Effect of salinity on the microwave emission from dry soil surface

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(brightness temperature)

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(1.4GHz and 5GHz)

.$(20.4\,c^{0})$

(1.4GHz)

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ABSTRACT

The goal of this study was to apply the concept of passive microwave remote sensing to find the data set of microwave brightness temperatures of the dry soil surface as a function of actual salinity factors that influence the dielectric properties of the soil.

From the agricultural point of view, salinity factor refers to the state of accumulation of the soluble salts in the soil. In many area, this factor limiting plant growth (such as sodium chloride).

The measurements of the dielectric permittivity were conducted using shorted-circuited-waveguide technique at L-and C-band microwave frequencies (i.e. 1.4GHz and 5GHz, respectively). The dielectric properties of the salted soil samples were investigated at a thermodynamic temperature of 20.4 c^o.

The results show that the frequency of 1.4GHz (L-band) is more effective frequency for study of the penetration depth of the soil surface. Also the vertical polarized microwave signals is preferred to study the variation of the emission characteristics of the dry soil with respect to the salinity by using the microwave radiometric remote sensing techniques especially at low microwave frequency.

Introduction

In remote sensing, microwave radiometric sensors are among the most widely used techniques for the information acquisition of both soil moisture content and soil salinity ref.(1, 2). Since both of these properties will vary over an area, it is important when evaluating the capabilities of remote sensing techniques to know how a single variable can be isolated while the effects of the other are minimized .

Soil salinity is a worldwide phenomenon, it is classified as either primary or secondary. Primary salting occurs naturally while secondary salting is induced by human activities such as irrigated agriculture. Secondary salinity is an insidious problem that may be undetected for years until saline discharge is discovered at the soil surface. From the agricultural point of view, salinity factor refers to the state of accumulation of the soluble salts in the soil**.** Manmade factors are responsible for saline conditions on about 77 million hectares globally of which about 45 million hectares are in irrigated areas. Much of this land lies barren and unused (ref.3).

The knowledge gained from the remote sensing techniques is offering many insights to the causes of salinisation. This is aiding soil scientists in the development of methods to predict sites most at risk of salinisation according to the microwave emission properties of the study area (ref.2).

However, in Iraq, Northern irrigation project in Rabe'a area is one of the locations that considered to be an ideal area for study salinisation problem in arid and semi-arid region.

The purpose of this paper is to study the microwave emission properties of the dry soil at different actual salinity. Four samples of dry

with different levels of salinity soil from (Rabe'a area) are adopted in this study.

The relative dielectric constant of the soil samples were measured laboratory by using short-circuited-waveguide techniques. The measurements were made at microwave frequencies of 1.4GHz (L-Band) and 5GHz (C-band).

Principle of Passive Microwave Remote Sensing

Passive microwave remote sensing is based on the measurement of thermal radiation (referred to as brightness temperature) in the centimeter wave band of the electromagnetic spectrum. This radiation is determined largely by the physical temperature and the emissivity of the radiating body which can be approximated by (ref.4):

$$T_B(p) = e_s T \qquad \ldots\ldots\ldots\ldots\ldots 1$$

Where;

T_B = observed brightness temperature

T= physical temperature of the emitting layer

p= refers to vertical or horizontal polarization

e_s =smooth-surface emissivity

This emissivity is further defined as (ref.5):

$$e_s(p) = (1 - R_S(p)) \qquad \ldots\ldots\ldots\ldots\ldots.. 2$$

Where (R_S) is the smooth-surface reflectivity.

For a homogeneous soil with a smooth surface, the reflectivities at vertical and horizontal polarizations, $R_S(v)$ and $R_S(h)$, are given by the Fresnel expressions (ref.5):

$$R_S(v) = \left| \frac{\varepsilon_r \cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\varepsilon_r \cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}} \right|^2 \qquad \ldots\ldots\ldots\ldots\ldots 3$$

$$R_S(h) = \left| \frac{\cos\theta - \sqrt{\varepsilon_r - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon_r - \sin^2\theta}} \right|^2 \qquad \ldots\ldots\ldots\ldots\ldots. 4$$

Where θ is the incidence angle (relative to the surface normal) and ε_r is the relative permittivity (represented the absolute value of the soil bulk dielectric constant) which a measure of the response of the soil to an electromagnetic wave.

