Salinity Effect on The Microwave Backscattering of The Calm Water Surface

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الخلاصة

يقدم هذا البحث نتائج مختبرية لقياسات التشتت الخلفي (backscatter) لموجات المايكرويف المرتدة من سطح ماء هادئ (خالي من التموجات) بنسب ملوحة مختلفة وعند درجة حرارة (19,7م°).

تم إجراء القياسات باستخدام منظومة قياس مختبرية تعمل بتردد (10كيكاهرتز/موجة مستمرة) كدالة لزاوية السقوط و حالة استقطاب الهوائي المستخدم. أظهرت النتائج أن تأثير الملوحة على الإشارة المرتدة من سطح الماء عند التردد (10كيكاهرتز) يكون قليل جدا. كذلك أظهرت النتائج أن قياسات الاستقطاب العمودي تكون نوعا ما أفضل مقارنة مع نتائج الاستقطاب الأفقي.

كما تم إجراء قياسات نظرية لحساب عمق الاختراق لموجات المايكرويف بالاعتماد على خواص العزل للماء المستخدم.

ABSTRACT

The present paper illustrates the experimental results of the salinity affecting the backscattering signal from the calm water surface at an actual temperature of (19.7c°).

The measurements were performed as a function of incident angle and antenna polarization by utilizing a specially designed and constructed laboratory measuring set-up operating at frequency of (10GHz/CW-mode).

The experimental results shows that the effect of water salinity on the backscattered signal from calm water surface (i.e., no roughness surface) was insignificant at microwave frequency of (10GHz), and the vertical polarization has been found to be relatively better as compared to the horizontal polarization.

Theoretical calculations of skin depth of the adopted saline water were also carried out depending on the complex dielectric constant of water.

INTRODUCTION

In more than twenty years, microwave remote sensing techniques have provided unexpected insights in the earth surface structure and processes, and triggered the development of entirely new research fields (1).

Experimental studies of the microwave backscattered cross-section of sea water surface at X-band have been studied by (2, 3), these studies demonstrated the feasibility of measuring sea surface conditions by using microwave systems.

The radar backscattered cross-section of the sea surface dependent on many parameters including incident angle, microwave frequency, transmit and receive polarization, wind direction, salinity of the water, water temperature, and other factors (4).

This paper presents the theoretical calculation of complex dielectric constant of saline water and the laboratory experimental results obtained by measuring the backscattered power (then normalized backscattered cross-section) from a water surface at different parameters (salinity, antenna polarization, and incident angle) at actual water temperature of (19.7c) in attempt to complement efforts published in (5,6), by utilizing a specially designed and constructed laboratory scaterometer set-up operating at frequency of 10 GHz (CW-mode) under acceptable level of accuracy.

Laboratory microwave scatterometer set-up

Microwave scatterometers are radar devices capable of measuring radar backscattering cross-section, it is a special purpose radar device which is used to quantitatively measure only the target reflectance or scattering cross-section (7). It is simpler than conventional radar mechanism because range and velocity measurements capability and the high special resolution requirements are eliminated.

In remote sensing studies the knowledge of backscattering cross-section is considered to be very important (8).

Figure (1) shows the laboratory simulating model (i.e.; microwave scatterometer system) used in this study. (9) adopted this system.

The transmitting and receiving horn antennas have been mounted side by side on specially designed metallic arcs.

The transmitted signal of (10mW/CW-mode) at frequency of (10GHz) was fed directly to the transmitting horn antenna of gain (17.51dB). This power was monitored to be constant throughout the measurement.

The receiving horn antenna of gain (17.51dB) picked up the backscatter power from the water surface, then the receiving signal was processed to produce an indication of backscattered power.

The incident angle was varied (20-60 degree) taking into account the practical limited inherited in the measuring set-up.

The tank used in this laboratory model was made of wood with dimension of (135cm*45cm*15cm) this tank was filled with (81liters) of tap water. The chemically pure sodium chloride was mixed in the water and the water was stirred to conform with a homogeneous saline water solution of approximately 20ppt, and 35ppt respectively. These values of salinity were adopted for this study at actual water temperature of (19.7c°).

