Performance of a Yagi Antenna During Snowfall

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Abstract

Precipitation in the form of snow could severely degrade the performance of the planned EISCAT_3D radar antenna array. In this paper the performance of the antenna elements, crossed yagi antennas, is studied using both simulations and measurements. The results shows that during snowfall the performance of the antenna is degraded, and under severe conditions the antenna becomes non-operational. To guarantee operability of the system, the effect of snow cover should be taken into account when designing the final antenna.

1. Introduction

Antennas operating in an arctic environment may have their properties degraded significantly due to snow falling on the antennas. This could cause severe problems for applications where high accuracy is crucial, such as antenna arrays. In this paper, the performance of a dual polarized crossed yagi antenna during snowfall is investigated using both measurements and simulations.

The antenna studied here is currently used as an antenna element in the EISCAT_3D test array, which is used to test radar hardware for the planned upgrade of the EISCAT radar in northern Scandinavia [1]. It consist of 48 crossed yagi-antennas operating at 224 MHz with 6 MHz bandwidth and have separate channels for both polarizations. The array is a receiving antenna for the EISCAT VHF transmitter in Tromsø, Norway. The final EISCAT_3D radar antenna is expected to have several thousands of elements, which means that even a small error in the individual antenna elements may results in a significant error in the beam shape and pointing direction.

The performance of antennas during different weather conditions, particularly snowfall, have received significant attention. The effect a snow cover have on the input impedance of an antenna element in an array was studied experimentally in [2] where an array of dipoles was cover with snow layers of different depths. It was here found that the performance of the antenna array was degraded successively with increasing depth of the snow layer. The effect of snow accretion on reflector antennas have long been of interest in the Nordic countries. This was studied in [3] where it was found that the beam shape and pointing direction can be severely distorted under such conditions. The investigation presented in this paper is limited to the effect a snow cover could have on the reflection coefficient of the antenna. This was measured during a snowfall and compared to meteorological data from the same period. The measured results are also compared with simulations done using the method of moments (MOM).

2. Dielectric Properties of Snow

Most work on determining the dielectric properties of snow has been done by the remote sensing community, where the main interest is the permittivity, which is important when determining refractive index and reflection coefficient. In [4], a theoretical model of the permittivity of snow is presented with the snow being modeled as a mixture of ice grains, water, and air. For dry snow the single most important factor affecting the permittivity is the density [5]. The permittivity of snow is complex, although the imaginary part is often neglected [6] since it is considerably smaller than the real part. It is, however, included here for completeness. A more comprehensive model including both the real and imaginary parts and their dependence on factors such as frequency, density, water content, temperature, and pollution effects is presented in [7]. So far only the permittivity of snow has been considered although limited information on the conductivity can be found in the literature [8]. The permeability can be assumed to be very close to unity.

In this paper, the interest is in the performance of snow covered antennas and only the permittivity is considered. The real part of the permittivity depends mainly on the density and water content, although both temperature and pollution have a certain effect. The latter factors are, as mentioned above, included in the model presented in [7] but will be neglected here for simplicity. The relative permittivity, ε_{rs}, of snow is in [7] given by

$$\mathrm{Re}\{\varepsilon_{rs}\} = 1 + 1.7\rho_d + 0.7\rho_d^2 + 8.7W + 70W^2, \tag{1}$$

where ρ_d is the relative density of snow compared to water, and W is the water content by volume. For the imaginary part, only the frequency and water content is of importance, and this relationship is given by

$$\mathrm{Im}\{\varepsilon_{rs}\} = \frac{f}{10^9}\left(0.9W + 7.5W^2\right), \tag{2}$$

where f is the frequency. From Equation 1 it is found that the real part of the relative permittivity has a maximum of about 3.7 for heavy and wet snow (density of 600 kg/m^3 and 10 % water by volume) while the imaginary part is significantly lower with a maximum of 0.037. It should be noted the most heavy and wet snow is most likely to stick to surfaces and objects why this is also of most interest here.