In this study, the measured brightness temperature is related to the salinity and the dielectric properties of the dry soil at an actual physical temperature of ($20.4\,c^o$).

Physical properties of the soil samples
Soil salinity and electrical conductivity properties:

Soil salinity, as a term, that refers to the state of accumulation of the soluble salts in the soil. From the agriculture point of view, saline soils are those, which contain sufficient soluble salts in the root zone to adversely affect the growth of most crops (ref.3).

Soil salinity can be determined by measuring the electrical conductivity of a solution extracted from a water-saturated soil paste. Therefore, the soil can be described as a saline soils if the electrical conductivity of saturation extract more than 4 dS/m at $25\,c^o$ (ref. 6).

Electrical conductivity (EC) can be defined as, the ability of a material to transmit (conduct) an electrical current; it is an indicator for the salinity in the soil. EC is commonly expressed in units of millisiemens per meter (mS/m). Soil EC measurements may also be reported in units of decisiemens per meter (dS/m)(which is equal to the reading in mS/m divided by 100) or millimhos per centimeter (mmhos/cm), (ref.7).

The EC of the soil samples adopted in this study were measured by EC sensor (model: Multiline-F/set2).Some physical properties of the studied soil samples have been also measured and calculated at Soil Science and Water Department in Agriculture and Forestry college /Mosul University. Table (1) shows the physical properties of the soil samples as well as the geographical coordinates (measured by using GPS receiver) of the each sample location.

Table (1): The measured of some physical properties of the adopted soil samples

No.of sample	Geographical coordinates	Location	Land use	EC ds/m	Particles size distribution			Texture class
					Clay	Silt	Sand	
1	ϕ=36:45:05 λ=42:09:13	Tel-Esmar Irrigation unit N8	Cereal and vegetable	**0.23**	31	29	40	C.L
2	ϕ=36:44:50 λ=42:11:59	Tel-Talab Irrigation unit F1	Cereal crop and vegetable	**0.47**	25	58	17	Si.L
3	ϕ=36:40:10 λ=42:08:48	Al-Mura, Main channel, near Irrigation unit O1	Fallow	**39.1**	31	62	27	Si.C.L
4	ϕ=36:40:24 λ=42:07:19	Al-ganah Irrigation unit N2	Fallow	**49.7**	31	34	35	C.L

Where:
   ϕ=Latitude, and λ=Longitude
 and, the (Texture class) field represented the texture type according to the USDA textural triangle chart as follow (ref.8):
   C.L= Clay Loam
    Si.L=Silty Loam
    Si.C.L=Silty Clay Loam

Measurement of Dielectric property:
   The dielectric properties of the soil are important to determine its emission characteristics. The microwave dielectric constant of the soil changes as a function of water content, in the same way the concentration of salts in the dry soil also affects its microwave dielectric properties, which in turn changes the emission (ref.9).
   In general, the dielectric permittivity (ε^*) is a characteristic quantity of a given dielectric substance, it is a complex function with real and imaginary components and is defined as (ref.1):
   $\varepsilon^* = \varepsilon' - j\varepsilon''$ ………………………….5
   where, the real part (ε') is often expressed as relative permittivity (ε_r), which is the ratio of the electric-field storage capacity to that of free space. The relative permittivity is a frequency dependent variable. The imaginary part   (ε'') of the dielectric permittivity is usually expressed in terms of dielectric losses, which include dispersive losses, as well as free-water relaxation and bound-water relaxation losses.

They have been several theoretical models and laboratory techniques, which are used to estimate the soil dielectric properties (ref.1).

In the present study, the short-circuited-waveguide technique have been adopted. The ability of this technique for measuring dielectric properties of materials at microwave frequencies is applicable to a wide range of materials and has been used extensively.

In the shorted-circuited-waveguide technique, a slotted section is used to measure the shift in minimum of a standing wave and the change in standing -wave ratio. The minima of the standing-wave pattern occur at intervals of one-half wavelength from the short circuit when the sample is absent. When the sample is inserted in the front circuit, the minima shift toward the short circuit.The principles of the dielectric properties measurements by this technique was given in detail by (ref.10, 11).

