Experimental Study on Permittivity Estimation for Vegetation and Soil by Using Brewster's Angle

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Abstract

Vegetation monitoring is one of the major applications of polarimetric synthetic aperture radar (PolSAR). In this report, a concept of experimental verification of permittivity estimation method for vegetation and soil by using multi-angle polarimetric radar is proposed. The method utilizes Brewster's angle of double-bounce scattering component.

Keywords : Brewster's angle PolSAR Permittivity estimation Vegetation

1. Introduction

Nowadays, many methods for PolSAR image analysis have been proposed and widely used. By using the PolSAR, polarimetric dependent parameters of each target can be discriminated. Vegetation monitoring, permittivity and moisture estimation for example, is one of the major applications of the PolSAR. However, it often becomes a difficult problem because scattering phenomena in the vegetation area are complicated due to interaction between the vegetation and the ground [1]. Therefore, development of robust and simple method is needed.

In this report, we discuss a method of experimental verification of permittivity estimation for vegetation and soil by utilizing Brewster's angle. Theoretically, for TM (vertically polarized) wave incidence, no reflected wave can be observed when the incidence angle is equal to the Brewster's angle of the target medium. The angle is only a function of permittivity of the medium. In other words, if we have a knowledge of Brewster's angle, we can readily estimate permittivity of the medium. In our proposal we observe vegetation at multiple incidence angles at VV channel by the PolSAR. Though bistatic SAR system can observe only single Brewster's angle, ordinary monostatic SAR system allows one to observe two Brewster's angles when focusing on the double-bounce reflection in the vegetated area. Details of this mechanism are shown in the next section. We demonstrate availability of this method by simple model experiments in a radio anechoic chamber. Experimental result of the model for vegetation area covered by canopy is also provided.

2. Brewster's Angle

First, let us consider the Brewster's angle of the ground for bistatic case as shown in Figure 1. In this case, the reflection coefficient for horizontal and vertical polarization can be given by

$$r_h = \left(\cos\theta_i - \sqrt{\varepsilon_g - \sin^2\theta_i}\right) \Big/ \left(\cos\theta_i + \sqrt{\varepsilon_g - \sin^2\theta_i}\right), \qquad (1)$$

$$r_v = \left(\varepsilon_g \cos\theta_i - \sqrt{\varepsilon_g - \sin^2\theta_i}\right) \Big/ \left(\varepsilon_g \cos\theta_i + \sqrt{\varepsilon_g - \sin^2\theta_i}\right), \qquad (2)$$

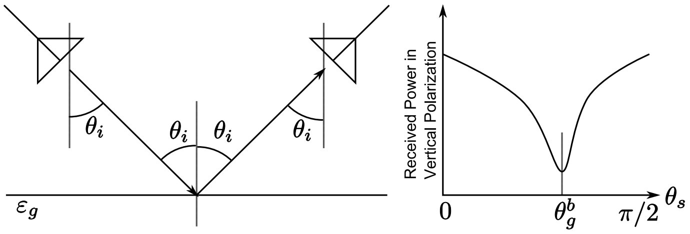


Figure 1: Brewster's angle shown in forward scattering

where ε_g is the permittivity of the ground, and θ_i is the incidence angle. These equations are well known as Fresnel's equations. If the incidence angle is equal to

$$\theta_b^g = \tan^{-1}\sqrt{\varepsilon_g}\ , \tag{3}$$

no reflection can be observed for TM incidence case. This angle is called Brewster's angle. Also we can readily invert the permittivity from equation (3).

Next, we discuss the case for double-bounce backscattering in the vegetation area as shown in Figure 2, where two sharp drops are appeared as mentioned in [2-3].

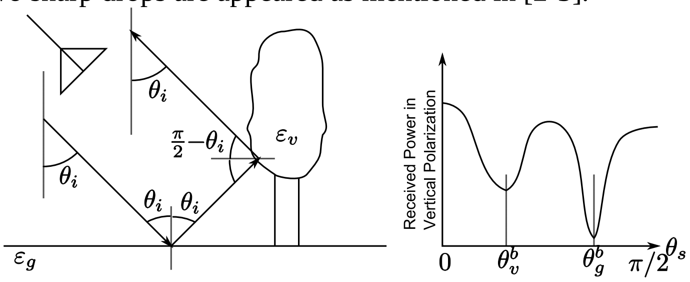
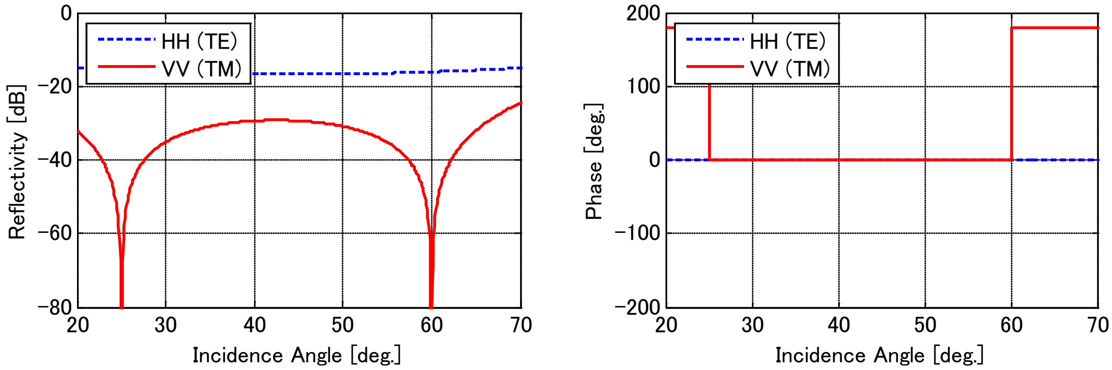