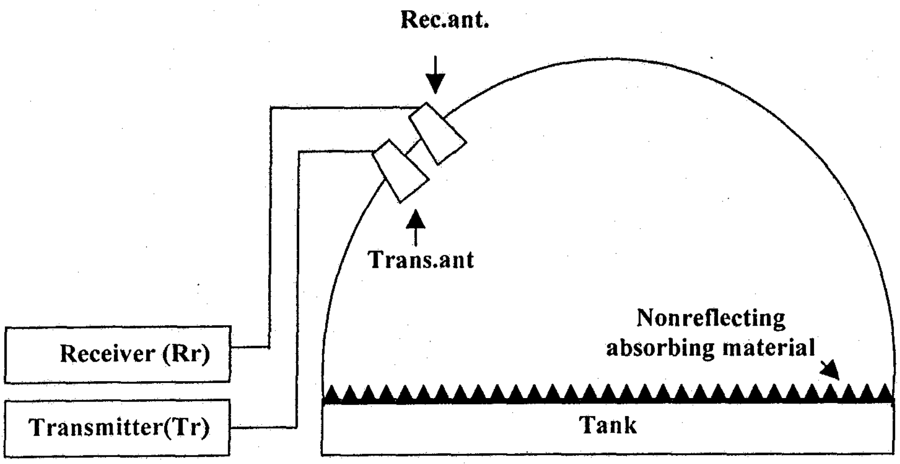

Figure (1): The schematic diagram of the set-up used in this study

Calculation of complex dielectric constant of saline water

The complex dielectric constant is an important parameter in the interaction of microwave radiation with water surface.

Because of not availability of the instruments that can measured the complex dielectric constant of saline precisely at the microwave frequency, the present study depend on mathematical model that used in such research where salinity and water temperature are varied.

The variation of dielectric properties of pure water with frequency and temperature can be represented to a close approximation by the equations (8):

$$\epsilon'_{pw} = \epsilon_{w\infty} + \frac{\epsilon_{w0} - \epsilon_{w0}}{1 + (2\pi f \tau_w)^2} \quad \text{.....................(1a)}$$

.......................(1b)

In the case of a solution of an electrolyte such as sodium chloride in water, the dielectric properties appropriate to the pure solvent at a given temperature and frequency are modified by an amount depending on the concentration of the electrolyte.

The precise nature and extent of this modification has been investigated by various workers from time to time (10,11)

An adopted model used in this research was given by (12), expression for real and imaginary parts of the dielectric constant described in this model was drived from the Deby equation and appeared to be the same of the pure water but the ionic conductivity part must be added to the imaginary part, i.e.:

$$\in'_{pw} = \in_{w\infty} + \frac{\in_{w0} - \in_{w0}}{1+(2\pi f \tau_w)^2} \qquad \text{......................(2a)}$$

$$\in''_{pw} = \frac{2\pi f \tau w(\in_{w0} - \in_{w\infty})}{1+(2\pi f \tau_w)^2} + \frac{\sigma_i}{2\pi f \varepsilon_0} \qquad \text{......................(2b)}$$

where ;

the absolute permitivity (ε_0)=8.85*10^{-12} F/m

f is the frequency in(Hz)

$\in_{w\infty} = 4.9$

The static dielectric ($\in_0$), the relaxation time (τ_w), and the ionic conductivity (σ_i) of water can be expressed in term of salinity(S_w)and water temperature (T) as the following combinations (Ref.8) :

$$\left.\begin{array}{l} \in_{w0} = \in_{w0}^{(p)}(T)A(T,S_w) \\ \tau_w = \tau_w^{(p)}(T)B(T,S_w) \\ \sigma_i = \sigma_i^{(s)}(S)e^{-\phi(T,S_w)} \end{array}\right\} \qquad \text{..........................(3)}$$

where ($\in_{w0}$) and (τ_w) represent static dielectric constant and the relaxation time of pure water respectively, (σ_i) is the ionic conductivity of saline water at ($25 c^o$), *A*,*B*, and ϕ are some empirical function of S_w and *T*.

