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Fundamental Study of Wet Antenna Attenuation

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Abstract

This article presents a fundamental view on the effect of wet antenna attenuation (WAA) in point-to-point radio links. Wet antenna attenuation is observed as an additional contribution to the overall received signal fading during rain events along the link path. A theoretical model of this effect is developed. It separates the total observed effect into three contributing processes, namely degradation of antenna efficiency, changes in directivity, and variation in antenna feed port reflectivity. The latter is characterized by the antenna's receptivity. To quantify these effects, a pyramidal horn antenna with different grades of radome wetness was analysed at 18 GHz using numerical full-wave simulation. Evaluation was done by generating a homogeneous water film on a prototype antenna and by performing a scan of the radiated near-field in an anechoic chamber. Antenna feed port reflectivity was measured synchronously by the network analyser of the near-field scanning system. In this way, antenna efficiency, directivity, and receptivity could be measured and compared to numerical results. This verified the ternary composition of WAA.

Keywords: wet antenna effect, microwave links, received signal level, radome wetness

1. Introduction

Measuring ground precipitation by evaluation of path attenuation and fading in terrestrial microwave point-to-point links is a strongly emerging technology in weather observation and hydrology, first introduced by [1]. It offers dense coverage in many countries and can provide short-term precipitation measurement for severe weather warning. For a more accurate estimation of rain rates from the measured signal levels, a better understanding of the effect of wetness on the antenna radome is needed. The following paper presents a fundamental study of wet antenna attenuation (WAA) in terrestrial microwave point-to-point links. WAA appears in addition to atmospheric path attenuation when the antenna, particularly its radome, is wet. Therefore, it is a significant source of error when the received signal level (RSL) is used as the basis for rain rate estimation of rain fields in the link path (cp. [2]). Hence, a better understanding of the WAA would enable a better quantification of its effect and subsequently increase the accuracy of this rain rate estimation process from RSL. In this work, a model is presented which explains the three components directivity, efficiency and antenna reflectivity that constitute the WAA. These three parameters, and thus the whole effect, depend on the strength and structure of the antenna's wetting. The validity and the application of the model is shown by measurement results of a directive antenna with different grades of wetness generated by a controlled sprinkler system in the lab. In the paper, a possible modification of the link budget, based on the antenna parameters, is suggested. In the second and third section, the WAA dependency on the antenna parameters is analysed by full-wave simulations and near-field measurements in an anechoic chamber.

2. Theoretical Model

The monitoring systems of the large microwave link network, typically operated by cell phone providers, provides the received signal level (RSL) and the available transmit power P_{TX} of each microwave link. However, it has to be noted that the actual transmit power may be lower due to variable antenna mismatch. Furthermore, the path length, the frequency of the radio signal and also the nominal gain of the two antennas in the dry case is known. For a better consideration of the antenna parameters in RSL-models, we combine and modify existing RSL-models, such as [3]. Up to now, the influences of the two antennas on the RSL in RSL-models for rain rate estimation are described by only one parameter, the gain. Usually, terms with the factor gain have the following form:

$$\mathrm{RSL} = P_{\mathrm{TX}} G_1 A_{\mathrm{Link}}^{-1} G_2$$

The link attenuation A_{Link} represents the attenuation of any link model (like [4]). In the model we present here that the influence of the antenna is described not only by a single gain factor, but by three parameters, yielding the relation

$$\mathrm{RSL} = P_{\mathrm{TX}} (1 - |\Gamma_1|^2) \eta_1 D_1 A_{\mathrm{Link}}^{-1} (1 - |\Gamma_2|^2) \eta_2 D_2.$$

Where η is efficiency, Γ is reflectivity and D directivity of the antenna. In RF engineering it is common to describe an antenna by those three parameters (cp. [5]). From the efficiency η and directivity D we can derive the gain G as

$$G = \eta D.$$

From the data as it is presently available from the network operating company contains information about the transmitter output power. It does not provide information about the antenna's feed port reflectivity and, therefore, lacks information about the actual power accepted by the antenna. In particular, when antenna reflectivity degrades due to wetness of the radome, part of the transmit power will get reflected back to the transmitter. This effect will reduce the RSL even though it is not represented by the monitored value of the transmit power level. The WAA of a single antenna relative to the dry case is:

$$\mathrm{WAA}^{-1} = \frac{(1 - |\Gamma_{\mathrm{wet}}|^2)\eta_{\mathrm{wet}} D_{\mathrm{wet}}}{(1 - |\Gamma_{\mathrm{dry}}|^2)\eta_{\mathrm{dry}} D_{\mathrm{dry}}}$$

Furthermore, it is possible to determine these three antenna parameters by an electromagnetic simulator like CST and also by a measurement in an anechoic chamber.

