2.** Variation of dielectric constant and dielectric loss with moisture content for loam sample.

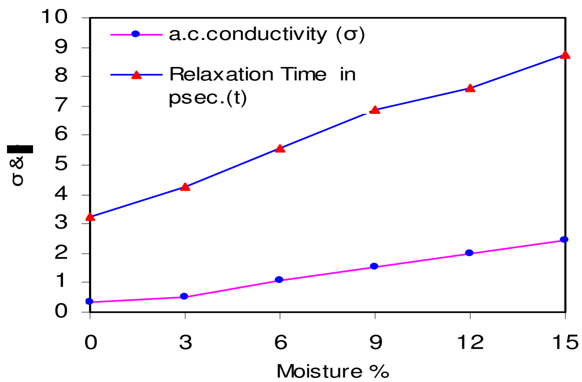


**Figure 3.** Variation of conductivity and relaxation time with moisture percentage for sandy loam sample.

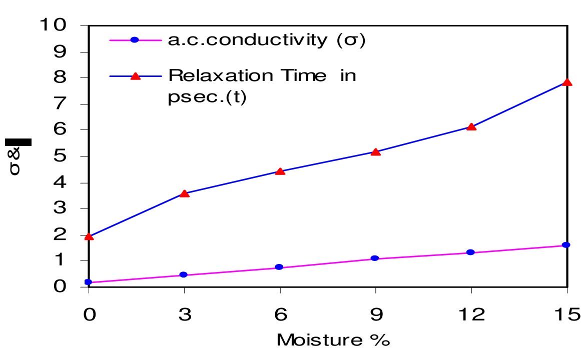


**Figure 4.** Variation of conductivity and relaxation time with moisture percentage for loam sample.

The correlation between dielectric properties and the ra-dar 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 data-base.

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