A 77 GHz Eight-Channel Shaped Beam Planar Reflector Antenna

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***Abstract*— An eight channel planar dual reflector antenna to be used in a 77 GHz automotive radar sensor is presented. To meet the requirements of a combined medium and long range sensor, the antenna beams are shaped by use of dielectric radiators as feeds. These feed elements are designed to broaden particular beams either only in the azimuthal plane or in both planes.**

The characteristics of the feed elements were simulated using the Finite Integration in Time domain method (CST Microwave Studio). To predict the radiation pattern of the dual reflector antenna, the FIT simulation results served as input for a ray tracing based mathematical antenna model.

I. Introduction

The integration of different functionalities into one sensor system is the goal when developing a combined medium and long range automotive radar sensor. The possible applications range from simple obstacle detection at a distance of a few meters to sophisticated adaptive cruise control (ACC) features. The latter one should work in complex stop and go situations as well as at very high speeds.

Of course all these requirements can only be met with a multichannel sensor [1][2] together with a special antenna configuration as shown in Fig. 1 for an eight channel arrangement [3]. The forward looking beams have to be very narrow to cover a long range for high speed ACC and to associate vehicles to their lanes. In contrast, stop and go automation requires a wide angular coverage. Up to now this problems have been solved using multiple antennas with different beamwidths in the azimuthal plane or a multi-port Rotman lens [4].

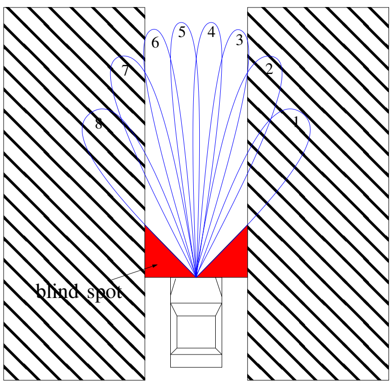

Fig. 1. Configuration of eight antenna patterns suitable for a combined medium and long range automotive sensor.

II. Antenna Principle

In [5] a multiple-beam planar reflector antenna was presented. The basic principle of this antenna is shown in Fig. 2. The antenna consists of two planar reflectors with an acrylic spacer in between. The lower reflector includes a polarization twisting, and the ground plane of the upper reflector is replaced by a grid. In this way, in one polarization, reflection phase angle is controlled, while the reflector is transparent in the other polarization.

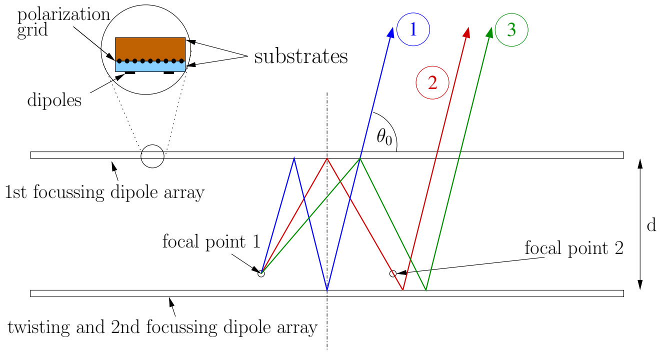

Fig. 2. Principle of the bifocal folded dual reflector antenna and three typical rays.

Due to the degree of freedom introduced by the use of a second planar reflector, it is possible to design an antenna with two symmetrical focal points (or a focal ring, if the rotational symmetry is taken into account). This allows an extended scanning range even for antennas with a comparatively short focal length as shown in [5].

III. Mathematical Model of the Bifocal Dual Reflector Antenna

As one can see from Fig. 3 the power radiated into one space segment $d\theta_1 d\varphi$ is mapped to a surface segment $dr d\varphi$. Let $S_p(r,\varphi)$ be the power density on the lower reflector and $I_f(\theta_1,\varphi) = S_f(\theta_1,\varphi,R)\cdot R^2$ the normalized distance independent radiation intensity in the farfield of the feed. Due