3. Numerical Study of WAA

In this section the influence of water on a radome is shown by simulating an antenna with a water film covered radome. Highly directive commercial microwave link antennas are large compared to their operating wavelength. Additionally, they contain a rather complex interior structure. Therefore, their simulation is a numerically very large problem which requires computation in the order of several days with our equipment. In order to do a parameter study within reasonable time, we use a model of a simpler and smaller horn antenna to study the wet antenna effect by making a full-wave analysis. On the surface of the radome, a thin film of water is added and the parameters (directivity, efficiency and reflectivity) of the antenna are computed. By varying the thickness of the water film in the CAD model (see Fig. 1) and the following full-wave analysis using version 2015.06 of CST MICROWAVE STUDIO®, we obtain the dependence of the antenna parameters on the water thickness. To derive the receptivity from the reflectivity Γ we use the relation:

$$\mathrm{receptivity} = 1 - |\Gamma|^2$$

The results of the simulations are shown in Fig. 2. To resemble the configuration of the subsequent experimental measurements, a polyester film with the thickness of 0.1 mm is also added to the water film in the simulations. Thus, a better comparison between the results of the simulation and the experiment can be achieved. To model the electromagnetic properties of the transparency film a relative permittivity of 2.8 is assumed.

4. Experimental Study of WAA

The manufactured horn antenna mounted in the sprinkler is shown in Fig. 3. It has the same geometry as the antenna model in the numerical study above with a square aperture with a side length of 50 mm. The measured frequency is 18 GHz and the antenna is fed by a WR42 rectangular waveguide. To create a homogeneous water film, the water runlets from the water distributor are caught between the radome and a transparency film made of polyester with a thickness of 0.1 mm and a width of 85 mm. The thickness of the water film between the radome and the transparency film is tuneable by manipulating the water flow.

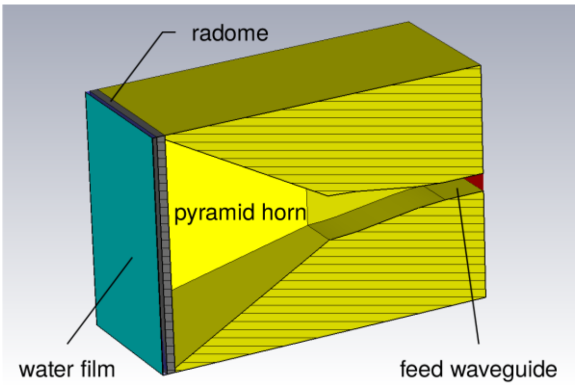

Figure 1. Cross section of the horn antenna CAD. Right: WG42 rectangular waveguide for stimulation of the antenna. On the left side the radome (2 mm thick) is covered by a water film and a membrane (turquoise sheet). The aperture of the antenna is 50 mm x 50 mm and the length of the antenna is 80 mm. The geometry equals the one of the manufactured antenna.

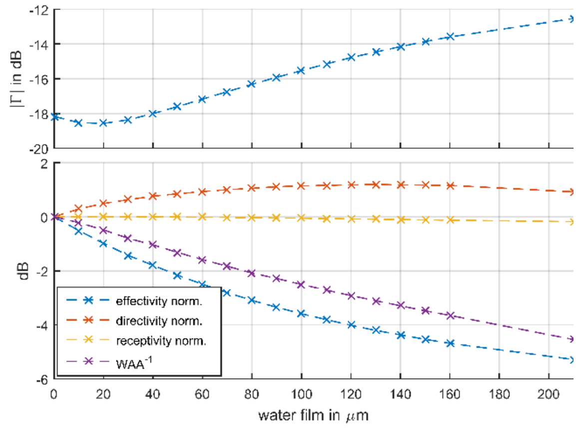

Figure 2. Top: Simulated (frequency domain solver) result of the reflectivity Γ depending on the water film thickness. With increasing thickness, the reflection increases, too. Bottom: WAA and its components (efficiency, directivity and receptivity) depending on water film thickness. For increasing water film thickness the directivity increases, too, but the losses in the water film rise and so the efficiency decreases. The influence of the reflectivity is low and combining all three components we see that the WAA is increasing with increasing water film thickness.

Flow control is implemented by a controlled pump and a flowmeter. In Fig. 4 the whole set-up in the anechoic chamber at the Technical University of Munich is shown.