Figure 2: Brewster's angles shown in backscattering

From geometrical property, the additional Brewster's angle shown in Figure 2 can be measured at

$$\theta_b^v = \frac{\pi}{2} - \tan^{-1}\sqrt{\varepsilon_v}\ , \tag{4}$$

where ε_v is the permittivity of the vegetation. As mentioned in [3], it should be possible to estimate the permittivity of the ground and the vegetation using these relationships. Figure 3 shows the numerical example for $\varepsilon_g = 3.0$ and $\varepsilon_v = 4.6$. These two Brewster's angles coincide with those derived in equations (3) and (4), respectively.



(a) Incidence Angle vs. Magnitude (b) Incidence Angle vs. Phase

Figure 3: Incidence angle vs. reflection coefficient

3. Experimental Verification

To demonstrate Brewster's angle measurement of double-bounce scattering, we carried out the indoor experiment using the X-band fully polarimetric radar system. The overview of the measurement system is depicted by Figure 4. The vector network analyzer is used as transmitter and receiver. The four horn antennas are employed in this experiment. The antennas are scanned vertically to obtain synthetic aperture images. The incidence angle is changed by rotation of the target(s) on the turntable. The synthetic aperture image is generated each incidence angle. The test target is a dihedral reflector constructed with two wooden plates. To realize more realistic situation of vegetation phenomena, the random oriented dipole cloud as volume scatter of vegetation canopy is placed on the front of the test target in the additional experiment. The wires are distributed on the styrofoam plate at random location/orientation. Several styrofoam plates are stacked to realize three dimensional distribution. The experimental parameters are listed in Table 1.

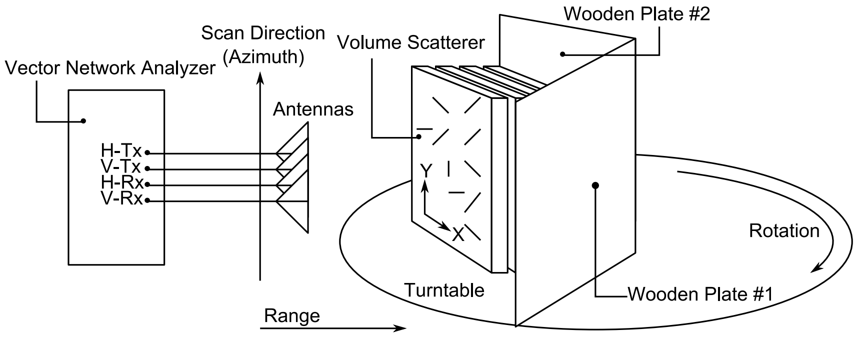
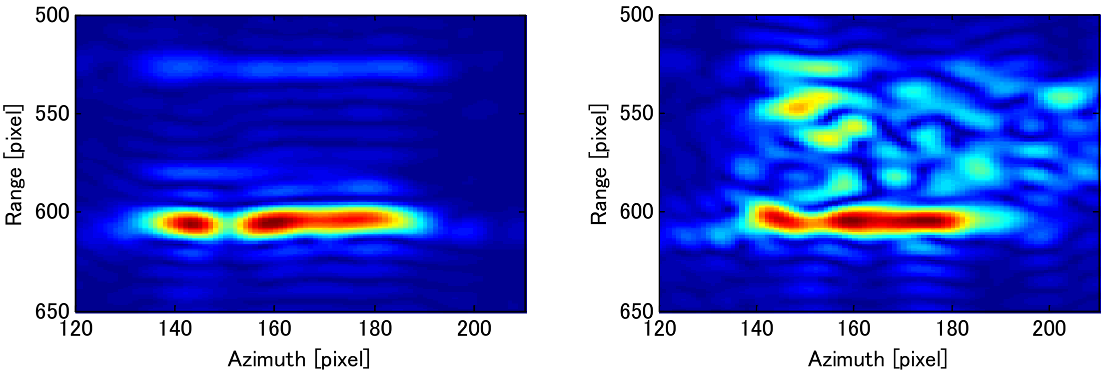


Figure 4: Measurement System

Table 1: Experimental Parameters

Test Piece Size	Wooden Plate #1	60 cm × 40 cm
	Wooden Plate #2	60 cm × 35 cm
Volume Scatterer	Wires per Plate	40
	Wire Diameter	3 mm
	Wire Length	30 cm
	Styrofoam Plate Size	60 cm × 60 cm
	Number of Styrofoam Plates	4
Frequency	Center	10 GHz
	Band Width	2 GHz
Synthetic Aperture Length	1.7 m	
Incidence Angle	$20^\circ - 40^\circ$, $50^\circ - 70^\circ$	

Figures 5 (a) and (b) shows the obtained images in VV polarization at 20° incidence for with and without volume scatterer, respectively.