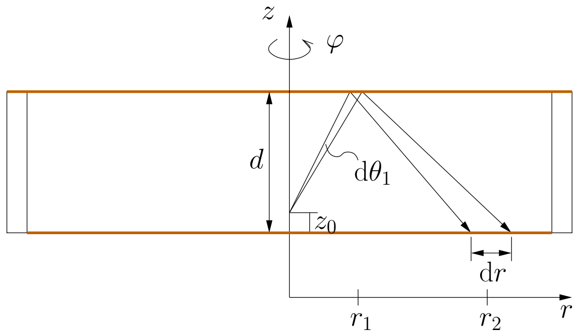

Fig. 3. Definition of the coordinate system und variables.

to energy conservation the following integral equation can be derived:

$$S_p(r,\varphi) \cdot r \cdot \mathrm{d}r\mathrm{d}\varphi = I_f(\theta_1,\varphi) \cdot \sin\theta_1 \cdot \mathrm{d}\theta_1\mathrm{d}\varphi \quad (1)$$

which leads to the magnitude of the electric field strength on the lower reflector:

$$|E_p(r,\varphi)| \sim \sqrt{\frac{1}{r} \cdot I_f(\theta_1,\varphi) \cdot \sin\theta_1 \frac{\mathrm{d}\theta_1}{\mathrm{d}r}} \quad (2)$$

In general, the differentation $\frac{\mathrm{d}\theta_1}{\mathrm{d}r}$ cannot be calculated analytically. Therefore, the simple first order approximation

$$\frac{\mathrm{d}\theta_1(r)}{\mathrm{d}r} \simeq \frac{\theta(r+\Delta r)-\theta(r)}{\Delta r} \quad (3)$$

was used in the numerical computation.

The phase of the electric field Φ_e can be calculated incorporating the geometrical path length Φ_{geo} and the additional location dependent contributions Φ_1 and Φ_2 made by the upper and lower reflector and the direction dependent feed characteristic Φ_f:

$$\Phi_e = \Phi_{\mathrm{geo}} + \Phi_1(r_1) + \Phi_2(r_2) + \Phi_f(\theta_1,\varphi) \quad (4)$$

Once the electric field on the lower reflector is known in magnitude and phase, the radiation pattern of the overall antenna can be calculated.

IV. Design of Dielectric Feed Elements

The desired broadening of particular antenna beams can be realized by reducing the beamwidth of the respective feed antenna in one plane. Usually a sectorial horn would be used for this purpose (cf. Fig. 4). By estimating the dimensions

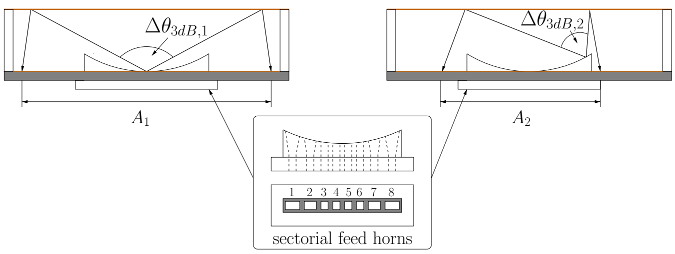

Fig. 4. Influence on the effective aperture by using feeds with appropriate beamwidths.

of such a horn it becomes obvious that this solution is not applicable in multibeam antennas, because the spacing of the feed elements is very dense. Alternatively, dielectric radiators [6] have been investigated.

Fig. 5 shows an example of a waveguide excited dielectric cuboid with a narrow beamwidth in the E-Plane (azimuth) and a wide beamwidth in the H-Plane (elevation). The respective measured radiation patterns are depicted in Fig. 6.

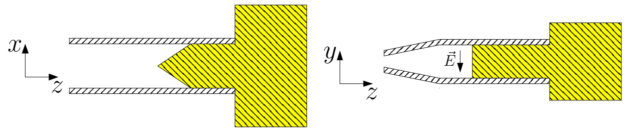

Fig. 5. Waveguide excited dielectric cuboid suitable as feed radiator.

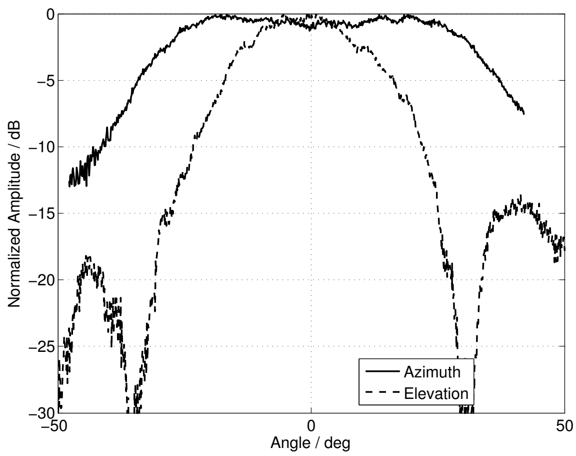

Fig. 6. Measured radiation pattern of the dielectric cuboid in azimuth and elevation.

