Using of Microwaves for Skin Depth Determination of Moist Soils for Mosul City

Sabah Hussein Ali[1] **, Muhammad F. O. Khattab**[1] **and Manaf Ezzldien Al-Sabbagh**[2]

[1]Remote Sensing Center, University of Mosul, Mosul, Iraq
[2] Department of Electrical Engineering, University of Mosul, Mosul, Iraq

Abstract:

Results of an experimental and theoretical programs were presented to determine the impact of soil moisture content and the soil composition on microwave radiometric emission and microwave signal skin depth (which is one of the most importance parameter in remote sensing data set), as well as attenuation coefficient within nonvegetable soil surfaces. The measurements are depending on the relative dielectric constant that practically carried out by this research. The measurements have been conducted for three common types of soil in Mosul area (ornamental, cropland, and orchard) at a microwave frequency of 6GHz (C-band).

The expected brightness temperatures of these soil samples and the skin depth have been computed. The results show that the observed microwave skin depth is relatively high for ornamental type more than that of cropland and orchard.

Keyword: skin depth, soil, water content, brightness temperature.

Introduction:

The soil moisture is difficult to define because it means different things in different disciplines. However soil moisture is the water held in the space between soil particles (Leonaro, 2002).

Compared to other components of hydrologic cycle, the volume of soil moisture is small, nonetheless, it is of fundamental importance to many hydrological, biological, and into modeling of various ecosystem processes (Eni & Peggy, 1982). Despite the importance of soil moisture, widespread and, or continuous measurement of soil moisture is all but nonexistent.

The lack of a convincing approach of global measurement of soil moisture is a serious problem. Clearly, a need exists for continuous measurements of surface soil moisture with global coverage.

Remote sensing of soil moisture from the vantagepoint of space is advantageous because of its spatial coverage and temporal continuity (Farnsworth et al., 1989). Radiometric microwave remote sensors a board earth orbiting satellites have potential for providing soil moisture information, with the necessary temporal and spatial coverage.

The potential of microwave techniques lies in the marked effect of soil moisture on the soil emission and the skin depth (penetration) properties at microwave frequencies (Ulaby et al.,1986), (Wang et al., 2005).

The purpose of this paper is to study the effects of soil moisture content on the radiometric microwave emission properties (reflectivity and brightness temperature) and the skin depth for three types of common existing soil in Mosul, namely cropland, orchards, and ornamental.

The practical measurements of the real and imaginary parts of complex dielectric constant as a function of soil moisture for the above types of soil have been carried out. The measurements were performed at a microwave frequency of (6GHz).

Laboratory measurements and analysis:

Soil samples analysis

Soil is defines that it the external disassembled layer for earth surface, which have difference from deep rocky layers. The soil consist of five main materials; mineral material, water, air, organic material, and biological beings,(Alexander, 1982).The mineral material that represented the ratio between sand, silt, and clay in one side, and the organic material that reflect amount of carbon in the other side, were constant in one location. While each amount of water and air varies in soil for the same location (Deming, 2002).

This study included the collection of three soil samples represent three types of soil; ornamental area, orchards, and cropland. These types of soil reflect the common types of soil in Mosul city, and that which have a wide appearance wide in this area.

The laboratory analysis of soil samples included determination of: electrical conductivity (E.C.) which is an indicator of the salinity, acidity (pH), ratio of organic material (%O.M), and the ratio of sand, silt and clay. Table (1) shows the results of laboratory analysis of the adopted soil samples that have been analyzed at General Establishment for Agricultural Researches.

Table(1): Laboratory analysis of the soil samples adopted in this research

sample	Type of soil	PH	E.C. (mho/cm)	%O.M	%sand	%silt	%clay
1	Cropland	7.4	0.438	0.529	5.74	32.0	62.26
2	Ornamental	7.45	1.684	0.167	49.4	23.34	27.26
3	orchard	7.5	2.398	0.456	22.74	23.33	53.93

Relative dielectric constant measurements:

Water in the soil changes the microwave dielectric constant, which in turn change the emission. Several dielectric mixing models have been developed and evaluated to describe soil-water systems (Wang & Schmugge, 1980),(William & Charles, 2005).

