Performance of the Wet Radomes for Phased-Array Weather Radars: Evaluation and Applications

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***Abstract*— The concept for an analytical method for evaluating the electrical performance of a flat, tilted radome for a dual-polarized phased-array antenna under rain conditions was devoloped. Attenuation, reflections and induced cross-polarization are evaluated for different rainfall conditions, taking into account the properties of the skin surface, area, inclination, radome structure, and rainfall rate. In order to illustrate the utility of the new wet radome model, this paper evaluates four different scenarios which provides a better understanding of the model proposed.**

***Index Terms*— Index Terms— Radome, Phased-Arrays, Atmospheric Remote Sensing, Electromagnetic Modeling**

I. Introduction

In the past, the influence of water accumulation on radome surfaces has been extensively studied in terms of additional attenuation and depolarization effects in RF communication systems [1] and meteorological radar systems [2]. Early models estimate the distribution of rain based on laminar flow and surface tension for the radome, and do not include hydrophobic surface properties [1]. Currently most antenna radomes include repellent surfaces to mitigate the negative impact of rain on the radar performance. Experimental measurement has been the most trustworthy method to evaluate the radome under the influence of rain. A significant drawbacks of experimental measurements is the large space for deployment, expensive RF equipment, and the need to deal with measurement uncertainties in the testing process [3]. A simple and inexpensive new wet radome model which includes different water formation (film, droplets and rivulets), wall radome structures and repellent surfaces is presented in [4]. This paper presents four scenarios to illustrate the utility of the new model proposed.

II. Case of studies

The first case represents a situation where a flat tilted (34°) antenna radome designed without a hydrophobic surface, or when the hydrophobic properties of the radome has been deteriorated. The second case also represents a flat tilted (34°) antenna radome, but this time designed with the hydrophobic film. The third case uses the same radome, however, the tilted angle is reduced from 34° to 10°. For all three cases, the flat radome was designed to operate at 10 GHz, and the radome corresponded to a walled structure composed of one thin hydrophobic layer (12 mil) of Goretex (ε_r=1.55, tanδ= 0.0005) and a thick layer (250 mil) of core foam Rohacell 31HF (ε_r=1.046, tanδ= 0.0017). We assume for these cases a water dielectric constant of ε_r= 60.68+32.79i and tangent loss of tanδ =0.54, estimated for 10 GHz and at 20° C.

This work was primarily supported by the Engineering Research Center Program of the National Science Foundation under NSF Award Number 0313747. Any opinions, findings and conclusions or recommendations expressed in this material are those of the author and do not necessarily reflect of the National Science Foundation.

A. *Flat radome tilted 34° without hydrophobic surface.*

One of the biggest concerns with hydrophobic or water-repellent surfaces is their lifetime and their performance degradation over time when exposed to temperature, humidity, ultraviolet rays, air pollution and dust. Weigand in [5] evaluated the contact angle of several radome hydrophobic samples used for an airport surveillance radar. The study shows that weather and pollution reduce the contact angle up to 30° in an interval of time between 3 to 9 months. In 2009, a report by the Support Center for Advanced Telecommunications Technology [6], presented results of hydrophobic durability performed in a short term (1168 hours in accelerated weathering system) and long term (24 months in real environment). Significant degradation of the contact angle (from 151° to 132°) was found in the short term, and degradation of the contact angle (from 151° to 100°) was found 6 months after the long term experiment had started. Considering the fact that radomes with hydrophobic surfaces can lost their hydrophobic properties in a short periode of time, we present the case where film water can ocurr on the radome surface. The film water model for a flat tilted radome was formulated in [4] and represented in the Figure 1 a.

