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Passive Remote Sensing of Thin and Thick Components of Vegetation

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ABSTRACT

Electromagnetic (EM) waves can be used for constructing the EM model and analyzing the influence of various parameters. The outcome of the analysis can be useful as input to many remote sensing forecasting models. The present study is investigating the emissivity of thin and thick components of vegetation. The investigated terrain, which consists of leaves and branches is considered thin and thick bodies. The mathematical equations are constructed for, absorption cross-sections and emissivity. Then, by using this equation and already driven relations between relevant electromagnetic parameters of thin and thick are compared. Further, the dependency between the aforementioned parameters in emissivity modeling is examined. A comparison of our results with the literature has a good agreement.

Keywords: Electromagnetic (EM), Emissivity, Mathematical Modelling, Remote Sensing, Vegetation.

1. INTRODUCTION

The EM models in remote sensing are important in that they provide insight for authorities enabling them to take precautionary actions. [1] Additionally, the type and the relative orientation of the scatters in the layer play an important role. For example, the vegetation layer is modeled by a collection of randomly oriented leaves and branches over a flat loss ground in the discrete method. In this study. The leaves and branches gave as azimuthally symmetric with respect to the layer normal. The branches are modeled by circular dielectric rods with finite lengths and the leaves are taken as flat circular dielectric discs. The complication of studying each type of vegetation lead scientists to make rough estimates of the parameters of interest, via active and passive remote sensing. In this way, the cost of data acquisition and processing is minimized [1-5].

Our work is studying active and passive remote sensing modeling to obtain a formula relating two important parameters emissivity of thin and thick components of vegetation. We especially work with thin and thick dielectric bodies, which differentiates our research from the previous ones in the literature. Our work, allows us to model forests more easily and accurately since they can work with discrete modeling just direct conversion from the continuous model, avoiding the complex calculations.

2. MATHEMATICAL FORMULATION

2.1 Scattering Amplitudes

At first, the basic scattering amplitude formulation of thin dielectric bodies, our main formula given as [3]:

$$f(O^o, i^o, q) = A^* V_p^* q \quad (1)$$

Where 1) $A = \frac{k_0^2 \Delta}{4 \cdot \pi}$

$$V_p = \frac{4\pi b}{k_0 v_x v_y} \sin\left(\frac{k_0 2 c v_z}{2}\right) \times \sum_{n=0}^{\infty} (-1)^n \left(\frac{k_0 b^2 v_y^2}{a v_x}\right)^n J_{n+1}(k_0 a v_x) \quad (2)$$

$$q = (I - O^o O^o) \cdot [K_2 q^o + (K_3 - K_2)(q^o \cdot r^0) r^0] \quad (3)$$

The parameters in equations, 1-3 are given in [2-3]. We can find specific solutions for disc, rod, and sphere by taking appropriate K values.

The averaged forward scattering amplitudes for disc are,

$$\bar{f}_{hh} = V_p \frac{{k_0}^2 \Delta E_{0h}}{8\pi} \left[1 + I_2 + \frac{I_1}{\varepsilon_r}\right] \quad (4)$$

$$\bar{f}_{vv} = V_p \frac{{k_0}^2 \Delta E_{0v}}{8\pi} \left[(\cos\theta_0)^2 \left(1 + I_2 + \frac{I_1}{\varepsilon_r}\right) + 2(\sin\theta_0)^2 \left(I_1 + \frac{I_2}{\varepsilon_r}\right)\right] \quad (5)$$

where

$I_1 = \int_0^{\pi} d\theta\, (\sin\theta)^2 p_\theta(\theta)$ and

$I_2 = \int_0^{\pi} d\theta\, (\cos\theta)^2 p_\theta(\theta)$, $p_\theta(\theta)$ being the probability distribution. For the special case

$\theta_0 = 0$ and $\theta = \frac{\pi}{2}$ then $I_1 = 1;\ I_2 = 0;\ \beta = V_p \frac{{k_0}^2 \Delta}{4\pi}$

$$\bar{f}_{hh} == \frac{\beta E_{0h}}{2}\left[\frac{1+\varepsilon_r}{\varepsilon_r}\right] \qquad \bar{f}_{vv} = \frac{\beta E_{0v}}{2}\left[\frac{1+\varepsilon_r}{\varepsilon_r}\right] \quad (6)$$

which is same as Le Vine's result. [6]. We assume uniform probability distribution and let it take $\frac{1}{2\pi}$ value.