In this research the measurement of relative dielectric constant for the adopted three types of soil have been carried out as a function of moisture content (0-0.30 cm^3/cm^3) by using the shorted-line techniques. The principles of the dielectric properties measurements by this technique was given in detail by (Yonis,1983) and Nelson, et. al.,1974).

The measurements were made by packing the moist samples in (3-cm) length waveguide section.

Figure (1) shows the basic arrangement of the experimental set-up. In the shorted-line technique, a slotted line section is used to measure the shift in minimum of a standing wave and the change in the standing-wave ratio.

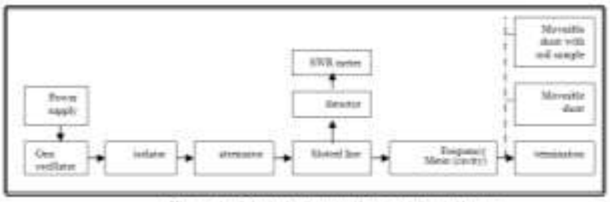


Figure (1): Schematic diagram of the experimental set-up

The minima of the standing-wave pattern occur at intervals of one-half wavelength from the short circuit when the soil sample is absent.

When the sample is inserted in the front of the short circuit, the minima shift toward the short-circuit as shown in figure (2).

The shift in minimum is a measure of the dielectric constant

$$\varepsilon' = (\frac{x\lambda}{2\pi d})^2 + (\frac{\lambda}{\lambda_c})^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

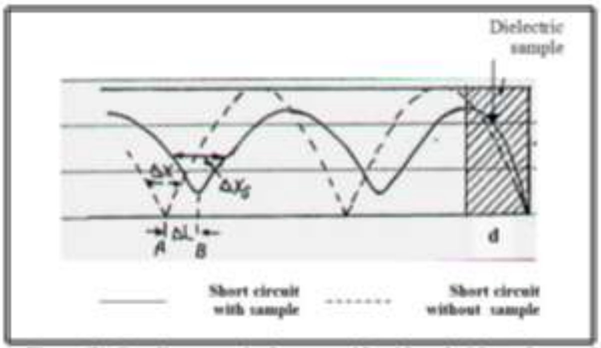


Figure (2): Standing waves in the waveguide with and without the sample

$\frac{\lambda}{\lambda_c}$ is the waveguide proportionality constant which is a function of the waveguide dimensions ($\lambda_c = 2a$, a being the width of the rectangular waveguide (cm)) and the mode of propagation (λ is the operating wavelength (cm)). *d* is the length of the soil sample (cm).

x is the multi-valued "theoretically infinite number of values",can be calculated from the following equation;

$$\frac{\tan x}{x} = \frac{\lambda_g}{2\pi d} \tan \frac{2\pi(\Delta L + d)}{\lambda_g} \quad \ldots\ldots\ldots\ldots(2)$$

where,

ΔL is the shift in the minimum (figure(2)).

λ_g is the waveguide wavelength(cm).

The signal that is lost in form of heat in the dielectric causes a decrease in the standing-wave ratio.

The decrease in the standing-wave ratio is a measure of the loss tangent ($\tan\delta$) (Yonis,1983):

$$\tan\delta = \frac{\Delta x_s - \Delta x}{\varepsilon' d} (\frac{\lambda}{\lambda_g})^2 \quad \ldots\ldots\ldots\ldots\ldots(3)$$

where,

$\Delta x_s, \Delta x$ denote the distances for a fixed voltage standing-wave ratio (VSWR) on either side of the minimum(fig.(2)).

Then, the loss factor (ε'') is calculated by;

$$\varepsilon'' = \tan\delta * \varepsilon' \quad \ldots\ldots\ldots\ldots(4)$$

Microwave Radiative Properties of Soil:

In passive microwave remote sensing, the data that a radiometer provides is commonly measured and expressed in terms of emissivity

Emissivity can be predicted from the dielectric constant for a wide variety of conditions. The simplest situation occurs when the dielectric constant of the moisture soil is uniform with depth (Charles, 2005).Under these conditions the Fresnel equations can be used to predict emissivity for any incident angle or polarization.