The parameters in equation (3) are represented as the following polynomials:

$$\left\{\begin{array}{l} \in_{w0}^{(p)}(T) = 87.134 - 1.949*10^{-1}T - 1.276*10^{-2}T^2 + 2.491*10^{-4}T^3 \\ A(T,S_w) = 1.0 + 1.613*10^{-5}T*S_w - 3.656*10^{-3}S_w + 3.21*10^{-5}*S_w^2 - 4.232*10^{-7}*S_w \\ \tau_w^{(p)}(T) = \frac{1}{2\pi}(1.111*10^{-10} - 3.824*10^{-12}T + 6.938*10^{-14}T^2 - 5.096*10^{-16}T^3) \\ B(T,S_w) = 1.0 + 2.282*10^{-5}T*S_w - 7.638*10^{-4}S_w - 7.76*10^{-6}S_w + 1.105*10^{-8}S_w^3 \\ \sigma_i^{(s)}(S) = 0.1825S_w - 1.4619*10^{-3}S_w^2 + 2.093*10^{-5}S_w^3 - 1.282*10^{-7}S_w^4 \\ \phi(T,S_w) = 2.033*10^{-2}T_\Delta + 1.266*10^{-4}T_\Delta^2 + 2.464*10^{-6}T_\Delta^3 - 1.849*10^{-5}T_\Delta \\ +2.551*10^{-7}T_\Delta^2*S_w + 2.551*10^{-8}T_\Delta^3 S_w \end{array}\right. \qquad (4$$

where :

T_Δ=25-T

S_w and T are expressed in parts per thousand on a weight basis and degree of C respectively.

The above models are valid under the following conditions:

$$4 \langle S_w \langle 35\text{‰}$$

and,

$$0 \leq T \leq 40^0 C$$

Microwave backscattered cross-section measurement

The scattered power (Pr) from the water surface in the tank was measured as a function of scatterometer incident angle, then the normalized backscattering cross-section was calculated by using the familiar radar equation (Ref.13,14):

$/(4\pi)^2 R^4 \lambda^2 \Pr / Pt = G^2)^* \sigma$ ....(5)

where:

$Pt =$ transmitted power(mw)
$G =$ antenna gain(dB)
$\lambda =$ wavelength(m)
$R =$ range(m)
$\sigma =$ radar cross-section(dB)

The normalized backscattered cross-section, σ^o, is given by:

$\sigma^o = (4\pi^2 R^2 V_B^2 Cos\theta / \lambda^2) * \Pr / Pt$ ....(6)

after making the substitutions,

$\sigma = \sigma^o * A$ ....(7)

and,

$G = 4 / V_B^2$ ....(8)

where ;

$A =$ illuminated area $(2\pi R^2)$
$V_B^2 =$ antenna 3dB beam width
$\theta =$ incident angle

This approximation to the antenna gain is a result of considering the gain function to be unity within the (3dB) points and zero elsewhere (9).

The attenuation of the saline water can be calculated in practical units of decibels per meter from the values of ($\in'$) and ($\in''$) directly by using the following equation (8):

Attenuation in Np/m $(2\pi k / \lambda\ \alpha) =$ ....(9)

where:

$\lambda =$ is the wavelength in meter.
$k =$ is the absorption coefficient for the saline water, given by:

$$2k^2 = (\epsilon'^2 + \epsilon''^2)^{1/2} - \epsilon' \quad \text{..............................}(10)$$

Then, the related quantity of interest in remote sensing, skin depth (δ) can be calculated from the following relation:

$$\delta = 1/\alpha \quad \text{(in meter)} \quad \text{...}(11)$$

Table (1) shows the theoretically computed (ϵ') and (ϵ'') by using the formulae (1,2,3, and 4) as well as the skin depth results (using equations 9,10, and 11) at the adopted salinity values in this study.

