Extended Characterisation Of A UHF Direction Finding Antenna With Optimised Radar Cross Section

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***Abstract*— In [1] the design of a UHF direction finding antenna with optimised radar cross section (RCS) was introduced. In the present paper the monostatic RCS of the antenna is characterised up to 18 GHz. Measured results of the RCS are compared to simulated results which are obtained using the new commercially available multilevel fast multipole method (MLFMM) [2].**

I. Introduction

A modern state of the art direction finder system consists of several direction finding (DF) antennas and the direction finder itself. The direction finding antenna system is designed for most accurate results, and often is built using a circular antenna array. On the other hand there are well known design rules for radar cross section (RCS) optimisation of different vehicles, planes and ships. Combining these two different fields of research aims at a new design of a RCS optimised direction finding antenna and leads to an increased number of design parameters which have to be considered. In this paper a solution for a fully featured RCS optimised DF-antenna design is explained in detail.

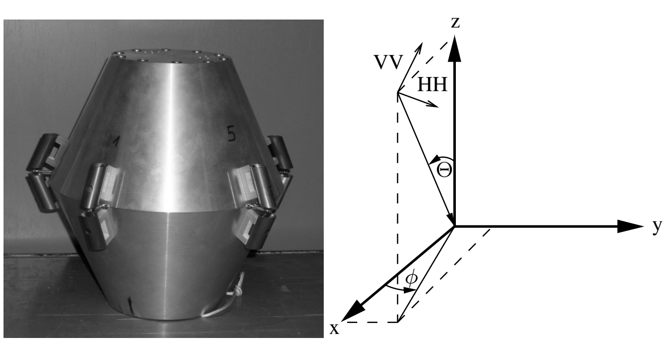

Fig. 1. DF-antenna prototype and the used coordinate system.

II. Antenna description

The introduced UHF DF-antenna consists of five dipoles positioned on a circle in front of a reflector. Figure 1 shows the prototype of the UHF DF-antenna. A beamforming algorithm as proposed in [3] is used to obtain the direction of the incident wave, which can be seen as an interferometric evaluation of the phase of each antenna. The DF-functionality should be fulfilled from 800 MHz up to 3 GHz and also the DF-sensitivity requirements should be met. To achieve the required low monostatic RCS in the elevation sector $\Theta = 65^\circ \cdots 115^\circ$ and for all azimuth angles, a method called shaping is applied. Using this method the antenna is formed in a way that the incident waves are reflected away from the transmitter and therefore the monostatic RCS is reduced. Hence the reflector is bent and formed out of two frustums, and also the dipoles are bent to fit to the reflector.

III. DF functionality

Figure of merits for the DF functionality are the RMS DF-error and the DF-sensitivity which are depicted in Figure 2 and 3. They were obtained by using a commercial 5-channel broadband direction finder. The RMS DF-error per frequency

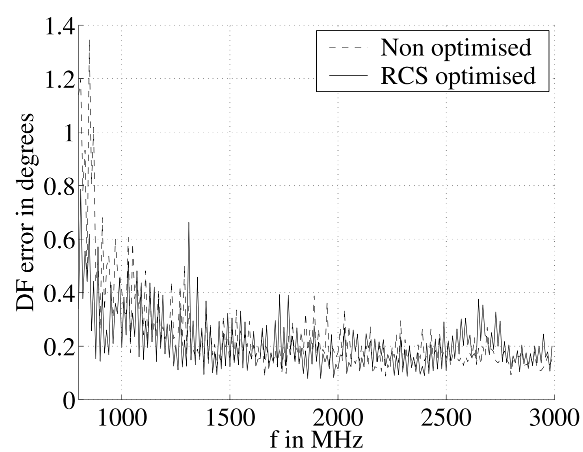

Fig. 2. RMS DF-error.

is a figure of merit for noise independent system errors and measured with sufficient S/N ratio. It is defined as

$$\mathrm{DF}_{\mathrm{error}} = \sqrt{\frac{\sum_{i=1}^{n}(e_i - e_A)^2}{n}} \quad \text{with} \quad e_A = \frac{\sum_{i=1}^{n} e_i}{n} \tag{1}$$

where e_i is the error at the i^{th} azimuth angle and n the number of azimuth angles. e_A is the so called A-error which stems from the misadjustment of the antenna mounting.