Microwave brightness temperature (TB) for a smooth surface is related to the relative dielectric constant (ε_r) through the reflectivity by (Jackson & O'Neill, 1987);

$$T_b(\theta, p) = (1 - R(\theta, P)) * T \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where,

θ is the incident angle

P is the polarization

R is the reflectivity,and

T is the actual soil temperature

The Fresnel equations that relate (ε) to(R) are given by (Zhao et al, 1983):

$$R(\theta, H) = (\frac{\cos\theta - (\varepsilon_r - \sin^2\theta)^{0.5}}{\cos\theta + (\varepsilon_r - \sin^2\theta)^{0.5}})^2 \quad \ldots\ldots\ldots(6)$$

for horizontal polarization, while for vertical polarization is;

$$R(\theta, V) = (\frac{\varepsilon_r \cos\theta - (\varepsilon_r - \sin^2\theta)^{0.5}}{\varepsilon_r \cos\theta + (\varepsilon_r - \sin^2\theta)^{0.5}})^2 \quad \ldots\ldots\ldots\ldots\ldots(7)$$

where;

$\varepsilon_r = \varepsilon' - j\varepsilon''$, and

$\varepsilon' =$ real part of relative dielectric constant

$\varepsilon'' =$ imaginary part of relative dielectric constant

Reflectivity is related to the emissivity by the expression (Charles, 1987):

$$e(\theta, p) = (1 - R(\theta, p)) \quad \ldots\ldots\ldots\ldots\ldots\ldots(8)$$

In this study, equations (5 through 8) have been adopted for calculating the emissivity and brightness temperature of the soil samples depending on the measured values of the relative dielectric constant.

Skin depth model:

Electromagnetic energy incident normally upon the surface of a homogeneous soil model is partly reflected and partly transmitted through the medium. If the medium is conductive, the transmitted portion will undergo attenuation at a rate defined by the field (electric or magnetic) attenuation coefficient(α).

Since the attenuation rate is exponential, at a depth ($\delta = 1/\alpha$) the field magnitude will reduce to $1/e(0.37)$ of its surface value and the power will reduce to $1/e^2(0.135)$ of the power at the surface (Charles, 2005).

In a nonhomogeneous medium where the soil dielectric parameters vary with depth, the contribution from a layer at a depth (δ) will undergo additional attenuation of 1/e2 thereby arriving at the surface with a magnitude 1/e4(0.0183) of its original incident value(Ulaby et al.,1974).

Hence neglecting contributions from deeper layers represents an omission of less than 2% of the returned power. The attenuation coefficient, α, in nepers/m is defined in terms of the operating wavelength (in meter), real and imaginary parts of the complex dielectric constant, ε' and ε'' respectively as(Ulaby et al.,1986):

$$\alpha = \frac{2\pi}{\lambda}\sqrt{\frac{\varepsilon'}{2}\left(\sqrt{1+\left(\frac{\varepsilon''}{\varepsilon'}\right)^2}-1\right)} \quad \ldots\ldots\ldots(9)$$

The skin depth (δ) of a non-homogeneous medium can be used to define an equivalent homogeneous medium having an effective attenuation coefficient:

$$\delta = \frac{1}{\alpha} \quad \ldots\ldots\ldots\ldots(10)$$

At a given frequency, values of (ε') and (ε'') are strongly affected by soil moisture content, but relatively little by other soil characteristics.

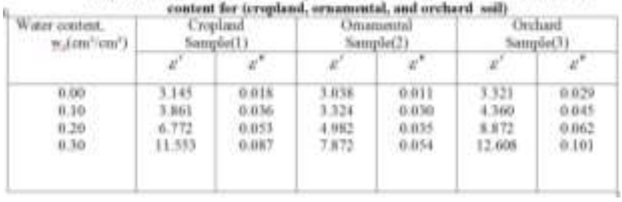
Results and Discussion:

The theory behind microwave remote sensing of moist soil is based on the large contrast between the dielectric properties of liquid water (~81) and dry soil (<4).

The dielectric properties have been studied and measured in this study to determined the microwave brightness temperature and the skin depth for a commonly types of soil in Mosul at a microwave frequency of 6GHz (C-band).