After similar calculations for the rod, the following averaged forward scattering amplitudes are obtained:

$$\bar{f}_{hh\Phi} = \left(\frac{{k_0}^2}{4\pi}\right) \Delta V_p \left(\frac{2}{\varepsilon + 1}\right) \left[1 + \frac{\Delta}{4} (\sin\theta)^2\right] \quad (7)$$

$$\bar{f}_{vv\Phi} = \left(\frac{{k_0}^2}{4\pi}\right) \Delta V_p \left(\frac{2}{\varepsilon+1}\right) \left[1 + \frac{\Delta}{4}((\sin\theta)^2 (\cos\theta_0)^2 + 2(\sin\theta_0)^2 (\cos\theta)^2\right] \quad (8)$$

2.2 Absorption Cross Section of Thin Components of Vegetation

Horizontal absorption cross section is using the definition [7-9]

$$\sigma_a^{(h)} = \frac{k * \varepsilon_r'' * V}{|1 + L_1 * \Delta|^2} \quad (9)$$

Vertical absorption cross section is (10)

$$\sigma_a^{(v)} = (k * \varepsilon_r'' * V) * \left(\frac{(\cos\theta_0)^2}{|1 + L_2 * \Delta|^2} + \frac{(\sin\theta_0)^2}{|1 + L_3 * \Delta|^2}\right)$$

The special case where the incident wave comes perpendicular $\theta_0 = 0$; the vertical and horizontal absorption cross sections become equal, i.e.

$$\sigma_a^{(h)} = \sigma_a^{(v)} = \frac{k * \varepsilon_r'' * V}{|1 + L_1 * \Delta|^2}$$

Furtherer calculations can be made for discs and cylinders:

1) For discs:

$$\sigma_a^{(h)} = k * \varepsilon_r'' * V \ (11)$$

$$\sigma_a^{(v)} = k * \varepsilon_r'' * V * \left((\cos\theta_0)^2 + \frac{(\sin\theta_0)^2}{{\varepsilon_r}^2}\right) (12)$$

2) For cylinders:

$$\sigma_a^{(h)} = k * \varepsilon_r'' * V * \frac{4}{|\varepsilon_r + 1|^2}$$

$$\sigma_a^{(v)} = k * \varepsilon_r'' * V * \left(\frac{4 * (\cos\theta_0)^2}{|\varepsilon_r + 1|^2} + (\sin\theta_0)^2\right) (13)$$

2.3 Backscattering Coefficients Discrete and Continuous Modelling

The q polarized discrete backscattering coefficient is [1-2].

$$\sigma^0_{qqd} = \rho \sigma_{qqd}\, u \ (14)$$

where

$$u = (1 - \exp(-4 \mathrm{Im}(k_q d)))/4 \mathrm{Im}(k_q)$$

(u=d for Half Space)

$$k_q = k_0 \cos\theta_0 + 2\pi\rho f_{qq,avg} / k_0 \cos\theta_0$$

k_0 is the free wave number. $f_{qq,avg}$ and θ_0 are the averaged forward scattering amplitudes for like polarization q and incidence angle respectively. d is the vertical distance between the vegetation boundaries. ρ is the number of densities in the layer.

The continuous backscattering coefficient for like polarization return is

$$\sigma_{\beta\beta}(\theta) = \gamma_0 \cos\theta(1-e^{-2\ K_e d \sec\theta})/2 \qquad (15)$$

where γ_0 is a constant independent of incident and scattering angles [4]. K_e is the extinction coefficient which is same as the absorption cross section. d is the same distance of layer.

2.4 Emissivity

The emissivity of the surface of a material refers to the effectiveness of the surface in emitting energy as thermal radiation. In another words, it is the electromagnetic radiation with wavelength depending on the temperature.