The dry soil samples were acquired manually at the depths of (2-5cm) form (Rabe'a area/Mosul). The dielectric properties of the samples were measured and calculated at the microwave frequency of (1.4GHz and 5GHz) in the Electrical Engineering Department/University of Mosul. Each soil sample is form to fit tightly into the waveguide, and the length of the sample (d=3cm) conform to the dimensions corresponding to the approximate value of dielectric constant. Table (2) listed the measured values of the real and imaginary parts of the adopted soil samples as function of operating frequencies with acceptable level of accuracy.

Table (2): The real and imaginary parts of the dielectric permittivity for the adopted soil samples as a function of frequency

Sample no.	Frequency=1.4GHz		Frequency=5GHz	
	ε'	ε''	ε'	ε''
1	4.324	0.003802	4.186	0.003583
2	4.021	0.0352	3.9785	0.0286
3	3.665	0.0227	3.4864	0.0194
4	3.792	0.0219	3.4784	0.014326

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 (ref.12):

$$\alpha = \frac{2\pi}{\lambda}\sqrt{\frac{\varepsilon'}{2}(\sqrt{1+(\frac{\varepsilon''}{\varepsilon'})^2}-1)}$$

......................(6)

Then, the penetration depth (δ) of the soil can be calculated by using the following relation:

$$\delta = \frac{1}{\alpha}$$

………………..(7)

Results and Discussion

In remote sensing science of soil, The dielectric properties of the soil is considered as an important parameter to determine the observed emissivity which is a representative temperature of the soil layer that should be used to interpret the measured brightness temperature by the passive microwave sensors on board of satellites especially at low microwave frequencies.

In this study, the variation of the soil dielectric properties were measured as a function of salt concentration in the dry soil samples. The salt concentration of each sample was measured and represented by electrical conductivity.

Figures (1and 2) shows the effect of the salinity on the real and imaginary parts of the relative dielectric constant of the adopted soil samples at the operating frequencies of 1.4 GHz and 5 GHz, respectively. As shown from figure (1), the influence of salt (represented as electrical conductivity) is manifested in the decreasing of values (ε') with increasing the electrical conductivity. For the case of non-saline soil, the values of (ε') is relatively larger than the saline soil.

Figure (2) demonstrates the variation of (ε'') with the electrical conductivity (i.e., salinity). For non-saline soil (range of 0.23-0.47ds/m) the value of (ε'') is linearly increasing, then it is deviating from its linear dependence to be decreasing with increasing salinity. Form the figure (2), it is possible to explain the decreasing behavior of the (ε'') by the high concentration of salinity without existence of water content. The absence of water content leads to state of not progressive dissolving of the soil salt and yield a decreasing in the expected value of (ε'') because the salt molecules haven't the ability to align its dipole moment along the applied field without the water content in the soil. Figures (1&2) gives a relatively high values of ($\varepsilon' and \varepsilon''$) for the frequency of 1.4GHz. Also at the two operating frequencies, the real part is much larger than the imaginary part of the relative dielectric constant.

The frequency dependence in the range up to 5GHz is little because there is only little variability in the real part of the relative dielectric constant as mentioned in (ref.3) and demonstrated in the experimental results shown in figure (1). The marked frequency dependence of the small imaginary part in this range influences only the penetration depth which is related to the attenuation coefficient by equation (7). Figure (3)

shown the variation of the attenuation coefficient with respect to the electrical conductivity according to the measured values of ($\varepsilon' and \varepsilon''$). The resulted penetration depth was illustrated in figure (4). This figure shown the frequency dependence of penetration depth, it is explain that the frequency of 1.4GHz gives higher penetration depth than 5GHz. This results is agreement with principle of the directly proportional of the penetration depth with the ($\lambda/\tan\delta$) as indicated in (ref.14) . The high penetration of the microwave signal providing access to a significant volumetric layer near the soil surface. Figures (3 and 4) shows relatively small dependence of attenuation coefficient and penetration depth on the electrical conductivity or salinity.

The microwave radiation from soil can be expressed, through the Rayleigh Jeans law, by means of an equivalent brightness temperature at both horizontal and vertical polarizations as given in equation (1). The brightness temperature is related to the physical temperature of the soil through an emissivity (equation (2)),. Figure (5) shows the variation of the emissivity at the two polarizations (horizontal and vertical) with respect to the electrical conductivity at the two operating frequencies. Emissivity takes into account the part of emission reflected at the soil surface, therefore it is strongly dependent on the dielectric properties of the soil. In the vertical polarization, the values of emissivity for the two frequencies is larger than that of the horizontal polarization.