As shown on table (2), the relative dielectric constant (ε_r) of soil (in general) varies with volumetric moisture content. At moisture contents greater than zero, figure (3) shows (ε_r) to be dependent also upon soil composition and mineralogy.

Table (2): Measured values of complex dielectric constant as a function of water content for (cropland, ornamental, and orchard soil)



Water content, w_v(cm³/cm³)	Cropland Sample(1)		Ornamental Sample(2)		Orchard Sample(3)	
	ε'	ε''	ε'	ε''	ε'	ε''
0.00	3.145	0.018	3.038	0.011	3.321	0.029
0.10	3.861	0.036	3.324	0.030	4.360	0.045
0.20	6.772	0.053	4.982	0.035	8.872	0.062
0.30	11.553	0.087	7.872	0.054	12.608	0.101

Within the soil medium, the dielectric properties of a water molecule are governed by the strength of forces acting on the molecule. The volume percent of soil water at a given distance from a soil particle surface is determined by the specific surface area and the pore size distribution of a soil, both of which are strong functions of soil composition and mineralogy (Mitchell, 1976).

However, figure (3) clearly indicate that real and imaginary parts of the relative dielectric constant of the three types of soil increase with the water content were identical in behavior. Also it is found that the real and imaginary parts of the dielectric constant for the soil types of orchard and cropland are higher than that of ornamental (figures (3a) and (3b), respectively). This is probably due to the fact that the specific surface area increases as soil particle size decrease from sand to clay size and is even large for expanding layer lattice clays such as (Dobson & Ulaby, 1981). The results shows that the salinity factor play a minor role as compared to the soil content and texture to influence on the soil dielectric constant.

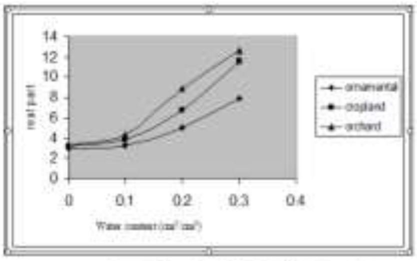


Figure (3a): real part of relative dielectric constant

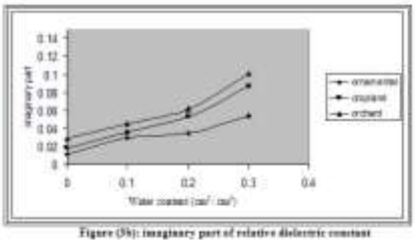


Figure (3b): imaginary part of relative dielectric constant

Figure (3): Relative dielectric constant of cropland, orchard, and ornamental as a function of water content at 6GHz

As water in soil changes the microwave dielectric constant, it changes the brightness temperature emission of the soil that measured by radiometer. figure (4) shows the brightness temperature variation with moisture (water) content for the samples adopted in this research at incidence angle (400.) and (600.) as indicated in figure(4a and 4b, respectively). The calculation were taken for vertical and horizontal polarization as well as physical temperature of soil in order to derive meaningful soil moisture information from the microwave radiometer data.

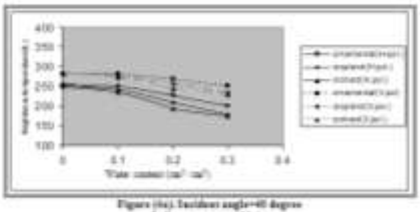


Figure (4a): Incident angle=40 degree
Soil temperature=28.4 c

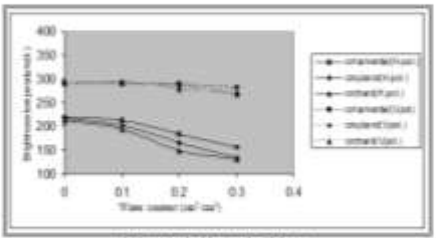


Figure (4b): Incident angle=60 degree
Soil temperature=28.4 c

Figure (4): variation of brightness temperature versus soil water content for vertical and horizontal polarization