From the energy conservation relation, the emissivity of the vegetation component formula is [7,8]

$$e_q(\theta) = 1 - R_q(\theta) - T_q(\theta) \qquad (16)$$

According to the average scattering patterns of randomly oriented cylinders and discs, if the cylinder dimensions are larger than the wavelength, the bistatic scattering cross sections are peaked in the forward direction. Thus, some approximations and assumptions can be made based on these average scattering patterns that show a forward behavior to avoid the calculation complexity arising from the integrals in the formulas above. For the upcoming formulas cylinders are assumed to behave like absorbers. The resulting transmission function equation for the approximate absorbing object is [7,8].

$$T_q^A(\theta) = e^{-\frac{n\Delta z\sigma_a^q(\theta)}{\cos\theta}} \quad (17)$$

Since the scattered is taken as an absorbing object,

$$R_q(\theta) \ll T_q(\theta)$$

$$T_q(\theta) \approx T_q^A(\theta)$$

By using these approximations, emissivity of vegetation in Eq. 22 it can be simply written as

$$e_q(\theta) = 1 - T_q^A(\theta) \quad (18)$$

The emissivity at angle θ is the following simple approximate relation between the backscattering coefficient and passive emissivity experimental measurements for half-space obtained [8];

$$\sigma_{\beta\beta}(\theta) = \frac{\left(1-e_\beta(\theta)\right)*\cos\theta}{1-(\cos\theta)*\ln(1+\sec\theta)} \quad (19)$$

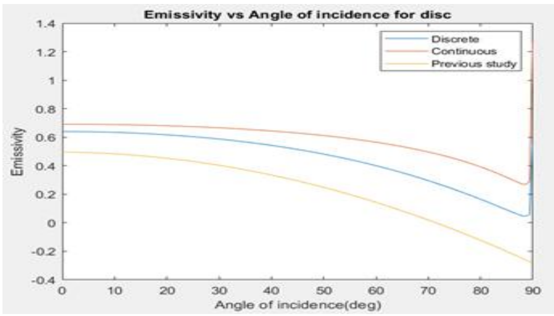
By rearranging the terms, we obtain the emissivity formula in terms of backscattering coefficient.

3. SIMULATIONS

3.1 Simulations of emissivity of thin components of vegetation

The behavior of emissivity of disc and the increasing trend of emissivity of rod with respect to angle of incidence is observed in both models. The difference in the positions of disc and rod plots of discrete and continuous model arise from our probability distribution assumption, since normally the probability function constant as 1/2pi throughout our simulations was assumed.

In Figure 1 and 2, the simulation results are compared with the plot for emissivity at different angle of incidence of corn leaf with 16% moisture for vertical polarization. [10-11] The plots are similar in behavior. The difference between my output and literature result is due to the different dielectric constant i.e., type and moisture level of leaf here [1]



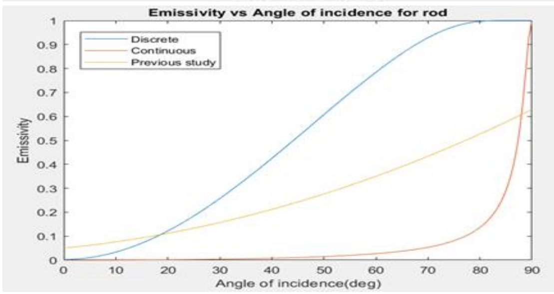


Fig 1 and Fig 2: The simulation results are compared with the emissivity at different angle of incidence of leaf and rod

The upward plots are similar except the differences that is due to the size and probability distribution differences. The relation of backscattering cross section and emissivity for discrete and continuous model given below by eqs.15. For half space when $d \to \infty$ we can expand eq.15 as sing $e^x = 1 + x + \ldots$ then obtain $u = d$. Hence Backscattering coefficient become $\sigma = \rho\sigma_{RCS}d$. again expanding eq.19 exponential term in series then $\sigma = \gamma_0 K_e d$ is obtained. Therefore, two backscattering coefficients are the same if

$$\gamma_0 K_e = \rho\sigma_{RCS} \quad (20)$$

The emissivity in terms of backscattering of half space is given by eq. 19. From eq. 19 emissivity is function of backscattering cross section as $e_p = 1 - \alpha\sigma_{pp}$ with $\alpha = \frac{1-cos\theta \ln(1+sec\theta)}{cos\theta}$, $\alpha_{max} = 0.31$ when incidence angle $\theta = 0$ (perpendicular incidence).

3.2 Emissivity Simulations of the Thick Components of Vegetation

EM radiation that is emitted by the object carries specific properties about the object. The effect of the object is investigated, and some unique properties are obtained. In literature, remote sensing of vegetation includes different methods that are based on measurements with active and passive remote sensing. In this work, vegetation components are considered separately that leaves are modelled as thick dielectric disks and branches and trunks are modelled as cylinders or the first time in the literature. Emissivity and absorption cross section equations of geometrically facilitated vegetation are found out using two approximations. Emissivity for leaves is calculated using physical optics approximation on disk. In branches and trunks, infinite length approximation is applied on a thick cylinder. To check the accuracy of calculations, absorption cross section calculation results are compared with literature studies, and good agreement is found. The last emissivity of human is simulated, and the effects of each parameter are examined.