3. Simulations

In this Section the antenna's performance when influenced by snow is simulated using a commercial MOM software. The antenna is a dual polarized crossed yagi-antenna consisting of a feed element, which is a folded dipole, a reflector element, and three parasitic elements. The polarizations have an offset of about 0.33 m (corresponding to a phase-shift of approximately 90° at 224 MHz. In this paper only one of the polarizations have been studied. It is assumed that the supporting bar have a negligible effect on the properties of the antenna.

In the simulations the snow has been modeled as a complex dielectric medium as described above assuming a density of 600 kg/m^3 and a water content of 10 % (by volume). The real and imaginary parts of the relative permittivity is then 3.7 and 0.037, respectively. This snow is heavier and contains more liquid water than the snow that typically falls during winter but it should have the most severe effect on the antennas as it have a large permittivity. It is also expected that this is the type of snow that would stick most efficiently to the antennas.

In Fig. 1 the simulated return loss is shown for a bare antenna and an antenna covered with 0.5 mm and 1 mm of snow uniformly distributed on all conducting parts. The operating band of the antenna is shifted significantly down in frequency even for thin layers of snow. This is consistent with analytical results for an antenna covered with a dielectric material with large real part of the permittivity [9]. The lowest return loss should decrease when the antenna is covered with a dielectric. This can be seen for a thin coating of snow but as the thickness of the snow coating is increased the effect is reduced by limited bandwidth of the balun. It should be noted that in reality, the snow will be distributed on one side of the wires only instead of coating the entire wire and the simulations therefore gives a conservative estimation.

4. Measurements

The return loss of the antenna was measured continuously on January 18-21, 2008, in Luleå, Sweden. During this period, a considerable amount of snow fell and the temperature oscillated around 0°C which resulted in a very heavy and wet snow/rain mix. In Fig. 2 the return loss of the antenna is shown for a frequency of 224 MHz (top right). It is also shown as a function of frequency (left) for two selected occasions marked in the plots to the right. In addition, the center frequency and bandwidth of the antenna is shown as well as the measured precipitation at a meteorological station in Luleå (this data was provided by the Swedish Meteorological and Hydrological Institute). Before any snow fell on the antenna the bandwidth was 6 MHz and the band was centered around 224 MHz. At the onset of the snow (close to midnight on January 19) the return loss is increased dramatically and the antenna is non-operational

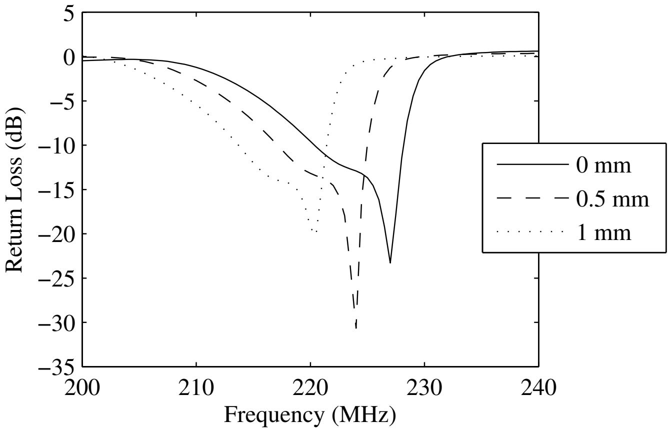

Figure 1: The simulated return loss of a crossed yagi antenna covered with snow.

during this period. The reason for the increased loss is that the whole band of the antenna is shifted downward in frequency until it is entirely outside of the desired band. This behavior can be seen in the plots of the center frequency and bandwidth. In the plot of precipitation there seem to be a discrepancy between the start of the snow as indicated by the antenna measurements and the measured precipitation. This is most likely due to the distance between the meteorological station and the location of the antenna measurements.

