Investigation of Wideband Millimetre-Wave Reflectarrays for Radar Applications Operating in the W Band

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Abstract— **This paper describes the investigations conducted at the LEAT for wideband reflectarrays. Two antenna structures are presented. The first one is an offset reflectarray operating at the centre frequency of 94 GHz with a prolate horn as primary feed for wideband operation purpose. 17% gain bandwidth at 3 dB was obtained. The second one is a cosecans square folded reflectarary operating in the76-81 GHz band.**

I. Introduction

Nowadays, the millimetre-wave radars are widely used in the civil applications like adaptive cruise control or helicopter crash avoidance [1]. It requires an antenna system of high gain, low side lobes and low profile. Printed reflectors or reflectarrays have become the best solution against parabolic reflectors or lenses, due to their low cost, low profile and fabrication facilities [2,3]. Recently, the 77 GHz band has been extended to 76-81 GHz resulting in an increasing interest for wideband reflectarray operating at millimetre–waves. Different solutions to obtain an enhancement of the reflectarray bandwidth are proposed in the literature [4]. One of them consists to use radiating elements having several stacked patches [5]. However, this solution is more complex and more expensive compared to single layer structures. Single layer solutions exist [6,7]. They are based on specific radiating elements improving the reflectarray bandwidth.

Two antenna structures are presented. Section II describes the offset reflectarray operating at the centre frequency of 94 GHz with a prolate horn as primary feed for wideband operation purpose. 17% gain bandwidth at 3 dB was obtained. The third section deals with a cosecans square folded reflectarary operating in the76-81 GHz band.

II. Wideband offset reflectarray

To avoid blockage, which degrade measurements, an offset fed reflectarray has been developed. The diameter of the reflectarray is 130 mm and the f/D ratio is equal to 1. The primary source's offset is -27° (Fig.1), the main radiation is in the direction 27° and the operating frequency is 94 GHz.

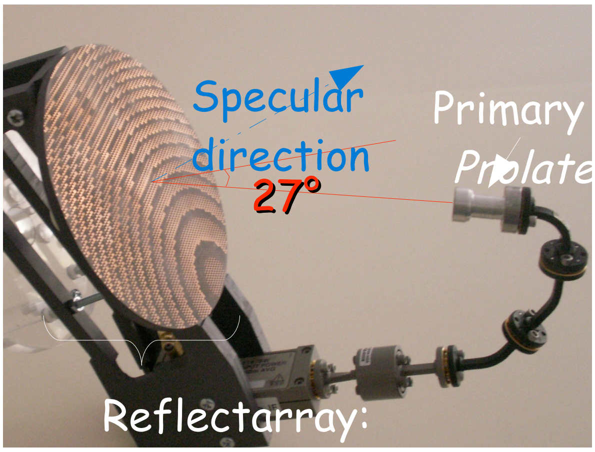

Fig. 1 Photo of the 94 GHz offset reflectarray

The reflectarray is composed of rectangular patches etched on a single layer duroid substrate. The patch dimensions are calculated with Ansoft-HFSS for obtaining the desired reflection phase to compensate for the propagation delay.

The primary feed (Fig. 2) is a small horn antenna (length: 24mm, width: 12.6 mm) whose radiation pattern is as close as possible to a prolate spheroidal function [8]. This function is known to produce an apodization window that drastically reduces the side lobes. The horn radiation patterns and measured gain are shown in Fig. 3 in the W-band.