Dielectric thick bodies can exhibit different behaviors against the radiation depending on the wavelength. Therefore, different wavelengths provide the detection of different properties of the target object. Different from the emissivity calculation from the measured power, in this work, the emissivity of the object is calculated reversely like calculation from the object using its absorption cross section. Estimation of the emissivity before the measurements allows the prediction of the specification of the object and its content [8,10,11]. In this section, the vegetation component is modelled as discs and cylinders e.g., disk model is used for modelling vegetation leaves and cylinder geometry is utilized for branches and trunks. Physical optics and infinite length approximations are used for the derivation of the absorption cross sections. Absorption cross section derivation is one of the key points to define emissivity. The emissivity of the defined vegetation components is simulated with changing different parameters account in real life. The emissivity of vegetation is simulated for different conditions to provide applicable useful model results.

Emissivity and back scattering evaluations of vegetation require a model that relates these characteristics with definable structures in theory. Vegetation components are leaves, branches, and trunks; that is considered as absorbing and scattering objects. Leaves of the vegetation are modeled as a thin and thick layer of disk shape with complex permittivity. The cylindrical shape is taken for branches and trunks.

3.2.1 Modelling of Leaves as Thick Disks

Leaves of vegetation are modelled as disks. Physical optics (PO) approximation is proper to be employed at this step of the calculation since the cross section of the disk is large compared with the wavelength. A large cross section with respect to wavelength and thickness provides the advantage of non-effective edges on the field. In PO approximation, it is assumed that if the disc axes are large with respect to the wavelength of the incident wave. The principle behind the approximation is to replace the unknown fielded object to a specific solvable object and then to use resulting field description in the object to obtain absorption cross section. Absorption cross section of the disk is founded as

$$\sigma_a^q = k\epsilon_r'' ab\delta \left[(|e_q^+|^2 + |e_q^-|^2) \frac{\sinh(k\delta Im(\beta_z))}{k\delta Im(\beta_z)} + Re(e_q^+ \hat{q}_\epsilon^+ . e_q^{-*} \hat{q}_\epsilon^{-*}) \frac{\sin(k\delta Re(\beta_z))}{k\delta Re(\beta_z)} \right] \quad (21)$$

where {Re} and {Im.} are the real and imaginary part operators of complex components. The parameters are defined in reference [6-8].

3.2.2 Modelling of Branches and Trunks as Thick Cylinders

Branches and trunks of the vegetation for absorption cross section have an expression like leaves mentioned in the previous section, therefore branches and trunks are modelled as a cylinder to calculate absorption cross section [7-9]. The parameters are defined in reference [6-7].

$$\sigma_a^q = 4\pi k \epsilon_r'' l \left(\sum_{n=-\infty}^{\infty} \left|e_n^q\right|^2 Y_n + 2\left|c_n^q\right|^2 Y_{n+1} + 2\left|d_n^q\right|^2 Y_{n-1} \right) \quad (22)$$

3.3 MODEL Comparison

The aim of this section is to present the accuracy of the created model by comparisons. In literature, disk and cylinder models are used for absorption and scattering cross section calculations with various materials. In these studies, the absorption cross section has been also calculated for vegetation parameters using similar approximations; however, the simulation tool and method are different therefore the comparison of results with literature provides accuracy of the model. In the simulation, the angle of incidence is taken as 0º and the disk radii are 7.0 cm. The thickness of the disk is 0.3 mm. The frequency range is selected as low frequency and high frequency values included from 1 GHz to 40 GHz. As we observe two curves in Fig. 3., it is seen that both graphs increase with decreasing slope. This is an expected situation. At low frequencies, meanly from 1 GHz to 5 GHz, the shape of the graphs is similar, however, absorption cross section values are different. Frequencies around 5 GHz absorption cross section values become consistent. After 10 GHz frequency, the slope is decreasing.