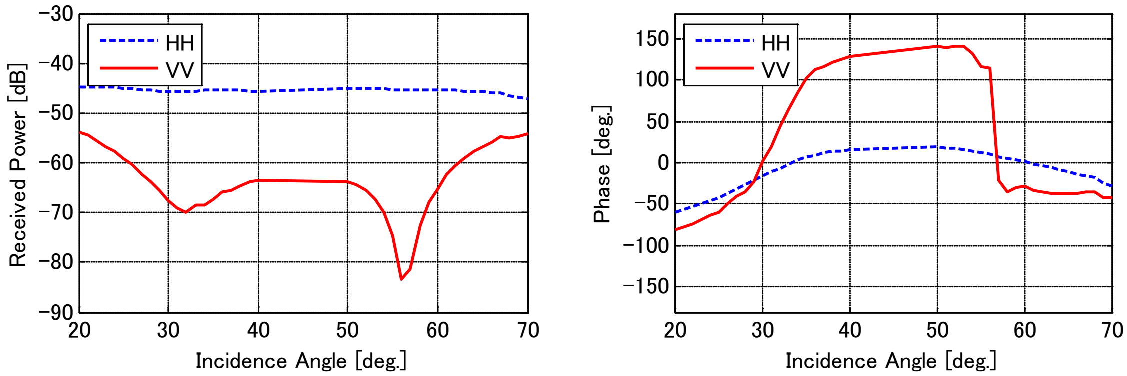


(a) w/o Volume Scatterer (b) w/ Volume Scatterer

Figure 5: Synthetic Aperture Image

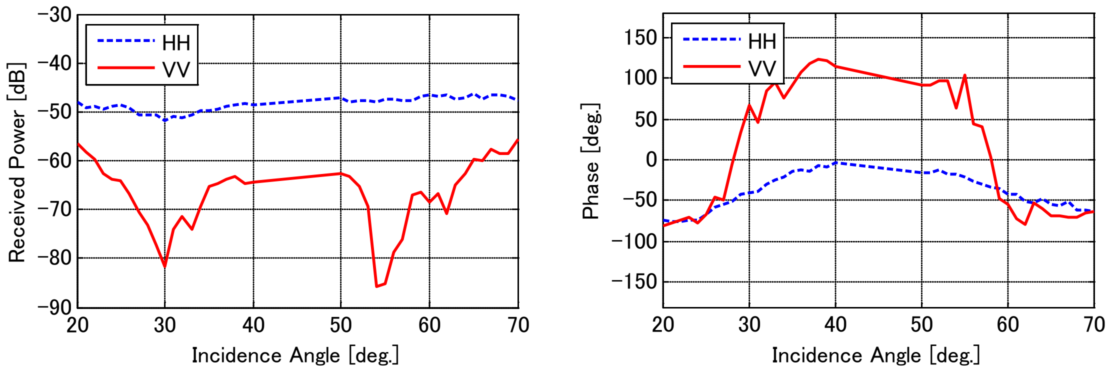
Since range resolution of the radar is high enough, we can clearly separate the dominant double-bounce reflection located at around 610 pixels in range in the both images. Also, we see the distributed volume scatterers from 530 to 600 pixels in range in Figure 5 (b). Note that, in practice, what we can observe is a mixture of multiple scattering components. The received power is estimated at the pixel that contains the double-bounce reflection from the plates. The experimental results of the first experiment without volume scattering are shown in Figure 6 (a) and (b). The observed Brewster's angles, θ_b^v, θ_b^v, are 32° and 56°, therefore permittivity of each medium can be estimated as 2.7 and 2.2, respectively.

Next, we examine the case with additive volume scatterer as vegetation canopy. The experimental result is shown in Figure 7, where we still observe the both the angles clearly even with the attenuation through the volume. The observed Brewster's angles seem to be slightly biased. This may be caused by the multiple reflections by the plates and dipoles in this model.



(a) Incidence Angle vs. Magnitude (b) Incidence Angle vs. Phase

Figure 6: Experimental Result (w/o Volume Scatterer)



(a) Incidence Angle vs. Magnitude (b) Incidence Angle vs. Phase

Figure 7: Experimental Result (w/ Volume Scatterer)

4. Conclusions

Possibility of an experimental verification of permittivity estimation method using double-bounce reflection has been proposed in this report. The experimental results showed that the permittivity of the ground and vegetation can be potentially estimated at once by the multi-angle observations. In future, we will thoroughly verify the observation of each scattering mechanism and interaction step by step.

References

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