Dielectric radiators are usually electrically small, and therefore a full wave simulation of such structures is easily possible. On the other hand it is very time consuming to use such simulators for the complete antenna. Therefore the simulated radiation pattern of this dielectric cuboid was used as input for the model described in section III. As a result the electric field on the main reflector's surface is obtained (Fig. 7). In the azimuthal plane only the center part of the reflector is illuminated whereas in the elevation plane the complete aperture is covered.

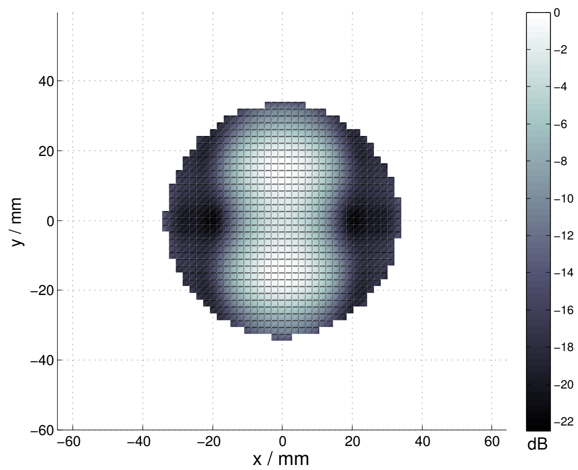

Fig. 7. Normalized electric field strength on the lower reflector.

The resulting simulated and measured radiation patterns of the bifocal dualreflector antenna using this feed element are shown in Fig. 8 and Fig. 9. As required, the half power beamwidth is about 8° in the azimuth and 4° in the elevation.

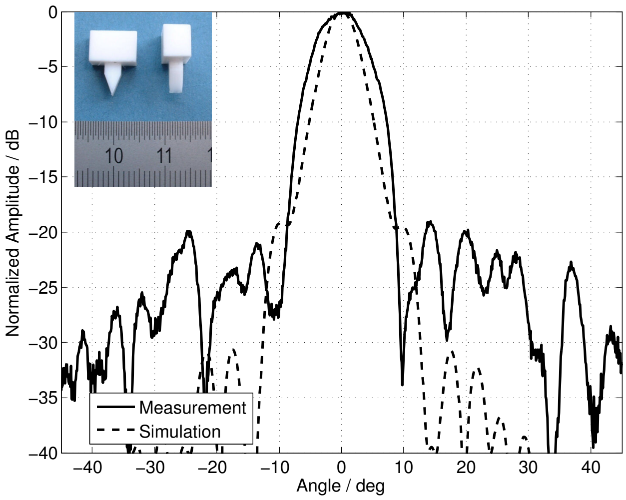

Fig. 8. Simulated and measured radiation pattern of the folded antenna in the azimuthal plane using a dielectric cuboid as feed element.

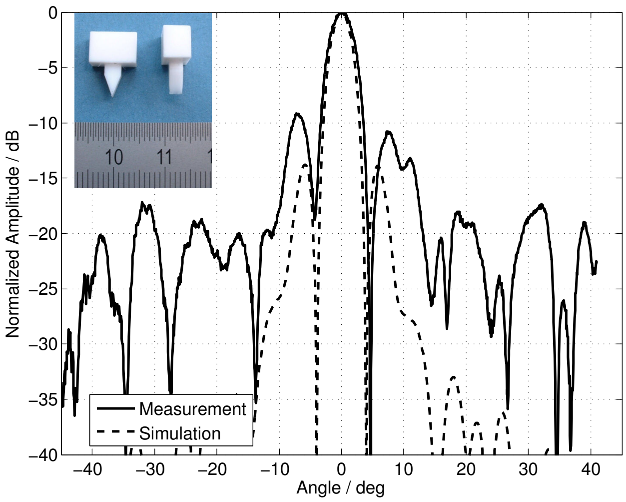

Fig. 9. Simulated and measured radiation pattern of the folded antenna in the elevation plane using a dielectric cuboid as feed element.