In the second comparison, the absorption cross section has been calculated using parameters from NASA report on high frequency scattering of dielectric disks [11-14]. Horizontal and vertical polarizations are both considered. The comparison has been done for three frequency values. 1 GHz, as low frequency, 4 GHz as mid and critical frequency, and lastly 7 GHz, as high frequency is calculated. 4 GHz is mentioned as critical frequency, because of the restriction in approximation.

The thickness of the dielectric disk is taken as 1 mm, and the radius is 7 cm. The angle of incidence is 30º for calculations. The relative dielectric constant is taken as 36 + 13i that corresponds to leave with 70% water content. Given in **Table 1.**

Table 1. Comparison of calculated absorption cross section with NASA report for horizontal polarization

Frequency	NASA Report	Our Model	Error %
1.0 GHz	0.00276	0.0025	9.42
4.0 GHz	0.00318	0.0032	-0.629
7.0 GHz	0.00264	0.0026	1.515

In Table 1, three values of the absorption cross section of the disk are given with frequencies. At 1 GHz, the calculated absorption cross section is about 0.0025 and for NASA report, that value is 0.00276. The error is about 9.4% that is not a small error. However, if the dimensions of the disk are considered, the radius of the disk (0.07 m) is much smaller than the wavelength (0.299 m). Results might be improved by another method. At larger frequencies, for 4 GHz and 7 GHz, the error percentage is smaller enough to accept that the calculated results for the model are accurate. At 4 GHz, the error is 0.6% and for 7 GHz, the error is 1.5%.

3.4 Leaf Model Emissivity Simulations

The model is simulated for horizontal and vertical polarizations of the wave. Different thicknesses and diameters for leaves are selected in simulations. Thick and thin leaves are considered according to the assumption that if the ratio of radius/thickness is smaller or equal to 10, then the leaf is called a thick disk. Otherwise, it is assumed as a thin disk.

The emissivity of leaf simulation with respect to frequency is given for three variables for horizontal polarization. In all, frequency is continuously changed, and three curves exist for each variable. An increase in frequency results decreases emissivity in all curves except for the smallest real component of the complex relative permittivity. In Figure 3, the frequency has been simulated for three radius values. The larger radius causes higher emissivity. The thickness of the leaf has a similar effect on emissivity. In Figure 3, three curves for thickness are given. Thick leaves have larger emissivity, which is also a result of the absorption cross section. The angle of incidence has a direct effect. If the cosine factor is considered, the higher angle of incidence causes lower emissivity

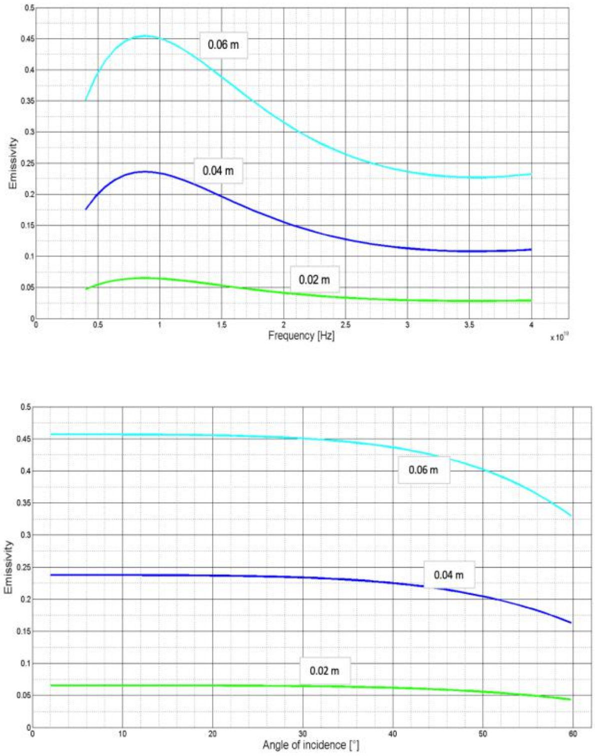


Fig 3: Emissivity versus frequency and incidence angle for leaves with three values of leaf radius for horizontal polarization

The emissivity results versus frequency graph for leaves with the thickness, angle of incidence, dielectric constant have similar shapes with different magnitudes. Emissivity decreases with an increase in the angle of incidence in curves generally. If the incident angle is large, the transmission factor is higher too. Transmission effects emissivity inversely. Larger real parts have lower emissivity values, and after some regions, emissivity decreases.