Figure (6) demonstrates the dependence of the brightness temperatures of soil samples on the salinity. As follows from a figure (6), the variation of brightness temperature with the salinity of the dry soil is relatively have similar shape at the horizontal and vertical polarization at the two frequencies. It is connected that on the non- moisture soil, the salts present in soil are in the not dissolved condition. The resulted datasets shows approximately linear increasing in brightness temperature with increasing electrical conductivity (i.e., increasing salinity) at the dual polarized microwave signal of the frequencies of 1.4GHz and 5GHz.

The brightness temperature at 1.4GHz is lower than the observed brightness temperature at 5GHz. This is due to the relatively high values of dielectric constant at this frequency. These results are in agreement with those obtained by (ref.13) It is connected that on the non- moisture soil, the salts present in soil are in the not dissolved condition.

Figure (6) indicates that the vertical polarization response of the brightness temperature with the electrical conductivity is larger than the horizontal polarization for the two operating frequencies. This result is confirmed with the related researches dealing with applied of microwave radiometric techniques for detecting moisture content and salinity of the soil (ref.3,2).

Finally, the study of the relation between electrical conductivity and brightness temperature is a useful and inexpensive tool in remotely sensed data with a suitable geographical information system(GIS) that precision farmers can use to quickly and accurately characterize soil difference within crop production fields.
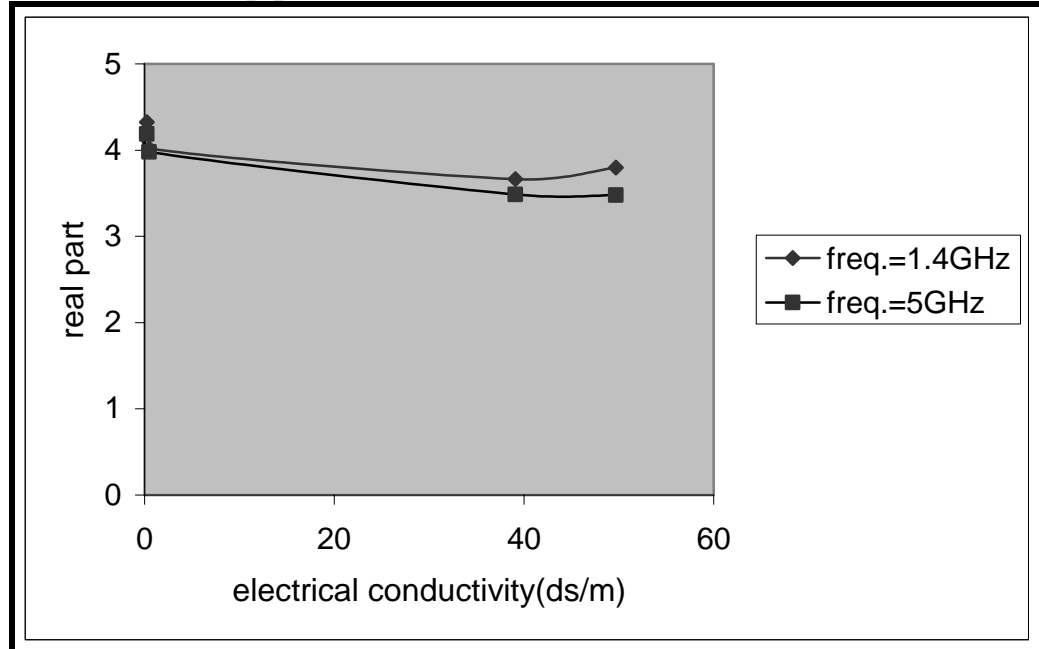