Table (1): The complex dielectric constant and the skin depth at water temperature of ($19.7c^o$) and the salinity values adopted in this study

Water type	**Real part (ϵ')**	**Imaginary part(ϵ'')**	**Salinity(ppt)**	**Skin depth(m)**
Fresh water	**60.8830**	**32.9305**	**0.04**	**0.1559**
Saline water	**57.7243**	**37.2151**	**20**	**0.1360**
Saline water	**55.7038**	**39.8962**	**35**	**0.1260**

RESULT AND DISCUSSION

In remote sensing studies, knowledge of the backscattered cross-section in the radar imaging is considered to be very important particularly in active remote sensing case. This parameter is one of widely used cases in developing inversion models which are helpful for interpreting remote sensing data obtained by air-borne, satellite borne, and ground base sensors.

Therefore, laboratory studies in this field should be continue to aim for developing microwave remote sensing techniques through defining the effect of one or more variable selected at a time under controlled conditions.

However, the backscattered cross-section and skin depth data of the calm water surface obtained by this study was calculated using the formulae (6,9,10, and 11).

The dependence of the normalized backscattered cross-section (σ° in dB) on the incident angle for fresh water(salinity of 0.04ppt) and saline water of (20 and 35ppt) was shown in figures(2,3, and 4).These figures explain that (σ°) from the water with different concentration of salinity follow the same pattren.It can be seen from figures that (σ°) decrease steadily with increasing incident angle for the horizontal and vertical polarization.

Vertical polarization measurement shows a significant different from the horizontal for the three figures, the difference was varies from (-1.62 dB) at (30 deg.) to (-8.40 dB) at (60 deg.).

The laboratory measurement of the backscattered signal from the calm water surface was compared with the figure (5) given by (Ref.15) for the smooth water surface. This figure demonstrates that the incident angle plays a crucial role in backscattering, for small angle less than 20 deg., specular reflection facets dominate the reflecting signal. In the case of incident angle between 20 and 70 deg., the dominating mechanism of the reflected signal is the Bragg scattering.

Bragg scattering is a mechanism in which the reflected signal is in resonance with the incident wave.

Also, it can be noted from the figures (2,3, and 4) that the salinity variation have insignificant influence on the microwave backscattered at any incident angle, this is due to the fact that at microwave frequencies the complex dielectric constant and conductivity (caused by a lateral flow of ions) for the saline water are slightly depends on the change in salinity as shown in table (1).

Figure (6) shows the theoretically relation between the salinity of water adopted in this study and the skin depth (penetration level).

The skin depth likes to be very small due to the fact that the effect of salinity on the penetration of microwave signal at (10GHz) is minimum.

The longer the wavelength of a signal, the deeper the signal penetrates the material (8,15).

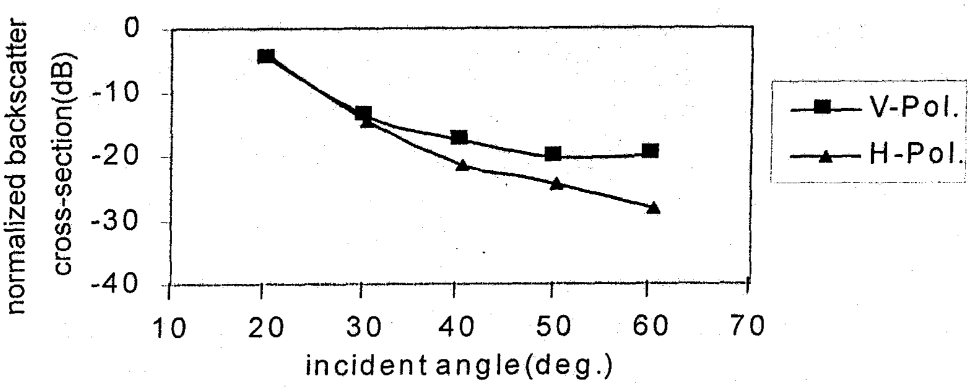

Figure 2: Normalized backscatter cross – section as a function of incident angle for a fresh water (0.04 ppt) at water temperature of (19.7c)

