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The double Brewster angle effect

Le double effet de Brewster

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A B S T R A C T

The Double Brewster angle effect (DBE) is an extension of the Brewster angle to double reflection on two orthogonal dielectric surfaces. It results from the combination of two pseudo-Brewster angles occurring in complementary incidence angles domains. It can be observed for a large range of incidence angles provided that double bounces mechanism is present. As a consequence of this effect, we show that the reflection coefficient at VV polarization can be at least 10 dB lower than the reflection coefficient at HH polarization over a wide range of incidence angle – typically from 20 to 70°. It is experimentally demonstrated using a Synthetic Aperture Radar (SAR) image that this effect can be seen on buildings and forests. For large buildings, the difference can reach more than 20 dB.

R É S U M É

Le double effet de Brewster (DEB) est une extension de l'effet induit par l'angle de Brewster au cas d'une double réflexion sur deux surfaces diélectriques orthogonales. Il en résulte alors deux pseudo-angles de Brewster se produisant dans des domaines angulaires complémentaires. La combinaison de ces deux mécanismes implique que cet effet peut être observé pour une grande gamme d'angles d'incidence, à condition que le mécanisme de double rebond soit présent. La conséquence remarquable est que le coefficient de rétrodiffusion en polarisation VV peut être inférieur d'au moins 10 dB par rapport au coefficient de réflexion en polarisation HH, et ceci sur une large gamme d'angle d'incidence – typiquement de 20 à 70°. Nous proposons une vérification de cet effet en utilisant une image radar à synthèse d'ouverture (RSO). Pour les grands bâtiments, la différence peut atteindre plus de 20 dB ; il est également observable, dans une moindre mesure cependant, pour la lisière d'une forêt.

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1. Introduction

When an electromagnetic wave is incident on a planar and horizontal interface between two dielectrics, a transmitted wave and a reflected wave are generated. When there are no losses within the materials, only the parallel component of the reflected wave exists for a specific angle, called the polarizing angle. This angle is bounded and can go from 45° to 90°, depending on permittivity. This effect was discovered more than two hundred years ago by Brewster [1]. When the incident wave is unpolarized, as for light, this effect could be used to polarize it. When the incident wave is polarized, as for radio waves, it acts as a polarization filter. Whatever the polarization state of the incident wave, this effect occurs for a narrow range of incidence angle, as seen in Fig. 2. In order to account for the losses of materials, the pseudo-Brewster angle has been introduced [2]. At this angle, the reflected intensity for the perpendicular component is no longer zero, but a minimum. Thus, the perpendicular component exists, but it may be strongly attenuated. In addition, this effect is then larger in angular range, as illustrated in Fig. 3.

The specular configuration is typically used in optics to retrieve the optical constants of the complex refractive index, which is the square root of the complex relative permittivity. However, for classical radar systems, the transmitter and the receiver are generally located next to each other, so the specular configuration on a single interface is not of prime interest. Now, if we combine two orthogonal interfaces, then a strong signal can be scattered back to the radar. This implies cascading two pseudo-Brewster angles: one that may range from 45° to 90° (horizontal interface) and the other from 0° to 45° (vertical interface). The combination of two nulls (Brewster effect) or two minimums (pseudo-Brewster effect) enlarges a lot the angular domain where there is a strong difference between parallel and perpendicular components. In what follows, we will refer to this phenomenon as the double Brewster angle effect, and it will be noted DBE.

In this paper, it is demonstrated both theoretically and experimentally that this double Brewster angle effect can be potentially observed in any monostatic radar images of the earth land surface. Indeed, by cascading two Brewster effects on two orthogonal surfaces, we obtain an effect that is observable for most of radar remote sensing configurations in terms of frequency and incidence angle. In addition, this effect exists for a wide angular range for a large variety of materials. We experimentally validate this effect on two radar images at different frequencies, and for two platforms – airborne and space borne – leading to various incidence angles and resolutions. Most of current space borne radar missions are concerned (RS2, TX, ALOS-PALSAR, Sentinel 1, etc.), as well as radar mounted on aircrafts by research agencies (SETHI, UAVSAR, E-SAR, CARABAS, etc.) as they all operate at incidence angles that may be affected by DBE. Consequently, we expect to observe this effect on a wide range of products delivered by these sensors.

In the next section, we recall the definitions of the Brewster and the pseudo- Brewster angles. In section 3, we introduce the double Brewster angle effect and show how sensitive it is to permittivity. Then in section 4, these results are illustrated and validated using real radar data, with a mixed landscape of urban and vegetated areas.

2. What are the Brewster and the pseudo-Brewster angles?

2.1. The polarizing angle of Sir David Brewster

Two hundred years ago, in March 1815, Sir David Brewster published his experimental results on the polarization of light [1]. His work actually extended the discovery of Étienne-Louis Malus, a French engineer, mathematician, and physicist who brought out the way to polarize the light using reflection on several materials. Sir David Brewster empirically determined that, for a specific angle – called the polarizing angle – "the reflected light is linearly polarized, but the transmitted light has both parallel- and perpendicularly-polarized components." [3] As Fresnel published his work later, in 1822 [4], Brewster could not express his observations in terms of reflection coefficients. The definition of this polarizing angle has evolved since then, and what we call now the Brewster angle is widely taught as the angle leading to a zero reflection coefficient for VV polarization, when transmission and reception are vertically polarized. As pointed out in [3], these two quantities (polarizing angle and zero reflection angle) are actually equal, provided that the experiment deals with "dielectric-dielectric interfaces". We investigate here the interfaces between air and either natural (wood, soil, etc.) or artificial (concrete, glass, etc.) materials. For these types of interface, provided that there is no loss, it is correct to define the Brewster angle as "a zero reflection coefficient" at VV polarization.

In Fig. 1, we consider an infinitely long interface between two media m_1 and m_2, characterized by their real relative permittivities ε_{r1} and ε_{r2}. For simplicity, we assume that m_1 is the air, so that $\varepsilon_{r1} = 1$, and the relative permeability of the two media is constant and equal to 1. We recall here that the permittivity may vary with frequency, temperature, moisture, and other contents of the material (see for instance [5] or [6]). For any incidence angle θ, we can determine the part of the incident field that is reflected in the specular direction using the Fresnel reflection coefficients R_v and R_h written as:

$$R_\mathrm{v}(\theta) = \frac{\varepsilon_{r2}\cos\theta - \sqrt{\varepsilon_{r2} - \sin^2\theta}}{\varepsilon_{r2}\cos\theta + \sqrt{\varepsilon_{r2} - \sin^2\theta}} \tag{1}$$

$$R_\mathrm{h}(\theta) = \frac{\cos\theta - \sqrt{\varepsilon_{r2} - \sin^2\theta}}{\cos\theta + \sqrt{\varepsilon_{r2} - \sin^2\theta}} \tag{2}$$