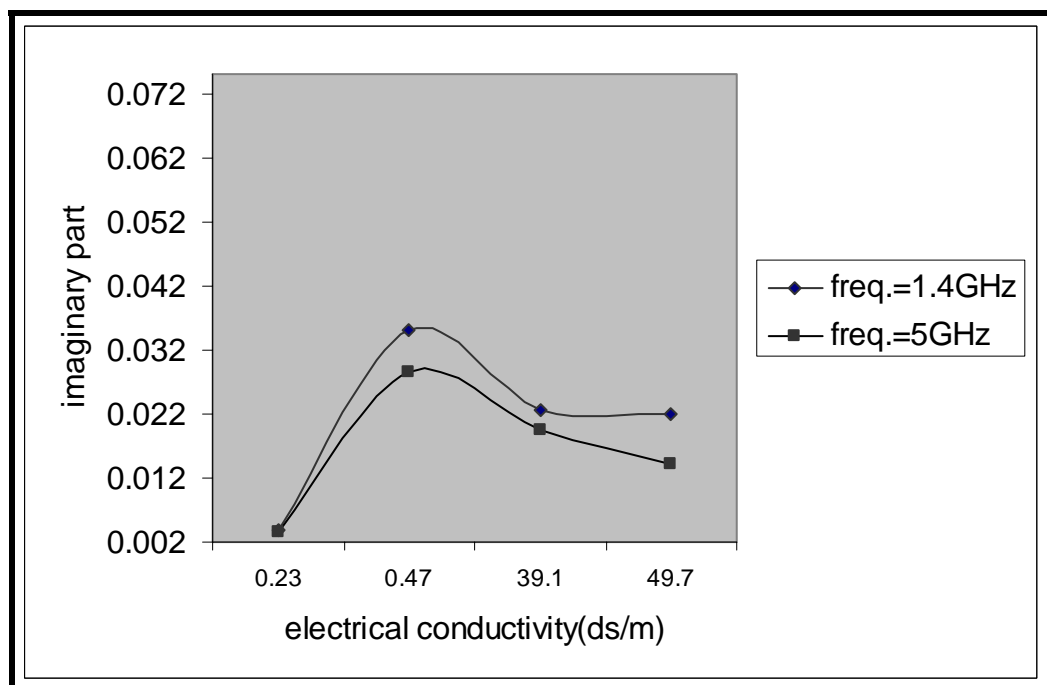Figure (1): effect of salinity on the real part of the relative dielectric constant at frequency of 1.4GHz and 5GHz