Figure 1 b shows the one-way attenuation when a uniform thin film water cover the radome. As it was expected a significant attenuation (1.6 dB to 4.5 dB) can result from moderate to high rain intensities (10 mmh^{-1} to 100 mmh^{-1}). A small variation (less than 0.01 dB) between H and V is observed in the near to broadside. However it increases up to 0.5 dB at a 45° incident angle. Figure 1 c shows the reflection coefficients of the radome. Results shows significant changes in reflection for H and V for a wet radome as compared to dry radome, even for small rain intensities. Reflections can be a concern for values higher than -10 dB, since those can considerably affect the scanning impedance of the antenna array and also the antenna patterns principally in the sidelobe region. Figure 1 d presents the cross-polarization ratio induced by the wet radome.

At broadside, negligible distortion of cross-palarization is produced. However when the antenna is scanned, the wet radome significantly affects the cross-polarization of the radar signal. At 45° scanning in the azimuth plane, we observe that the radome can degrade the cross-polarization by about 20 dB.

B. Flat radome tilted 34° with hydrophobic surface.

In this case we replaced the skin surface with a hydrophobic material. We selected Goretex since this material is commonly used for weather radome radars, due to the good RF and mechanical attributes. Figure 2 b illustrates the one-way attenuation, reflections, and depolarization for a flat radome with tilt angle θ_t=34° as a function of rain rate and scan angle in the azimuth plane. Figure 2 c a shows a comparison between the total reflections when the radome is dry and when the radome is wet for different rain intensities. The results indicate that the attenuation is drastically reduced compared to the previous case (non- hydrophobic surface or radome with film formation), by about 2.9 dB when exposed to 100 mmh^{-1}. As with the previous case, small differences in attenuation existed between H and V with respect to beam position. Figure 2 c shows the reflections. In the worst case scenario, for 100 mmh^{-1}, the reflections are below -25 dB for the overall scanning range required (±45°). Figure 1 d shows the cross-polarization ratio of this radome. For 45°, the cross-polarization induced by the radome is about 14 dB (16 dB better that in the previous case).

C. Flat radome tilted 10° with hydrophobic surface

In this case we used the same radome as in the previous case, but reduced the tilt angle from 34° to 10°. Figure 3 illustrates the one-way attenuation, reflections, and depolarization for a flat radome tilted θ_t=10° as a function of rain rate and scan angle in the azimuth plane. Figure 3 b compares the transmission coefficient of a dry radome with a wet one for different rain intensities. The results indicate a significant improvement can be obtained in the three parameters under evaluation by reducing the tilt angle of the antenna. For 100 mmh^{-1} at broadside, the improvement for a hydrophobic radome tilted at 34° is about 1.35 dB and the improvement can be 4 dB for a radome without hydrophobic skin. Figure 3 c shows that in the worst case scenario, for 100 mmh^{-1} the reflections are below -35 dB for the overall scanning range required (±45°). Figure 3 d shows the cross-polarization ratio of this radome tilted at 10° only degrade the radar signals 8 dB (6 dB better than the previous case, and 12 dB better when compared to the radome without the hydrophobic skin surface).

D. A special case when rivulets are present

Upon simple inspection, non-hydrophobic materials tend to spread water on a surface, creating uniform films of water that end in permanent rivulets, as illustrated in Figure 4 a. In a hydrophobic material, the rivulet formation does not occur at the same place. The origin of each rivulet starts when gravitational forces defeat the surface tension of a droplet on the radome surface. The inclination angle, number, and size of droplets define the number of rivulets for a given surface. The mathematical expression that helps to understand the origin of the rivulets and also permits the characterization of the drop size distribution for an inclined surface is showed in equation (5) in [6], and can be used to estimate the number of rivulets. However it is quite difficult to introduce rivulets in the model proposed. Instead, a numerical model using the full-wave solver Ansys/Ansoft HFSS is used. The HFSS model consists of a unit cell, where the droplets and rivulets were introduced as shown in Figure 4 b. Two models were considered; the first one represents the radome with droplets, and in the second one we add one rivulet in the unit cell. The results presented in Figure 4 c-d show the transmission and reflection coefficients versus incident angle relation changes drastically for both polarizations, and also changes with incident angle. These preliminary results are important considering that the differences between H and V (due the presence of rivulets in random fashion) can affect the performance of the radar system when it operates under rainy conditions; especially the differential reflectivity product.