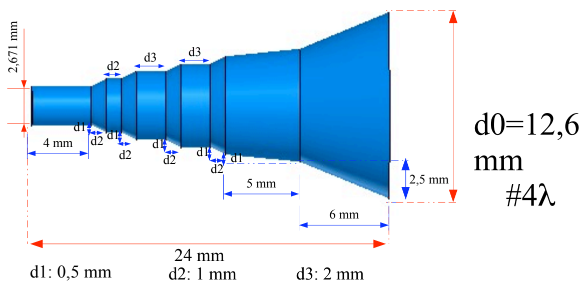

Fig. 2 Primary feed dimensions

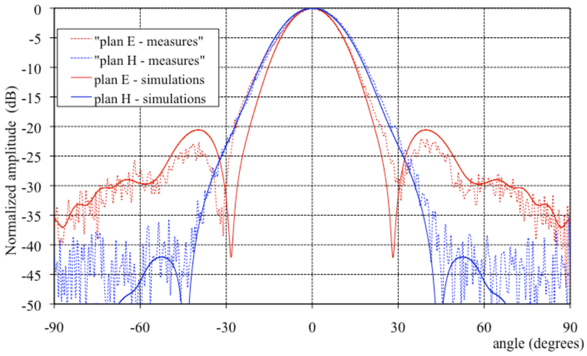

Fig.3.a Radiation pattern of the primary feed

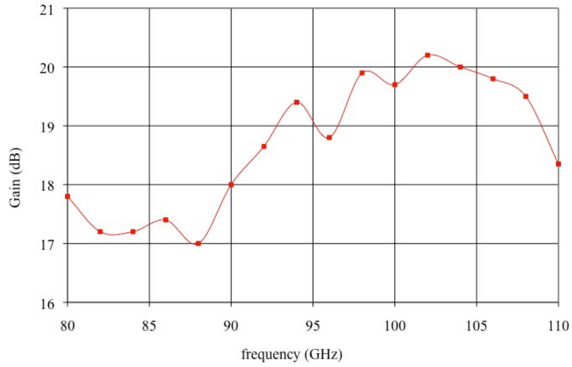

Fig.3.b Measured gain versus frequency

The overall radiation pattern of the reflectarray is shown in Fig. 4 and compared to the simulation.

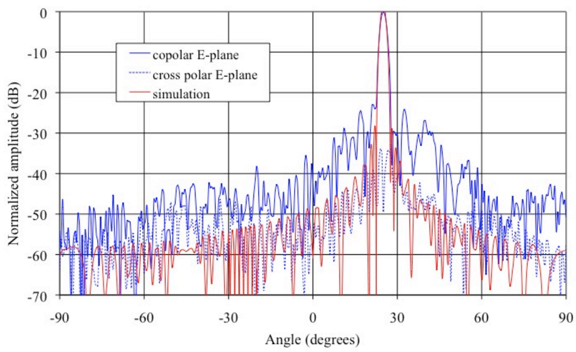

Fig.4. Radiation pattern at 94 GHz

The simulated results are obtained thanks to a program we developed and which is based on an equivalent aperture method for computing the radiation pattern.

The method we used takes into account the primary feed radiation pattern, its aperture blockage and the spillover but neglects the coupling between cells, the edge diffraction, the ohmic and dielectric losses and the surface waves.

The reflectarray is divided into square cells referenced by the integers (i,j).

The radiated field $\vec{E}_{ray}$ is the superposition of radiated fields by each cell ($\vec{E}_{ray} = \sum \vec{E}_{ray_{ij}}$). Each cell is assimilated to its equivalent aperture, so the complex amplitude of the far field is given by the formula:

$$\vec{E}_{ray_{ij}} = 2j\pi \frac{e^{-jkr}}{r} \vec{u} \times (\vec{E}_{0t_{ij}} \times \vec{u}_z) \quad (1)$$

where $\vec{E}_{0t_{ij}}(\alpha,\beta)$ is the 2D Fourier transform of the tangential electric field assumed to be constant on the cell and whose complex value is given by the radiation pattern of the primary source.

The gain variation versus frequency is plotted in Fig. 5.
The antenna exhibits 17% bandwidth centred at 94 GHz.

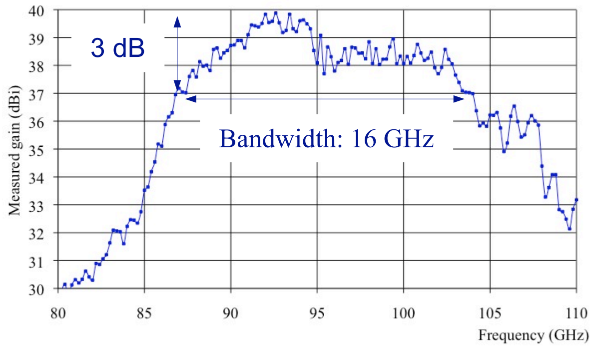

Fig. 5. Gain measurements

According to the prolate primary source properties, the radiation pattern has low secondary lobes. Further measurements have shown a good radiation pattern stability over the frequency bandwidth (Fig.6). The antenna aperture efficiency is 61% at 94 GHz.