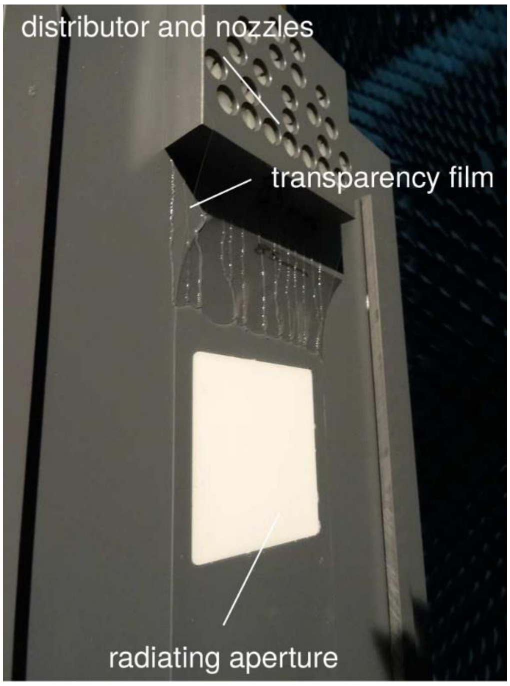

Figure 3. Close-up of the horn antenna mounted in the sprinkler. The white square in the middle is the radome (polystyrene) of the antenna and the grey area is made of polyvinyl chloride (PVC). The sprinkler nozzles distribute the water flow and the membrane (polyester) generates a thin water film coating the radiating aperture.

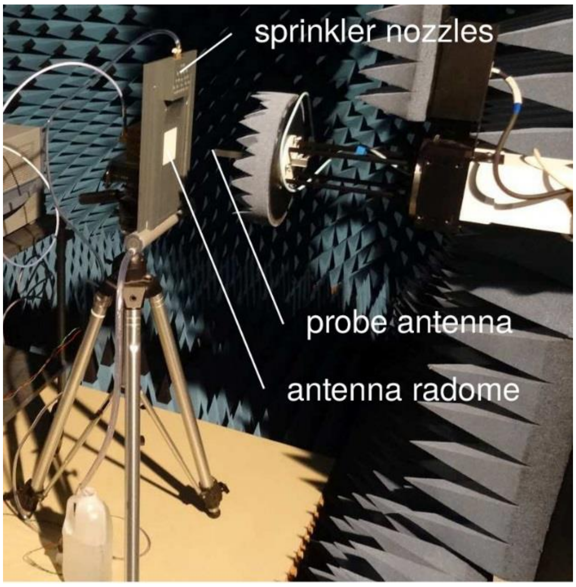

Figure 4. Set-up with the antenna in the anechoic chamber. Left: horn antenna mounted in the sprinkler. Right: near-field scanner. Bottom left: reservoir of the circular water flow.

After scanning the antenna's near-field with a near-field scanner by Nearfield Systems Inc. (NSI) at different water flows, the two parameters directivity and efficiency are computed with the software NSI2000. Also the reflectivity of the antenna is measured at the different water flows with a vector network analyser. In Fig. 5 the three antenna parameters are shown in relation to the water flow.

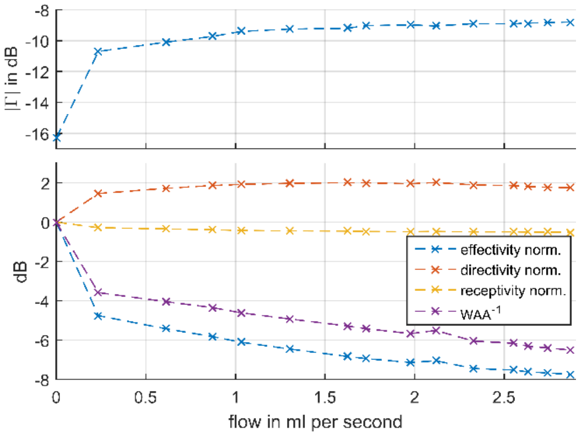

Figure 5. Top: Measurement result of the reflectivity Γ depending on the water flow and consequently on the water thickness. The reflectivity is very sensitive for very thin water films. Bottom: WAA and its components (efficiency, directivity and receptivity) depending on the water flow. The plot shows a behaviour comparable to the full-wave simulated results in Fig. 2.

5. Conclusion

A modification for RSL-models which includes not only the gain but also the reflectivity of the antennas was presented. Furthermore, the three antenna parameters which are relevant for the total WAA (directivity D, efficiency η and reflectivity Γ) are investigated in a full-wave simulation and are also measured under laboratory conditions in an anechoic chamber. The influence of the water film on the antenna parameters was shown and the parameters indicate comparable characteristics both in simulation and experiment. It was also shown that the reflectivity Γ is an indicator for the WAA (cp. [6]). Due to the fact that the reflectivity is easy to measure, this is a possibility to detect and estimated WAA in commercial microwave links of the next generation. For future studies it is necessary to study thinner water films (less than 0.25 ml per second) to increase the measurement resolution in the range of small water film thickness, as they occur in reality on the vertically oriented radomes of commercial link antennas. Therefore, it is planned to modify the test set-up to implement lower flow rates. For a better comparison between the results of the simulation and the experiment, a possibility to measure the thickness of the water film is additionally needed.

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