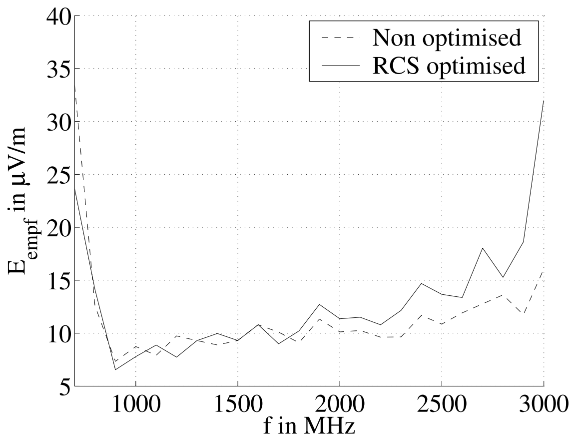

Fig. 3. DF sensitivity.

The DF-sensitivity is defined as the E-field strength for which the statistical spread of the bearing is less than 1° using a certain set of DF-parameters such as the integration time bandwidth product $B \cdot T$, the bandwidth and the filtering of the direction finder equipment.

Figure 2 shows a comparison of the measured DF-error of a non RCS optimised commercially available antenna and the RCS optimised prototype. The commercially available antenna acts in an analogous manner (five dipoles positioned on a circle in front of a reflector) like the RCS optimised prototype. It can be seen that the RCS optimised design performs as good as the non optimised design.

In Figure 3 the measured sensitivity of a non optimised and an optimised design is depicted. By comparing the two curves it can be seen that the sensitivity of the RCS optimised design at low frequencies is slightly better than the sensititivity of the non optimised design. For high frequencies it is reversed which implies a slight frequency shift between the designs.

IV. Radar Cross Section

The simulation and measurement results of the RCS shown in [1] are limited to the frequency range from 2 GHz up to 8.5 GHz. A new commercially available simulation technique called MLFMM [2] is used to obtain simulation results up to 14 GHz. The measurement was done up to 18 GHz in a 25 m long anechoic chamber in order to meet farfield conditions, using a vector network analyser. Fourier transformation, range gating and background subtraction were performed in order to obtain only the scattered fields of the object. Unlike the mounting with non metallic strings in [1], the object was mounted on a frustrum made out of material which has the permittivity ϵ_r close to air (Figure 4). It turned out that this mounting is superior regarding the stable support of the object and the scattering properties. No degradation of the measured RCS due to the mounting could be observed. As calibration, a measurement with a hollow stainless steel sphere using the same mounting was performed. All RCS results, measurement and simulation, given in this publication are normalised with respect to the maximum RCS at 14 GHz of a cylinder with same volume and height as the prototype. This normalisation was chosen due to the fact that the form of a non RCS optimised UHF DF-antenna is similar to the cylinder.

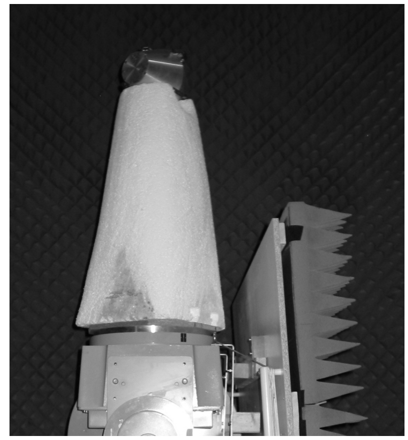

Fig. 4. DF-antenna prototype mounted on the turntable.

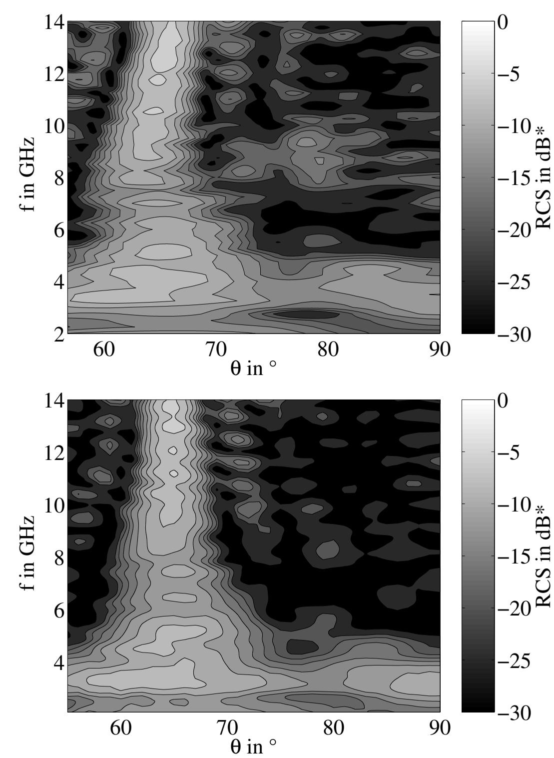

Fig. 5. Simulated (top) and measured (bottom) results at $\phi = 36°$ for vertical polarisation.