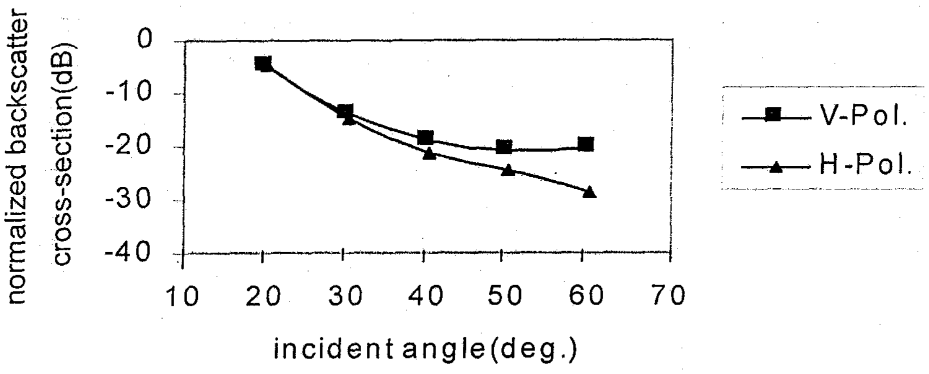

Figure 3: Normalized backscatter cross – section as a function of incident angle for a water salinity of (20 ppt) at water temperature of (19.7c)

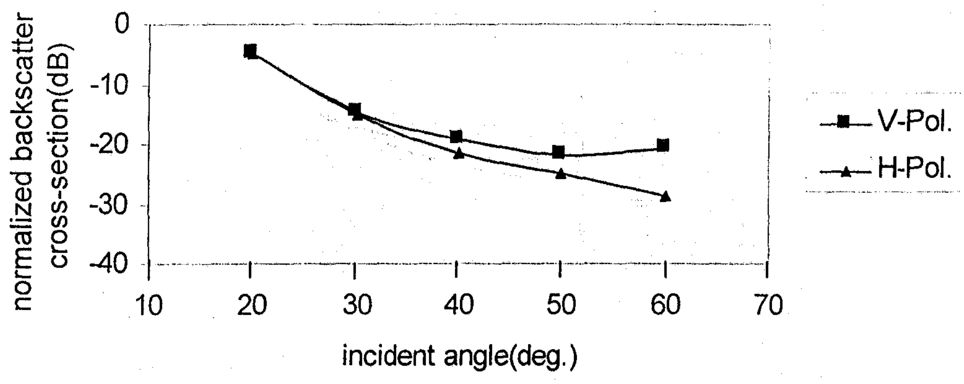

Figure 4: Normalized backscatter cross – section as a function of incident angle for a water salinity of (35 ppt) at water temperature of (19.7c)