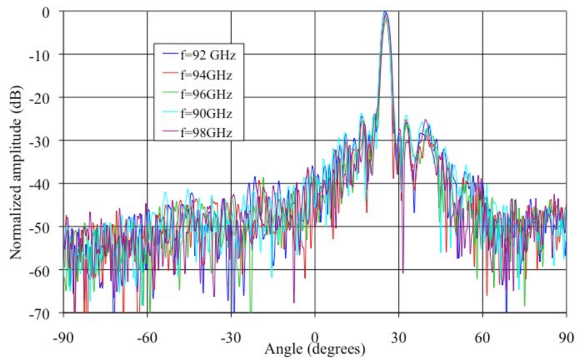

Fig. 6. Measured radiation pattern versus frequency

III. COSECANS FOLDED REFLECTARRAY FOR FOD DETECTION

The application of interest is shown in Fig. 7. The antenna for the FOD (Foreign Object Debris) detection radar will be used to detect misplaced objects. The overall system idea is to have several low-profile and low-cost mm-wave sensors placed beside the runway [9]. To keep the received power constant we use an antenna with a gain, which is proportional to the cosecans² function. Furthermore, a folded antenna is used for lateral compactness purposes [2].

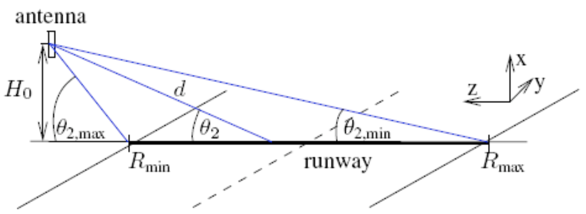

Fig. 7 Scenario for detection objects on the ground

A. Design and simulation Process

Radiation pattern investigations over a frequency between 76 and 81 GHz were done in simulations on circular reflectarrays. The process is shown below.

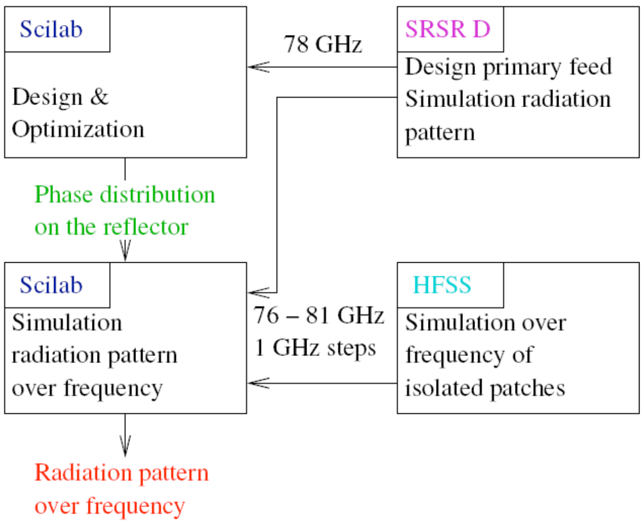

Fig. 8 Schematic of the design and simulation process

Simulations show a good frequency stability over 76 -81 GHz.

B. Simulation Results and Measurements

First, a primary feed was designed, fabricated and measured. The design rules are as followed:

(i) Classically, primary sources have to be as small as possible for reflectarrays applications because of the aperture blockage. In our case, i.e, folded reflector, the primary feed is located in the main reflector and the aperture blockage results in a loss of patches.

(ii) In the same time, it is important for our application to have a symmetrical radiation pattern in all the planes because it is one of the assumptions made in the design procedure. A small circular horn is a good candidate which fulfils both conditions provided that we add some steps to have the radiation pattern symmetric.

(iii) The radiation pattern has to be directive enough in order to get a proper aperture taper at the reflectarray edges. In our design the illumination angle is 45°. A parametric study was conducted during the design procedure (Fig. 8). The results showed that at least -10 dB are needed. It means that the horn diameter has to be larger that the one of the standard open-ended circular waveguide.

The circular horn geometry is shown in Fig. 9. It is designed with SRSRD [11].

