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Applications and measurement methods of Dielectric properties of soil at microwave frequency: A review

S. J. Bhurewal[1], S. B. Bajaj[2], K. G. Joshi[3]

[1]*P.G. Department of Physics and Physics Research Centre, J.E.S. College, Jalna-431203, Maharashtra, India*
[2] *P.G. Department of Physics and Physics Research Centre, J.E.S. College, Jalna-431203, Maharashtra, India*
[3] *Department of Electrical Engineering Sanjivani K. B. P. Polytechnic, Kopargaon (MS), India.*

ABSTRACT

An essential instrument for describing soil characteristics and keeping track of agricultural and environmental systems is microwave remote sensing. The dielectric constant, is one of the important soil characteristics that can be assessed using microwave remote sensing. The dielectric constant, which is influenced by the water content and texture of the soil, is a measurement of a material's capacity to hold electrical energy in an electric field. In this paper, an attempt is made to review the existing knowledge of complex permittivity and other electrical properties, their role and significance in the agriculture, as well as various measurement methods and their development is presented. The study includes a thorough analysis of the literature dielectric behavior of soil, its measurement methods, as well as comparisons and possible applications of dielectric properties.

Keyword: - Dielectric constant, soil, microwave remote sensing, agriculture.

1. INTRODUCTION

The majority of ground is covered in loose surface material called soil which is made up of both organic and inorganic matter. In addition to being a source of water and minerals, soil gives the structural support to the agricultural plants and nutrients to the crops that they need to grow. The various elements like soil texture, mineral content, temperature, moisture content and chemical constituents in the soil at microwave frequency, the dielectric properties of soil can change.

2. LITERATURE REVIEW:

V. V. Navarkhele et al. studied the dielectric properties of black soil with organic & inorganic matter at microwave frequency. In this study the dielectric property decreases with increasing frequency of oscillation and increases with increasing percentage of organic & inorganic matter also it is higher in organic matter as compared to inorganic matter [1]. M. D. Dhiware et al. showed that the dielectric constant of soil directly related to tangent loss, relaxation time (Γ), emissivity (e) and microwave conductivity(σ) at microwave frequency. Soil texture has remarkable effect on the dielectric properties [8]. S. S. Deshpande et al. reported that the salinity has little influence on the real part of dielectric constant ε' at 5 GHz. The imaginary part, ε" dielectric loss directly proportional to the salinity. The measurements are taken for dry saline soil. [3] The dielectric constant of a soil water mixture is a function of its volumetric moisture content and of the soil's textural composition over the 1.4- to 18-GHz range. If density effects are controlled, the dielectric constant of dry soil is essentially independent of soil texture and frequency. [15] Chaudhary H. C. et al studied increase in the organic matter content reduces the specific surface of the soil and reduces the typical bulk density. The net effect is that the observed range of moisture is smaller at higher organic matter contents. A series of emissivity observations obtained with different organic matter contents. The emissivity was directly related to the dielectric constant [10]. Ammonium Sulphate (NH_4SO_4) in soil appreciably affects its dielectric properties. From dielectric properties determine emissivity that will provide tools for designing the sensors [7]. The dielectric constant decreases with increasing salinity of soil while the loss factor increase with increasing the salinity. This is due to high conductivity of salt which increase the loss factor. The results indicate that the dielectric sensor could be used to detect salt in sand soil and quantify its salinity [16]. R. Rajesh Mohan et al. show that for the majority of soil samples, in both dry and wet conditions, real part of dielectric permittivity decreases with increasing frequency. Additionally, it is concluded that the free space transmission technique, which is considered to be challenging at low microwave frequencies due to the requirement for a large structure and a significant number of soil samples, can be easily used in conjunction with a straightforward micro strip patch antenna and an appropriate sample-holder that is microwave radiation-resistant [33]. The main purpose of this review is to provide information of soil's dielectric properties, various methods to measure them, and its applications in remote sensing and agriculture.

3. MEASUREMENT TECHNIQUES

Time Domain Reflectometry (TDR) and Frequency Domain methods used for measuring dielectric properties. Topp et al. first used TDR to measure the dielectric properties of soil [31]. A pulse generator generates and transmits a step-like pulse in the frequency domain and propagated down the transmission line for measuring dielectric properties [27]. Several well-known methods include the parallel plate method, open space method, cavity perturbation method, and coaxial probe method [10]. Together with the Vector Network Analyzer (VNA), it is used to quantify complex reflection coefficients. The measurement technique, equipment, and sample holder design depend on the dielectric materials to be measured, and suitable frequency range [30].