III. Conclusions

Four scenarios were presented and discussed in order to illustrate the utility of wet radome model proposed in [4]. The new wet radome model estimates the attenuation, reflection and depolarization as a function of rain rate, radome structure and type of skin material used (including super-hydrophobic surfaces). The scenarios selected represents realistic cases where water film, drop and rivulets formation can be produced. The results using a film water model resulted with the larger attenuation, reflection and depolarization. This model can be used only in cases of heavy rain conditions and where the radomes does not includes water repellent surfaces. Using the drops model proposed, for a same radome and rain conditions, a substantial difference of 2.9 dB in the attenuation, 15 dB in reflection and 8 dB in the cross-polarization is observed with respect to the classic film water model. Preliminary results of rivulet formation were presented, the results shows that rivulets formation affects considerably the vertical polarization. Further analysis of rivulets formation need to be addressed in order to evaluate the impact of rivulets to the differential reflectivity product.

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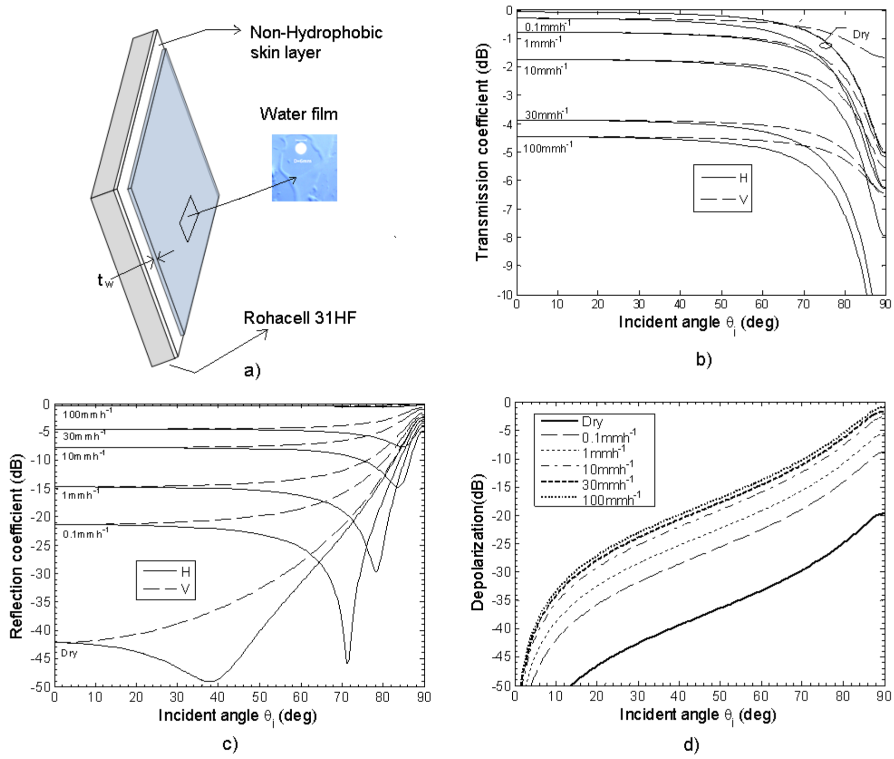

Fig. 1. Calculated results wet radome surface tilted (34 deg.) without hydrophobic surface under different rain intensity. a) Representation of water film formation in tilted (34 deg) flat radome. b) Transmission coefficient versus incident angle c) Reflection coefficient versus incident angle. d) Depolarization ratio versus incident angle