Figure (2): effect of salinity on the imaginary part of the relative dielectric constant at frequency of 1.4GHz and 5GHz
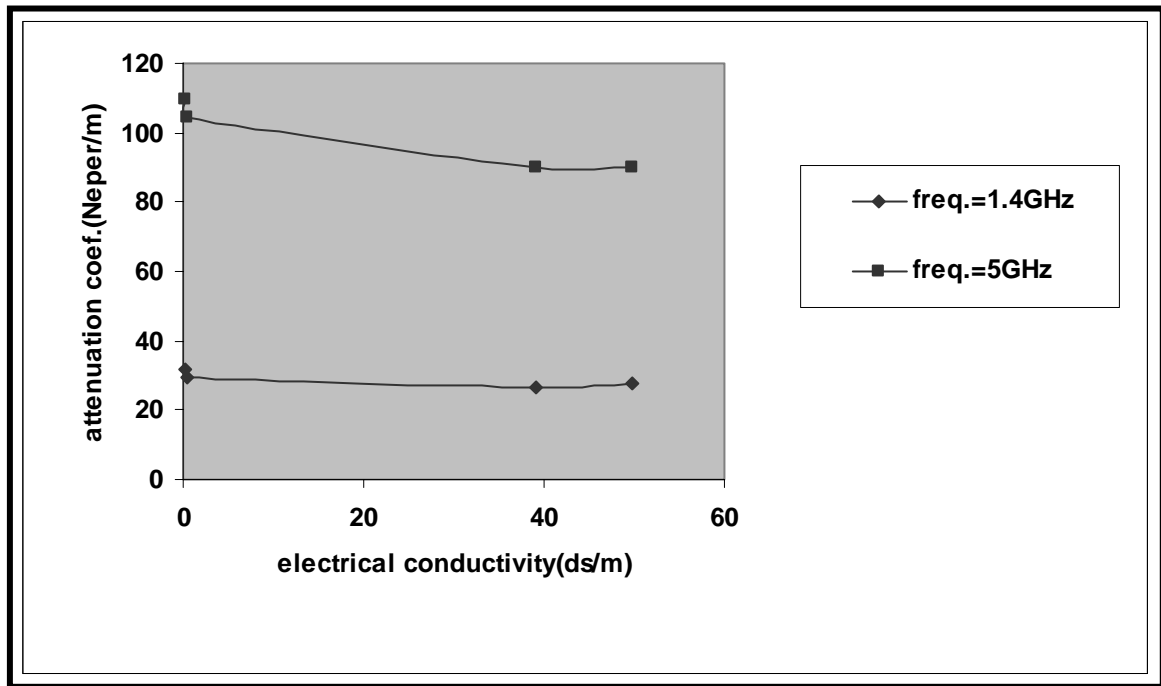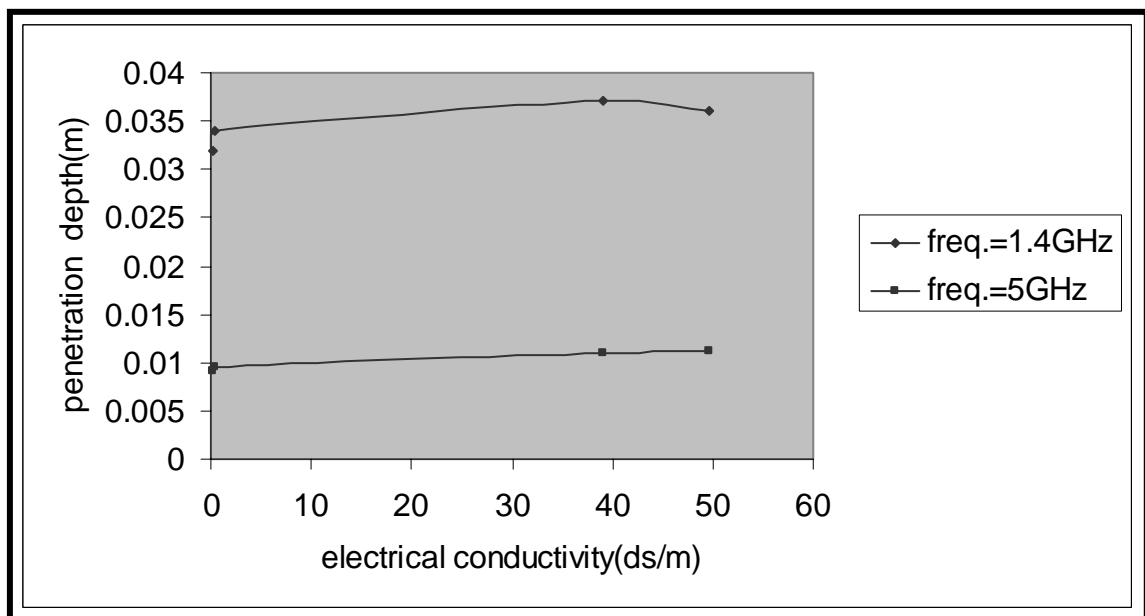
Figure (3): variation of attenuation coefficient with respect to
electrical conductivity at 1.4GHz and 5GHz