In general the measurement results match the simulation satisfactorily. Deviations can be explained by the fact that the measurements were done using the eight-channel feed fixture of the final antenna (cf. Fig. 11). In the simulation the feed elements were assumed to be centered which was not possible during the measurement due to the even number of feed radiators.

Unfortunately, two dielectric radiators of the presented kind cannot be used next to each other due to strong mutual coupling. In order to overcome this problem also dielectric rods [7] have been investigated. Due to their symmetry the use of such rods leads to broadened antenna patterns in azimuth *and* elevation. This would be disadvantageous for the long range central beams. But for the most outer beams, which usually have to provide only short distance detection, this is not a problem. In Fig. 10 the simulated and measured radiation pattern of the folded antenna is shown using a dielectric rod as feed element. Due to the symmetry only one plane is shown. Again the measurement result matches the simulation quite

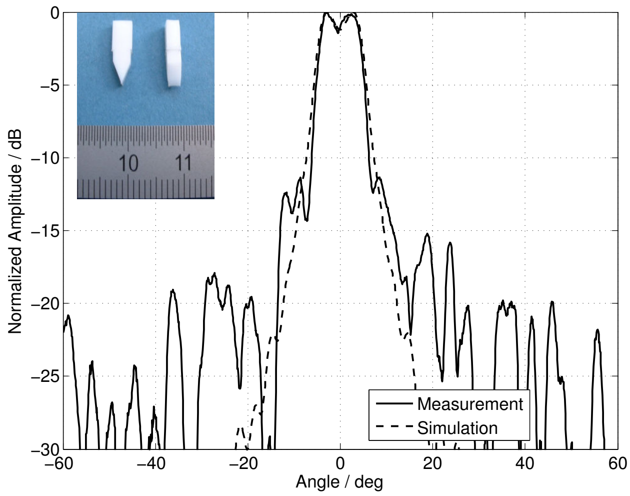

Fig. 10. Simulated and measured radiation pattern of the bifocal dualreflector antenna with a dielectric rod as feed element.

well. Even the 1.5 dB ripple within the main beam can be observed.

The final eight-beam antenna incorporates two dielectric cuboids, two dielectric rods and four open ended waveguides as feed radiators. The measured radiation diagrams together with the eight-channel feeding structure can be seen in Fig. 11. In principal the design goal could be met. The beams 1, 2,

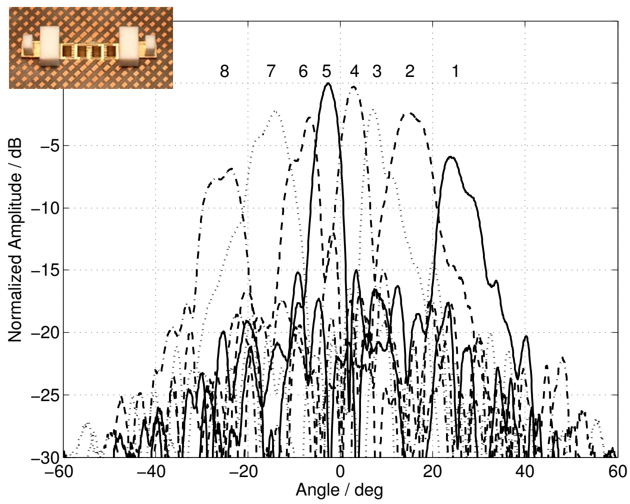

Fig. 11. Measured radiation patterns of the eight beam antenna.

7 and 8 could be broadened significantly compared to the inner beams 3, 4, 5 and 6. Mutual coupling between the feed elements could not be avoided completely. As a result beams with adjacent dielectric fed beams are not perfectly symmetric.

V. Conclusion

A design principle for shaped beam reflector antennas has been presented. The beam shaping was achieved by using primary feeds with appropriate patterns. For the simulation of the overall antenna the full wave simulation results of the feeds have been incorporated in a quasi-optical mathematical model.

It has been shown that even multi-channel antennas with a short focal length can be realized using small size dielectric radiators as feed elements.

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