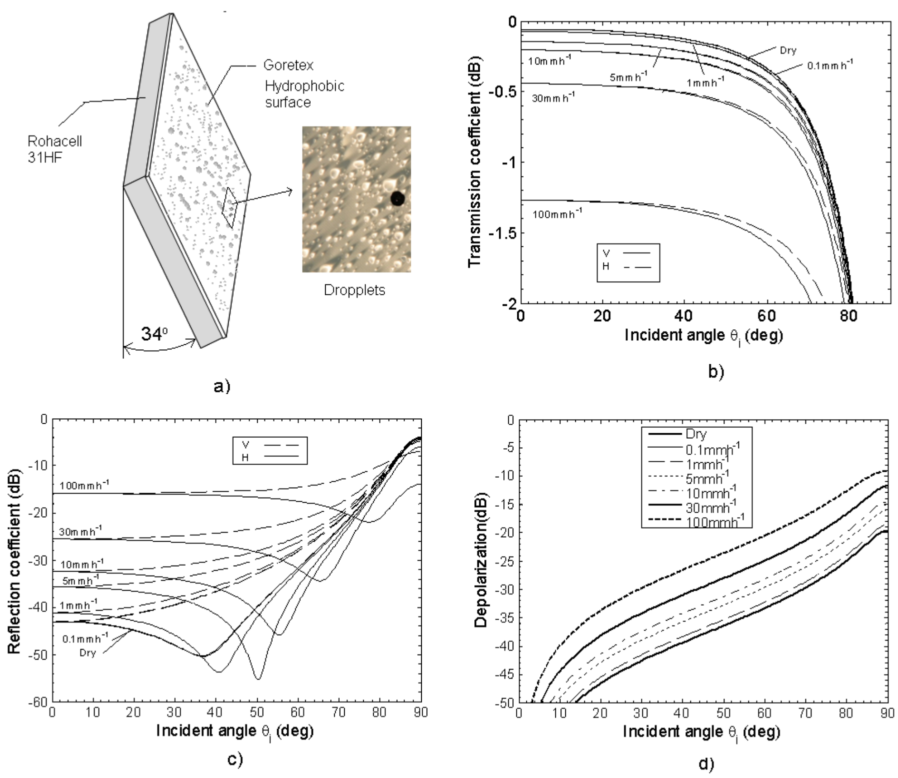

Fig. 2. Calculated results of hydrophobic (Goretex) wet radome surface tilted (34 deg.) under different rain intensity. a) Representation of drop formation in tilted (34 deg) flat radome. b) Transmission coefficient versus incident angle c) Reflection coefficient versus incident angle. d) Depolarization ratio versus incident angle