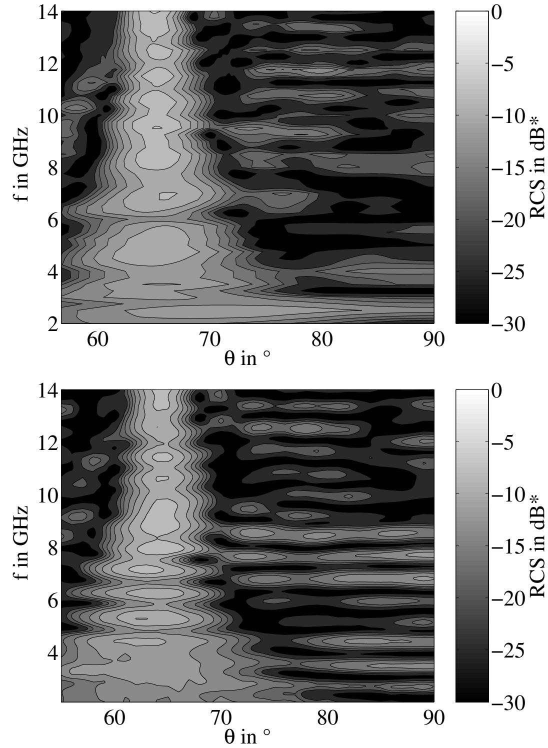

Fig. 6. Simulated (top) and measured (bottom) results at $\phi = 36°$ for horizontal polarisation.

The results shown in Figure 5 for vertically polarised transmit and receive signals and in Figure 6 for horizontally polarised transmit and receive signals show a good agreement between the results obtained by simulation and by measurement. For other angles ϕ the results also agree very well.

It can be observed that the maximum of the monostatic RCS is around $\theta = 64°$ which can be explained by the reflection on the frustrum. The incident wave is perpendicular to the lateral area of the frustrum and reflects directly back. I can be also seen that the focussing of this reflection increases with decreasing wavelength compared to the lateral area as expected. The increased RCS for vertical polarisation (Figure 5) around 3 GHz and $\theta = 80° \dots 90°$ stems from the dipoles which are still in the operating frequency band. For horizontal polarisation the dipoles are not excited by the incident wave, and therefore no reflection occures (Figure 6).

Furthermore, Figure 7 shows the measured results up to 18 GHz, where even the MLFMM simulation method needs too much system resources as well as computation time to simulate the RCS in these sectors of angles. It can be seen that the results of the measurement up to 18 GHz and the simulation results show a considerable reduction of the RCS in the required elevation sector of at least 12 dB compared to the cylinder. This reduction of the monostatic RCS corresponds to a reduction of radar range to a half according to the well known radar equation.

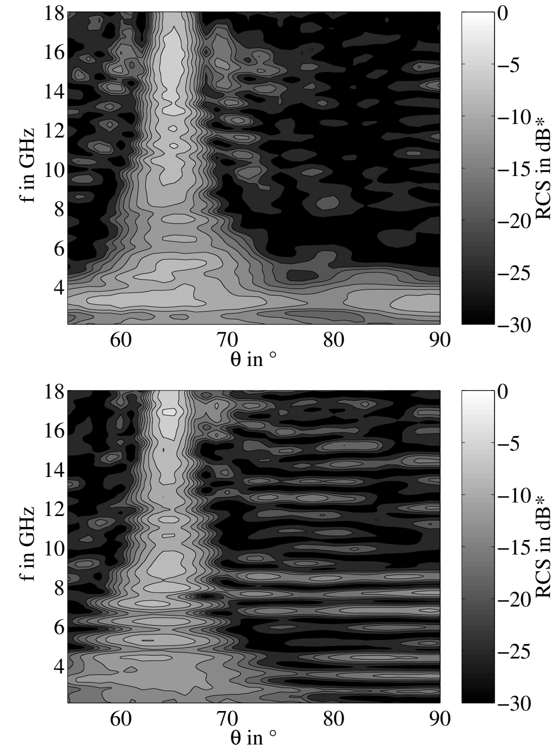

Fig. 7. Measured results at $\phi = 36°$ for vertical (top) and horizontal (bottom) polarisation.

V. Conclusion

The presented UHF antenna design shows no degradation of the DF-error and DF-sensitivity compared to a non RCS optimised antenna design. By application of the MLFMM simulation method the frequency range of the simulation could be extended to 14 GHz whereas the measurement was performed up to 18 GHz. The simulated and measured results show good agreement as expected. The presented RCS optimised UHF antenna shows the expected good results of the RCS reduction in the desired elevation sector covering the C, X and Ku band.

References

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