5. Discussion and Conclusions

The return loss of an antenna when covered by snow has been simulated using models of the permittivity of snow. It was also measured during a period with significant snowfall. The results shows clearly that snow covering antennas could alter the characteristics of an antenna significantly which could be serious problem in cases when it is important that the antenna is operational continuously.

Possible solutions to the problem are to place the antenna in a radome. This is, however, not practical in the EISCAT radar due to the physical size of the antenna. For the same reason heating the antenna elements is not a realistic option. To be able to have continuous operation of the antenna it should therefore be designed with a larger bandwidth than needed in order to be able to handle both the shift in frequency and the narrowing of the operational band.

So far, only the return loss of a single yagi-antenna have been studied. It is, of course, important to study the radiation pattern of the antenna and the characteristics of the antenna when placed in an array.

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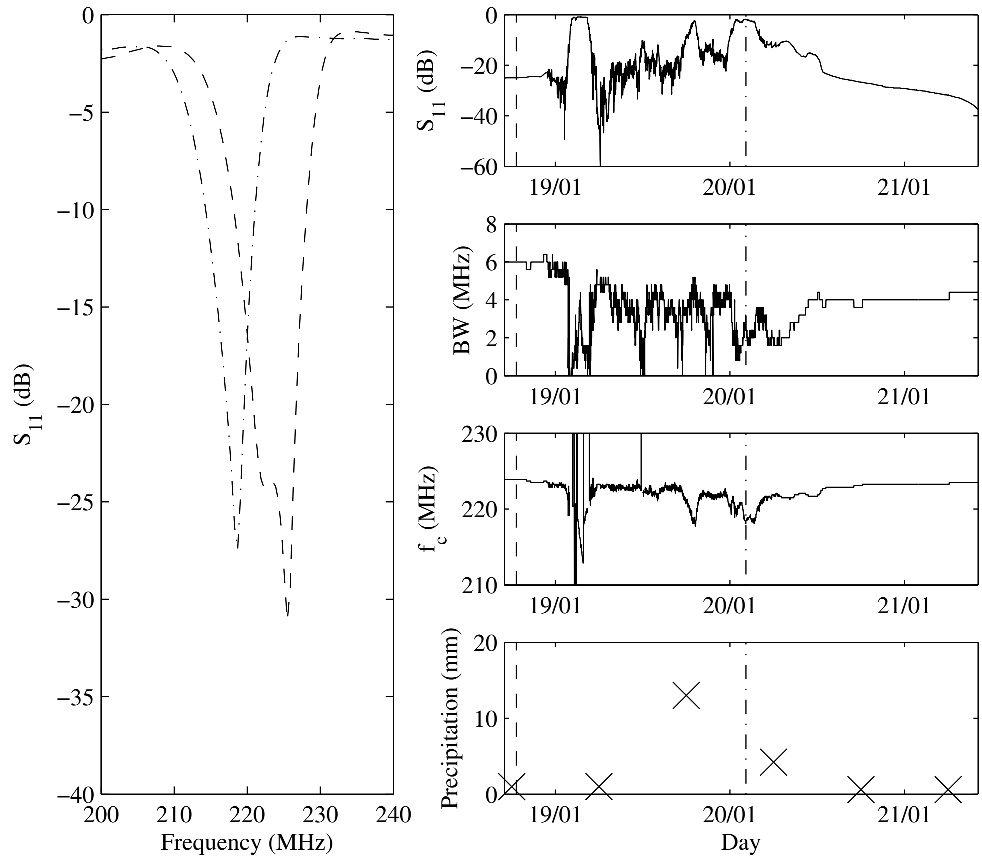

Figure 2: The measured return loss at 224 MHz (S_{11}), bandwidth (BW), center frequency (f_c), and precipitation during snowfall. To the left the return loss is shown as a function of frequency for two selected occasions. These are marked in the plots to the right with dashed and dash-dotted lines, respectively.

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