The emissivity results versus angle of incidence graph for leaves with the leaf thickness, frequency, dielectric constant have similar shapes with different magnitudes for vertical polarization. An increase in frequency results increases emissivity in all curves. In Figure 4 emissivity versus frequency graph for leaves with three values of leaf radius for vertical polarization is given. The radius is one of the multipliers, therefore, a larger radius value causes higher emissivity. Emissivity versus angle of incidence simulations for vertical polarization stays almost stable with an increase in the angle of incidence in curves. Vertical polarization changes the effect of angle of incidence on the internal electric field and absorption cross section.

The thickness of the leaf has a similar effect on emissivity; mainly an increase in thickness increases the emissivity. Thick leaves have larger emissivity, which is also a result of the absorption cross section. The angle of incidence is another parameter. At low frequencies, smaller than 15 GHz, change in angle is not effective on emissivity. For higher frequencies, the increasing angle increases the emissivity.

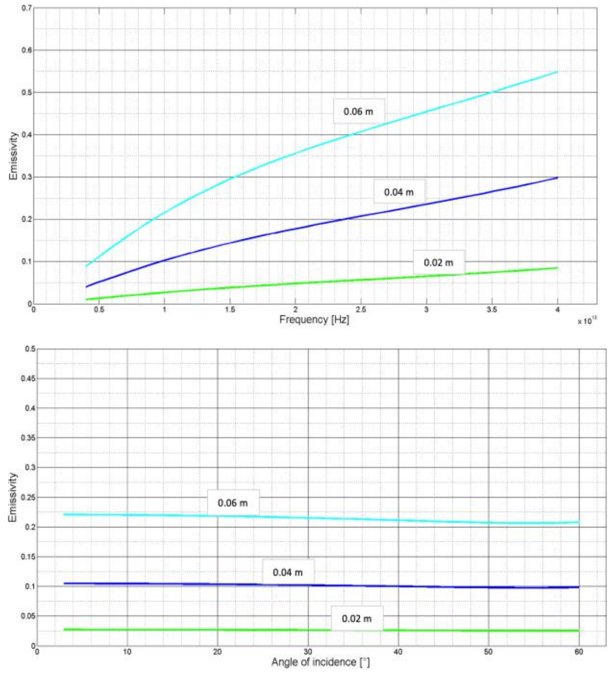


Fig 4: Emissivity versus frequency and incidence angle for leaves with three values of leaf radius for vertical polarization.

In Figure 4, emissivity is simulated with leaf radii. Like frequency, a higher radius has a higher emissivity value. Absorbed power increases while increasing leaf thickness. As mentioned before, the imaginary component of relative permittivity has a direct multiplier and therefore larger value increases the emissivity.

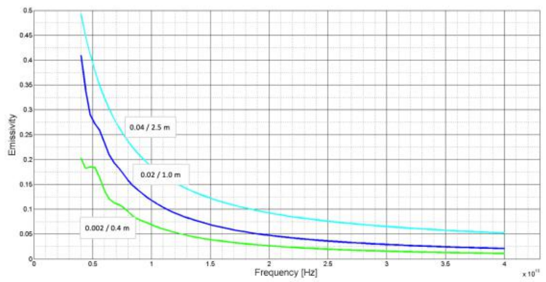
3.5. Branch and Trunk Model Emissivity Simulations

In this section, the emissivity of branch and trunks are simulated with respect to changing frequency. To some point, emissivity increases; however, at higher frequencies emissivity decreases. Together with changing frequency, cylinder radius, cylinder length, angle of incidence, and complex relative permittivity is simulated to obtain specific relations between pairs.

In the first graph, Figure 5, the effects of radius and length are displayed. Thin branches have lower emissivity and trunks have higher, as it is expected. Because of the volume integral of wave transformation equation, length and radius are direct multipliers.

The emissivity results versus incidence angles are given in Figure 5 too. Cylinder geometry is different from the disk geometry. Increasing angle effect, emissivity at 60º angle causes better absorption. The internal electric field constitutes the absorption cross section and emissivity.

The real and imaginary parts of dielectric constant are investigated in separate graphs similarly. The imaginary part is again a multiplier of the absorption cross section. For both components, higher value causes higher emissivity.