Figure (4): variation of penetration depth with respect to electrical
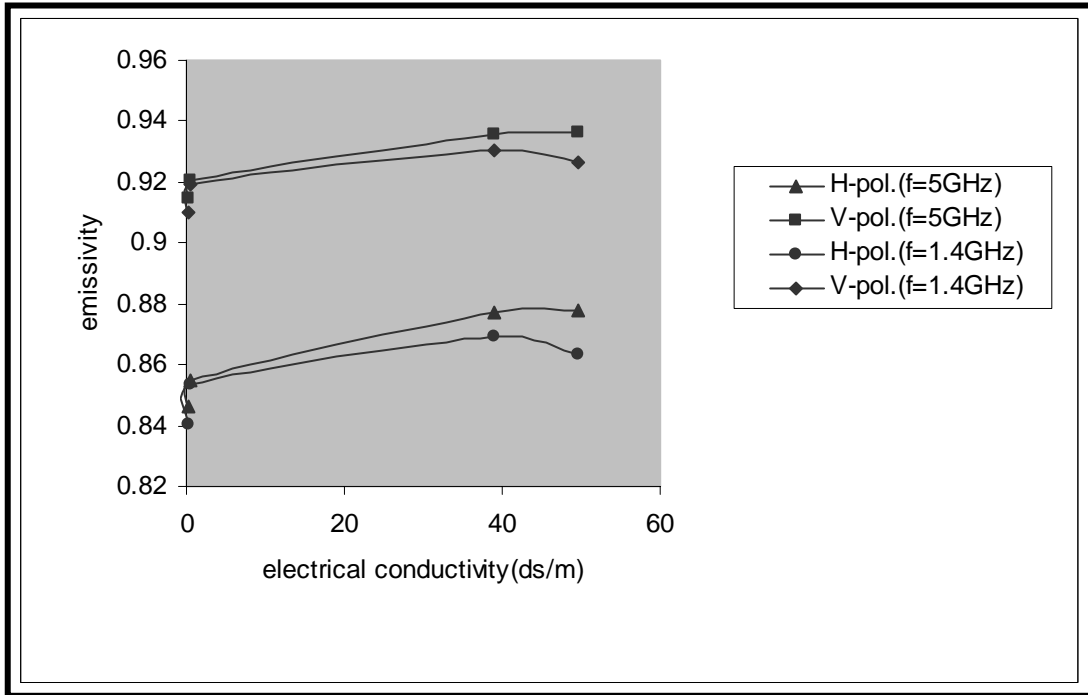

conductivity at 1.4GHz and 5GHz

Figure (5): comparison of horizontal and vertical polarized emissivity
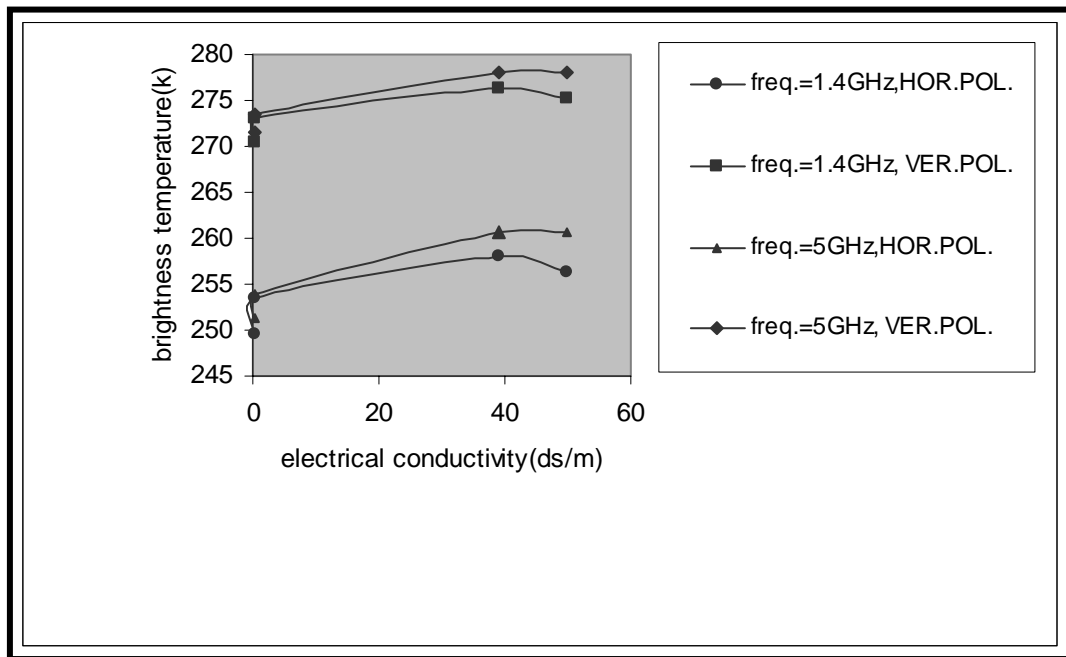variation as a function of electrical conductivity

Figure (6): comparison of horizontal and vertical polarized brightness
temperature variation as a function of electrical conductivity

Conclusions

In the an outcome of conducted research the following are conclude:

1- The variation of the electrical properties of the soil samples with respect to salinity are relatively similar in shape for both 1.4GHz and 5GHz.
2- The microwave frequency of 1.4GHz gives a better penetration depth for the soil surface.
3- The vertical polarized microwave signals gives a significant results for the soil emission characteristics of the soil surface.

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