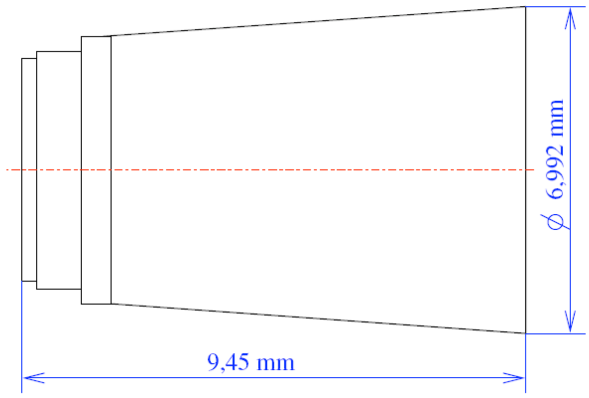

Fig. 9 Primary feed and associated dimensions

The radiation pattern of the primary source was measured in the E-, H- and 45°-plane. Afterwards these datas were filtered via a FFT with Scilab and compared with the simulation results (Fig. 10).

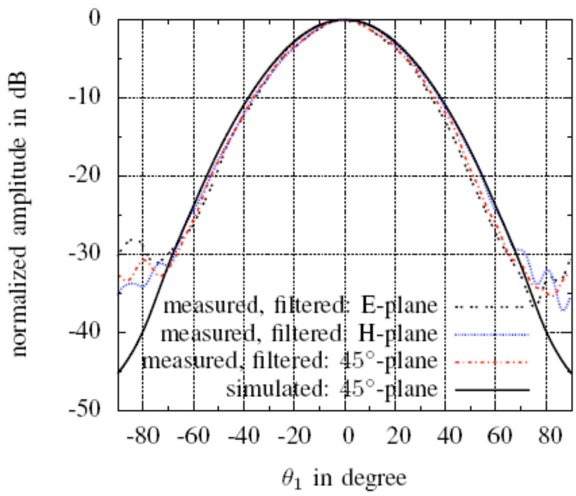

Fig. 10 Measured and filtered radiation pattern of the primary feed in the E-, H- and 45°-plane for 78 GHz and comparison with the simulated radiation pattern in the 45°-plane.

Very good agreement is obtained between the 45° plane and the simulations with SRSRD. Same agreement is observed in the E and H-planes but they have not been plotted for visibility reasons.

In a second step, the reflector antenna was fabricated. It is 120 mm diameter, with focal length to diameter ratio of 0.54. As it is a folded reflector this results in a 32.5 mm depth of the antenna. Picture of the main reflector is shown in Fig. 11. The phase profiles necessary for having square cosecans and pencil beams are obtained with single layer rectangular cells of 0.57*0.57λ containing rectangular patches. The cell dimensions are given at 78 GHz.

Measurements were conducted between 76 and 81 GHz. As the direction of the polarization of the outgoing wave is 45°

tilted to the pencil-beam-plane (Fig. 11), the electrical field was measured in this plane by turning the receiving antenna by 135° (Fig. 12). To measure the radiation pattern in the cosecans²-plane, the receiver was turned by 45°.

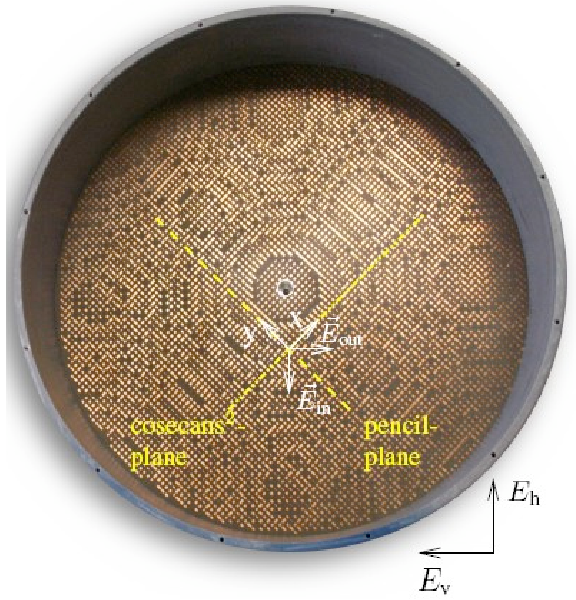

Fig. 11 Inlay of the folded reflectarray antenna with the primary feed and definition of the coordinates.