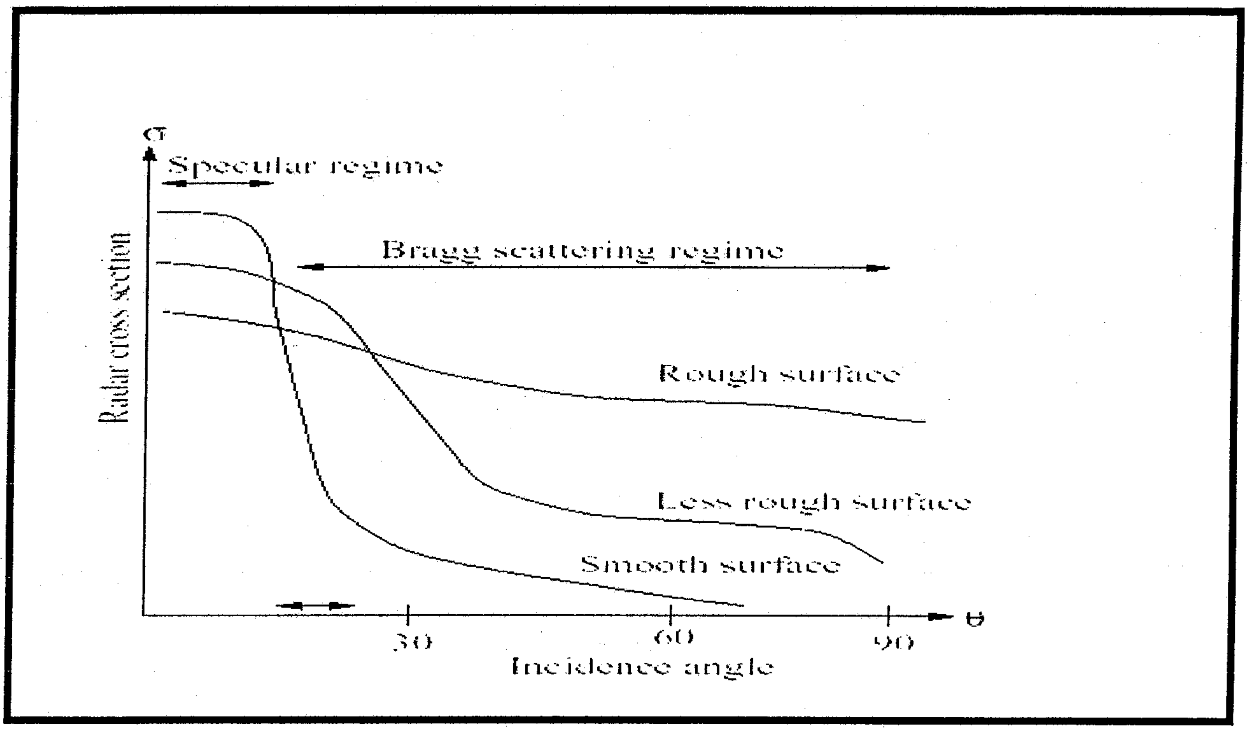

Figure (5) : Backscatter as a function of incidence angle and roughness (Ref. 15)

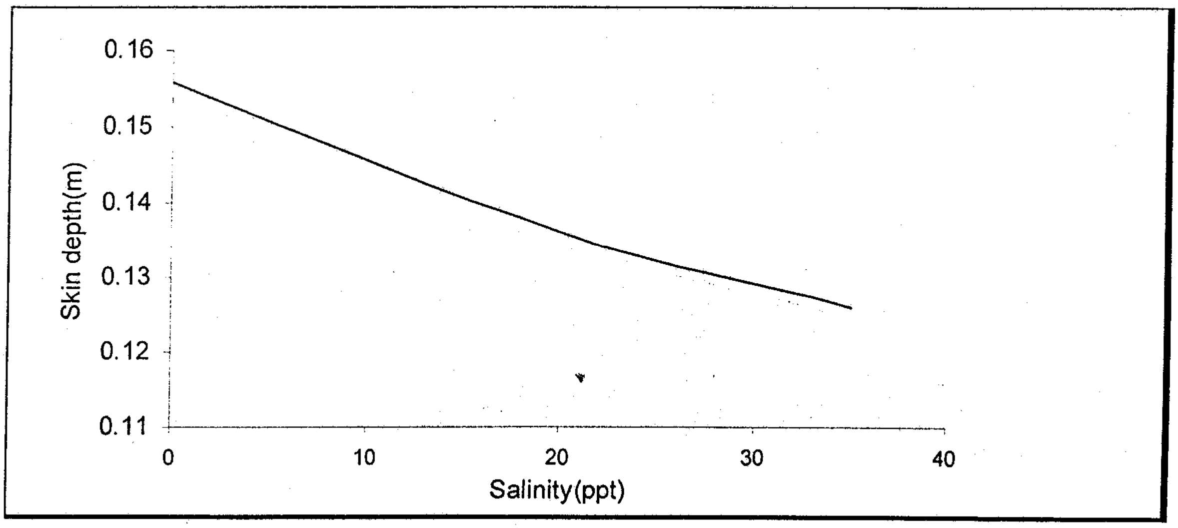

Figure (6): Theoretical variation of skin depth with salinity adopted for the study at water temperature of (19.7c)

CONCLUSIONS

Since this experiment was conducted as prerequisite for study the effect of salinity on the backscattered signal from the sea water, therefore it my be concluded here that the changing of the salinity of the calm (nearly smooth) water surface has minimal influence on the results, i.e., it is possible to substitute sea water with fresh water in processes of theoretical research or experiments.

The effective property that my be give high backscattered signal is rough surface water.

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