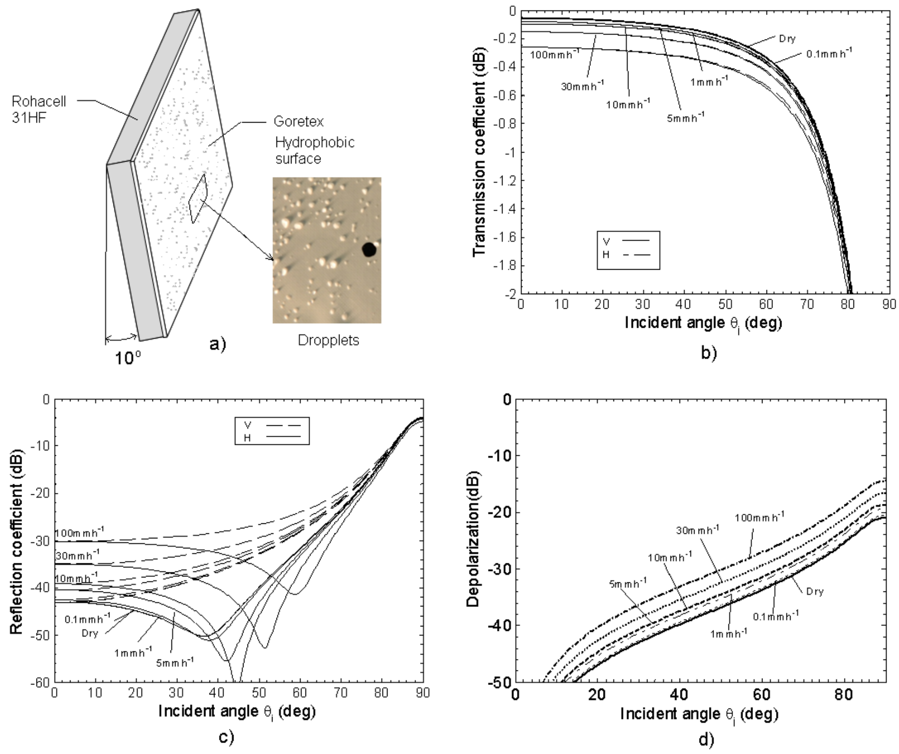

Fig. 3. Calculated results of hydrophobic (Goretex) wet radome surface tilted (10 deg.) under different rain intensity. a) Representation of drop formation in tilted (10deg) flat radome. b) Transmission coefficient versus incident angle c) Reflection coefficient versus incident angle. d) Depolarization ratio versus incident angle

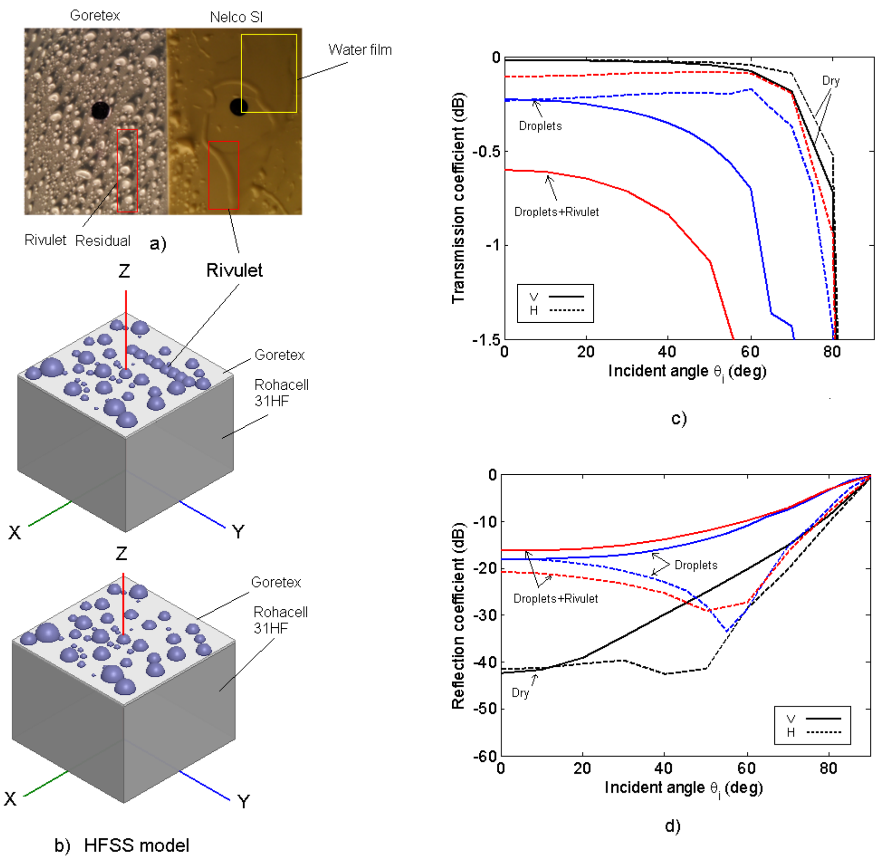

Fig. 4. Numerical simulation results of wet radome surface (Hydrophobic) with and without the rivulets formation a) Picture of water formation in a radome surface b) HFSS model for wet radome with and without rivulet formation. c) Simulated results of transmission coeffient and d) Simulated reflection coefficients.