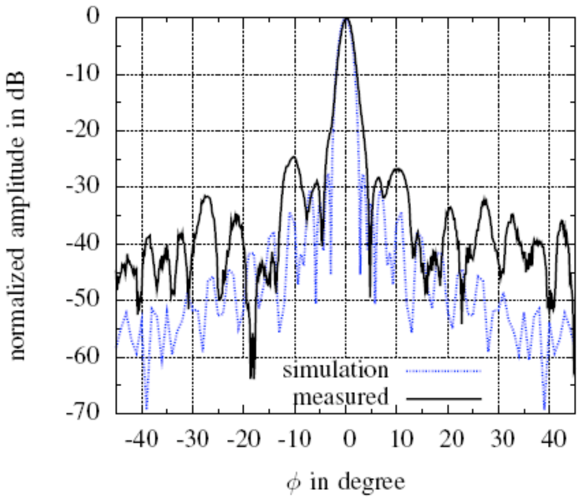

Fig. 12 Comparison of the measured and simulated radiation pattern for 78 GHz in the pencil-beam-plane.

To verify the measurements E_Φ and E_Θ were measured and out of it the E_v and E_h were calculated according to Ludwig [12] (Fig. 13). The first side lobe level in the pencil-beam-plane is below -20 dB for the frequency band of interest and the beamwidth less than 2.8°.

Gain measurements were also conducted they are reported in Fig. 14. The aperture efficiency is classically defined as:

$$\varepsilon_{ap} = \frac{G_{measured}}{(\pi D/\lambda)^2} \quad (2)$$

where D is the reflector diameter. Normally the aperture efficiency is given for a focused beam in both planes which is not the case here, so a further study should be conducted in order to evaluate the influence of a cosecans pattern on the efficiency drop.

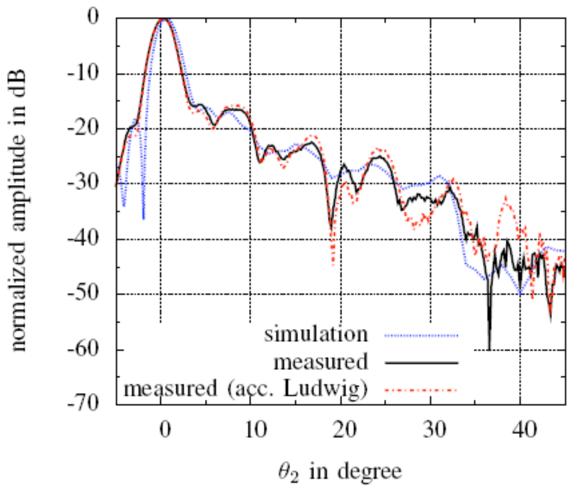

Fig. 13 Comparison of the measured and simulated radiation pattern for 78 GHz in the cosecans²-plane.

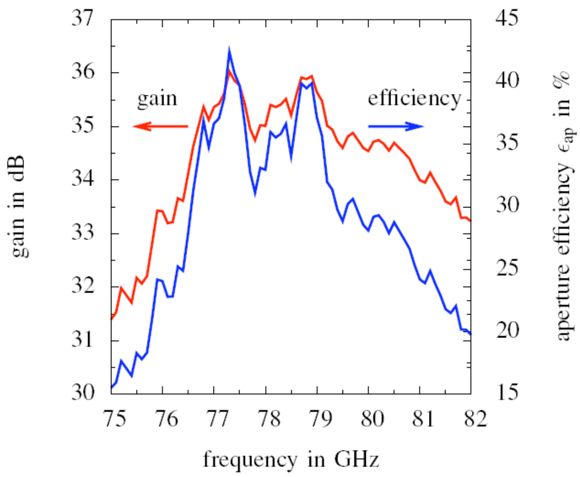

Fig. 14 Gain measurement and aperture efficiency

IV. Conclusion

Both antenna structures exhibit interesting properties for mm-Wave radar applications. The offset reflectarray, with 17% bandwidth is able to cover the wideband millimetre-wave standards. Nevertheless, its pencil radiation pattern and its long focal length to diameter ratio may be not suitable for on-board radar with more sophisticated antenna requirements. For this purpose, we designed a cosecans folded antenna operating in the 76-81 GHz band. Last but not least they are both made with classical printed techniques with a single layer structure. This enables an easy production which is an important advantage regarding low-cost and mass production.

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