4. DIELECTRIC MEASUREMENT

A part of the energy from microwaves that are directed at soil is reflected, some of it is transmitted through the surface, and a part of this subsequent amount is absorbed. In terms of the dielectric properties, the proportions of energy that fit into these three categories have been established. The complex relative permittivity of the soil, ε_r, is the fundamental electrical property used to identify relationships.

Mathematically it is written as:

$\varepsilon_r = \varepsilon' - \varepsilon''$ …. (1)

where: ε' is dielectric constant, and ε'' is dielectric loss factor.

4.1 Measurement methods using slotted line technique:

There are several methods of dielectric measurement of soil at microwave frequency [4]. The most common methods for dielectric measurements of soil at microwave frequency is Von - Hipple method and Two-point method. The experimental set up for dielectric measurements of soil using this method as shown in fig.1.

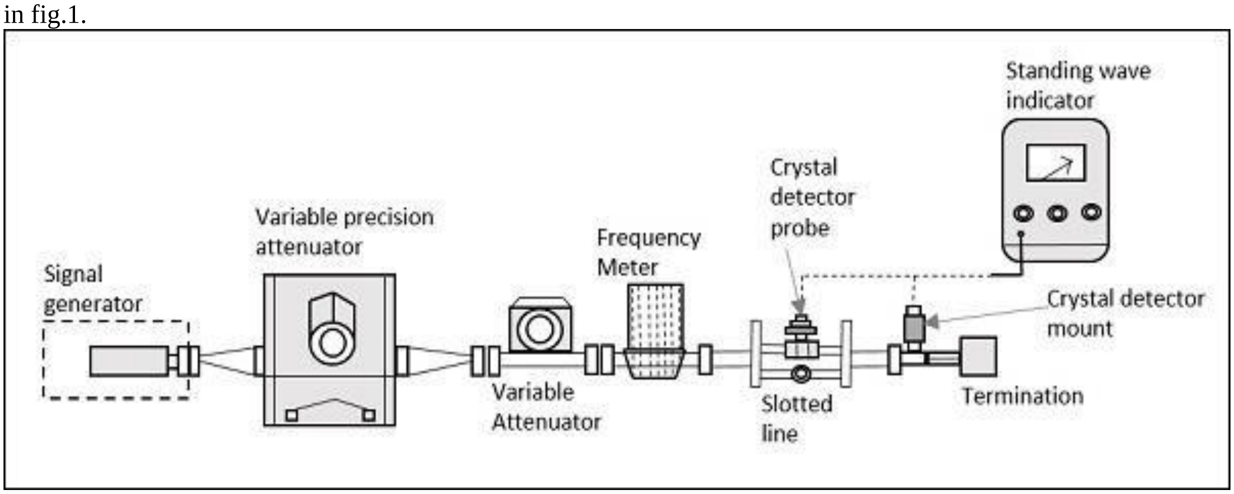

Figure no. 1 Experimental set up of Microwave Bench

In this technique slotted line is used to determine the dielectric properties of soil samples. A microwave bench set-up in the TE_{10} mode with Reflex Klystron or Gunn oscillator operating at desired frequencies. In Von - Hipple method a sample lengths are usually taken in the multiples of $\lambda g/4$. Any inaccuracy in sample length and measurement may lead to serious errors. The solid dielectric cell with soil sample is connected to the opposite end of the source. The signal generated from the microwave source is allowed to incident on the soil sample. The soil sample reflects part of the incident signal from its front surface. The reflected wave combined with incident wave to give a standing wave pattern. These standing wave patterns are then used in determining the values of shift in minima resulted due to before and after inserting the sample. The dielectric constant is calculated by measuring the standing wave ratio of the dielectric material and the shift in minima of the standing wave pattern in a rectangular waveguide. This shift takes place due to change in the guide wavelength when a dielectric material is introduced in waveguide.

(a) Von - Hipple method:

The method consists of reflecting microwaves at normal incidence in TE_{10} mode from a dielectric sample placed against a perfectly reflecting surface. The reflection sets up standing waves in space in front of the sample. The separation of the first minimum from the face of the sample will depend upon wavelength of the EM wave in the sample and on sample dimensions (thickness) and hence on dielectric constant. Further, the change in wavelength shall cause shift in the minima and in turn a change in half power width of the standing wave pattern. Also, losses in the dielectric shall decrease to VSWR (E max /E min) and so tan δ may be related to this decrease in VSWR. To proceed, consider that an EM wave travelling through medium 1 (air) strikes normally to the medium 2 (dielectric), a part of it is reflected and the rest gets transmitted. A standing wave pattern is thus produced in medium 1. [11]

$$\varepsilon' = \lambda_0^2\left(\frac{1}{\lambda_c^2} + \frac{(\alpha^2 - \beta^2)}{4\pi^2}\right) \quad \ldots (2)$$

A

r d

$$\varepsilon'' = \frac{\lambda_0^2 \alpha\beta}{2\pi^2} \quad \ldots\ldots(3)$$

Free space wavelength is determined by using the relation

$$\frac{1}{\lambda_0^2} = \frac{1}{\lambda_g^2} + \frac{1}{\lambda_c^2}$$

Where λ_c is the cutoff wavelength. It is given by λ_c = 2 x a, a being border side of rectangular wave-guide.