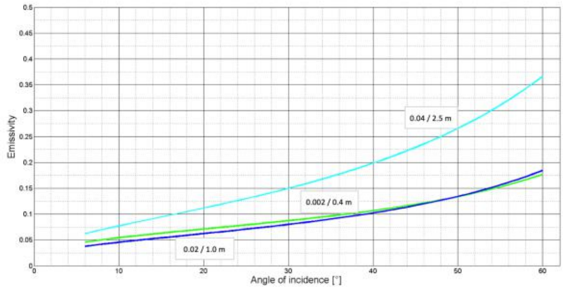


Fig 5: Emissivity versus frequency and incidence angle of branches and trunks with three values of cylinder length and radius for horizontal polarization The incident angle is considered as the second parameter in the emissivity simulation of the branch model. With different dimensions, frequencies, and dielectric constants three graphs are obtained. The obvious effect of the angle of incidence is an increase in emissivity. The geometry and therefore the effect on emissivity are different from the leaf model. In dimensional change, the angle of incidence affects the emissivity values of geometrically similar branches. At 50º, two curves intersect. The trunk has higher emissivity than others, because of higher absorption. Incidence angle affects the emissivity and absorption cross section separately. The dominant effect of geometry changes inversely with the change in the incidence angle. As frequency increases emissivity decreases in simulations. Similar to frequency simulation, larger values of real and imaginary parts result in higher emissivity values.

The emissivity of branches and trunks are simulated with respect to frequency. Vertical polarization results are like horizontal polarization. Cylinder geometry is different from the disk geometry; therefore, it has different results from disk model simulations. Increasing angle affects emissivity at 60º angle and causes better absorption and therefore the effect of the cosine factor is smaller. The obvious effect of the angle of incidence is an increase in emissivity. The geometry and therefore the effect on emissivity is different from the leaf model. Vertical polarization has a remarkable effect on leaf model simulations; however, for cylinder, vertical polarization results are almost the same with horizontal polarization case.

3.6. Simulations of Human Model

In previous sections, modelling and simulations for vegetation components are discussed. Many dielectric materials including human can be modelled as cylinders. With this parametric study and code, it is sufficient for modelling of objects with known dielectric constant and dimensions. In this section, a model of human as a cylinder and simulations according to this model will be made and interpretation of the results will be discussed. Using the data obtained in the literature, the dielectric constant of the human body depends on the body structure. The parameters of the model are length=190cm. diameter=50cmand dielectric constant=32-i5.1. The simulations of the emissivity versus frequency of modelled man with changing polarization is shown in Figure 6. The angle of incidence is taken as 45 degrees.

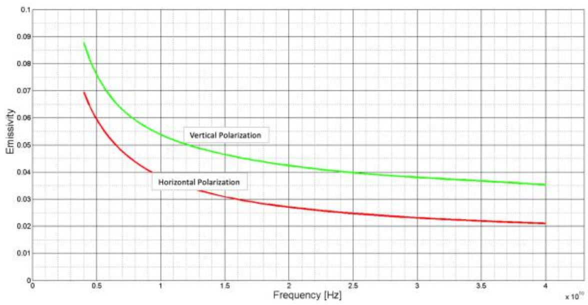


Fig 6: Emissivity versus frequency with horizontal and vertical polarizations

Considering the results in these figures, it appears that the emissivity decreases with increasing frequency. Vertical emissivity is higher than the horizontal polarization. If dimensions are different so that the difference between the emissivity of the models is related to the volume of the subject body. There is a direct correlation between the volume of the object and the absorption cross sections. Thus, the emissivity increases with increasing volume. The absorption cross sections are increased, and emissivity increases with increasing volume in the model for man.

4. RESULTS AND DISCUSSION

In this work,

1) We found the relations between emissivity and backscattering coefficients of discrete and continuous models.
2) As seen from the equation, the backscattering coefficients in discrete model and continuous model are related in a multiplicative manner.
3) The backscattering coefficient can be obtained using eq.19.
4) Emissivity and absorption cross section have been obtained for thin and thick scatters. Absorption cross section equations have been simulated and calculated to make a comparison with the results from the literature.

In horizontal polarization, the emissivity value is greater at low frequencies. In vertical polarization, higher frequencies give in greater emissivity value, therefore depending on frequency range, horizontal and vertical polarizations could be used in the model. In the thick cylinder model constituted for branches and trunks, simulation parameters are similar. Emissivity curves for both polarizations are decreasing with an increase in frequency. Wider incidence angle causes emissivity to increase.

5. ACKNOWLEDGMENTS

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