The data of figures(4a and 4b) demonstrates the inverse relation ship that exists between brightness temperature and soil moisture at the two polarization. The data in figure (4) show that soil ornamental indicates relatively more brightness temperature than cropland and orchard. At the two incident angles, data of the brightness temperature for the three samples is seen to be approximately close to each other, especially at vertical polarization which gives reliable results at (600) incident angle, this result give a good agreement with the results reported by (Thomas, 2003)

Figure (5) shows the monotonically increasing function of attenuation coefficient with the soil water content of the three soil samples tested by this research. It is shown that the ornamental exhibited low attenuation coefficient than that of cropland and orchard samples at the given values of water content, then the ornamental sample gives a relatively high skin depth as compared to other samples studied in this research as shown in figure (6). This is due to ability of microwave signal to penetrate in soil depend on the a mount of water in a unit volume of soil as well as the sand content of soil under investigation that characterized by continuity porous. Since the effective depth of penetration of microwave signal increase as increase of sand ratio and decrease of water amount (Ulaby et al.,1974), the observed signals were correlated with the moisture in skin depth as characterized by the attenuation coefficient (reciprocal of skin depth).

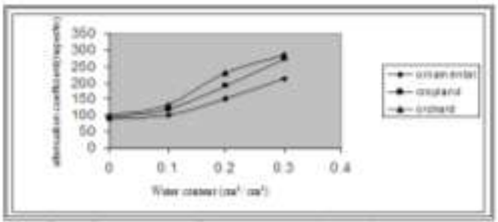


Figure (5): attenuation coefficient variation as a function of water content

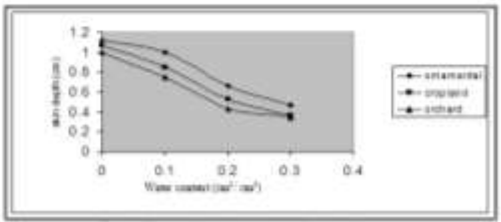


Figure (6): skin depth variation as a function of water content

Figure (6) indicate that at moisture content (0.1- 0.2) may be adequate region for distinguished between the three samples and the predicted attenuation coefficient.

Conclusions:

Measurements have been made of the relative dielectric constant for three types of soil (ornamental, cropland, and orchard) from Mosul area at 6GHz (C-band). The relative dielectric constant is found to be mainly affected by soil water content, It founds that at dry soil samples have relatively different dielectric constant(for the same real and imaginary part).

Microwave radiometric emission calculations of the soil samples have been also obtained depending on the measured electrical properties at vertical and horizontal polarization. Also the three soil samples show the anisotropic behaivour. The measurements show the inverse relationship between brightness temperature and the soil water content.

The predicted skin depth for the ornamental as a function of soil water content (0 ~ 0.3 cm3/cm3) is only of a centimeter order which relatively more than cropland and orchard samples. The results indicate that at moisture content (0.1- 0.2) my be adequate region for distinguished between the three samples and so we can predicted soil type from the skin depth and attenuation coefficient data set.

The above results point out the need for additional experimentation to:

1-Defined the response of relative dielectric constant to different soil water content at a different soil depth not only on the surface area.

2-Perform a field experiment which measured the in situ soil radiometric emission with microwave radiometer and soil skin depth as well as attenuation level with radar system as a part of the “ground truth” remote sensing data set.

Refrences:

1. Leonaro,L.L.,2002. Mobile field systems for rapid subsurface data acquisition using electromagnetic induction and ground-penetrating radar. M.Sc.thesis,The University of Tennessee Library, Knoxrille, TN-76P.
2. Eni,G.N., and Peggy,E.O.,1982. Multifrequency Microwave Radiometer measurements of soil moisture. IEEE Trans. Geoscience and Remote Sensing, vol.GE-20,No-4,October,pp468-475.
3. Farnsworth, R.k., Barreft, E.C., nd Dhansu, M.S., 1989. Application of remote sensing to hydrology including ground water. International Hydrological program, Unisco, Paris, 122P.
4. Ulaby, F.T., Moore,R.K.,and Fung,A.K.,1986. Microwave remote sensing active and passive. Vol.3,From theory to application ,Canada:Dedham MA:Artech House,pp2020-2022.
5. Wang, J.,R., Shiue,J., Engman,E., McMurtrey,J., Lawless,P., Scmugge,T., Jackson, T., Gould, W., Fuchs,J., Calhoon, C., Carnahan, T., Hirschman, E., and Glazar, W., 2005. Remote measurements of soil moisture by microwave radiometers at bare test site. NASA Technical Memorandum 80720,21 P.
6. Alexander, M.., 1982. Soil microbiology. John Wiley and Sons, INC. USA, 573 P.
7. Deming, D., 2002. Introduction to hydrogeology. Library of Congress Cataloging- in – Publication Data. McGraw Hill. 468P.
8. Wang, J., R., and Schmugge, 1980. An empirical model for the complex dielectric permittivity of soil as a function of water content. IEEE Trans. Geoscience and Remote Sensing, vol.GE-18,pp.288-295.
9. William, L.,C., and Charles, A., L., 2005. Comparison of two microwave radio brightness models and validation with field measurements. Available at:charles.laymon@msfc.nasa.gov., accessed at:28/May/2005.
10. Yonis, H., M., 1983. Some Effects of Sand and Dust Storms on Iraq National Microwave Links. Msc. Thesis , University of osul
11. Nelson, S.O., Stetson, L.E., Schlaphoff, C.W., 1974, A General Program for Precise Calculation of Dielectric Properties From Short-Circuited-Waveguide Measurements, IEEE Trans. Instrumentation and Measurement, vol.IM-23, no.4, pp.455-460.
12. Jackson,T.,J., and O’Neill,P.,E.,1987. Salinity effects on the microwave emissivity of soil. IEEE Trans.Geoscience and Remote Sensing, vol.-25,no.2,March,pp.214-220.

13. Zhao, B., Zhao, W., and Du, J., 1983. Microwave Remote Sensing Of Oil Slick On Water Surface. Scientia Sinica(series A), Vol.xxvi, no.9, pp.978-989.
14. Ulaby, F., T., Cihlar, J., and Moore, R., K., 1974. Active microwave measurement of soil water content.. Remote sensing of environment, vol.3, pp.185-203.
15. Mitchell, J., K., 1976. Fundamentals of soil behavior. New York:John Wiley & Sons, pp.422.
16. Dobson, M., C., and Ulaby, F., 1981. Microwave backscatter dependence on surface roughness. Soil moisture, and soil texture: Part III-soil tension", IEEE Transactions on Geoscience and Remote Sensing, vol. GE-19, no.1, pp.51-61.
17. Thomas, H, 2003,Measuring surface soil parameters using passive microwave remote sensing , HD-No.639, Vrije Universiteit, Amistrdam,

استخدام الموجات المايكروية في تحديد عمق الاختراق للترب الرطبة في مدينة الموصل

صباح حسين علي[١] و محمد فوزي عمر خطاب[١] و مناف عزالدين الصباغ[٢]

[١] مركز التحسس النائي، جامعة الموصل، الموصل، جمهورية العراق

[٢] قسم الهندسة الكهربائية، كلية الهندسة، جامعة الموصل، الموصل، جمهورية العراق

الملخص:

يقدم هذا البحث النتائج المختبرية و النظرية لقياسات تأثير المحتوى الرطوبي والمحتوى التركيبي للتربة على الانبعاث المايكروي وعمق الاختراق للإشارة المايكروية (الرادارية) بالإضافة إلى معامل التوهين للنماذج الشائعة من الترب الموجودة في الموصل (المحاصيل، المتنزهات، ألبساتين)، وتم القياس عند التردد المايكروي (٦ كيكاهرتز) والذي يقع ضمن حزمة (C). وتمت القياسات بالاعتماد على ثابت العزل النسبي لنماذج الترب والذي تم قياسه عمليا في البحث. تم إجراء القياسات النظرية لكمية الانبعاث الحراري المتوقع من النماذج المستخدمة ضمن الاستقطاب الأفقي و الاستقطاب العمودي فضلا عن قياس عمق الاختراق للإشارة الرادارية، وأظهرت النتائج أن عمق الاختراق للإشارة الرادارية يكون عالي نسبيا لنموذج تربة المتنزهات مقارنة مع نموذجي ترب المحاصيل والبساتين.