(b) Two-point method:

For lossy dielectrics i.e. complex permittivity **ε**' and **ε**" dielectrics. In these cases, we determine voltage standing wave ratio and compute reflection coefficient in complex form. The phase difference [Φ]. In the waves travelling in the guide with and without dielectric is Δx is the shift in minimum. Now reflection coefficient can be calculated by VSWR. Voltage standing wave ratio(S) is determined for the load and then magnitude of the reflection coefficient (Γ) is computed by employing the relation

$$\tau = \frac{s-1}{s+1} \quad \ldots (i)$$

In the two-point method, the complex dielectric constant is given by

$$C\angle{-\psi} = \frac{1}{j\,\beta\, l\varepsilon}\,\frac{1-|\tau|e^{j\varphi}}{1+|\tau|e^{j\varphi}} = \frac{\tan X\angle\theta}{X\angle\theta} \quad \ldots(ii)$$

Where, C and Ψ represent the magnitude and phase of the complex quantity respectively. X∠θ represents the corresponding solution of complex transcendental equation.

$$Y\varepsilon = \frac{X}{\beta l\varepsilon}\angle 2(\theta - 90^0) = g_{\varepsilon} + j\beta\varepsilon \quad \ldots(iii)$$

The dielectric constant ε' of the soils is then determined from the following relation:

$$\varepsilon' = \frac{g_{\varepsilon} + \left(\lambda_g/2a\right)^2}{1 + \left(\lambda_g/2a\right)^2} \quad \ldots (iv)$$

and

$$\varepsilon' = \frac{\beta_{\varepsilon}}{1 + \left(\lambda_{g} / 2a \right)^{2}} \quad \ldots(v)$$

Where, a is Inner width of rectangular waveguide g_{ε} is real part of the admittance. βϵ is imaginary part of the admittance.

By knowing admittance, we can relate it to **ε**' and **ε**". These parameters are mainly used to determine the values of dielectric constant and dielectric loss of the soils. By knowing these two dielectric parameters, the other parameters can easily be estimated [11].

5. CONCLUSIONS

A comprehensive literature review on measuring soil's dielectric properties is carried out in this paper. It explores how various methods to measure the loss factor (permittivity) and dielectric constant are applicable in agriculture. The other physicochemical properties of soil also effect on dielectric constant which are useful for crop yield [8]. The significance of knowing dielectric properties of soil for estimating soil properties from remote sensing data. Soil moisture sensors with appropriate design and a reasonable level of accuracy have been using dielectric properties. Moisture content in soil is the most important characteristic for agriculture, because it determines their suitability for crop.

6. Applications:

The primary application for knowledge of the dielectric properties of materials have been use to describe how the materials behave when exposed to microwave frequency, as well as their use for quick moisture sensors [19]. Nelson et al, studied the dielectric relaxation events in materials can also be explained using dielectric properties over a broad frequency range [30]. The Topp, Davis, and Annan model is a very good one for estimating volumetric moisture levels in soil using dielectric permittivity data [31]. It is usually a good idea to verify the results of soil whose dielectric properties are well understood can frequently be used. The dielectric constants and loss factors in the desired ranges and similar to those of the soils being studied, are not as common as frequently desired. By taking measurements using two distinct techniques and comparing the results, confidence can occasionally be attained. The different parameters of soil texture, mineral content, temperature, moisture content and chemical constituents in the soil at microwave frequency, the dielectric properties of soil can change. Using this property, we can monitor the particular type of soil. Monitoring soil health provides information of the nutrients that soil is lacking, which crops should grow in that soil and also help in choosing which fertilizers is suitable for the soil.

7. Future scope:

Researchers can create more precise models for calculating soil moisture and other soil properties using remote sensing data by analyzing the relation between the complex dielectric constant and soil characteristics. It is essential to have correct knowledge of the dielectric properties of soil at microwave frequency, in order to properly interpret the microwave remote sensing data. The models can develop to observe environmental systems and enhance agricultural management techniques more accurately.

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