A Folded Reflectarray Antenna for 2D Scanning

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***Abstract*— A folded reflectarray antenna is presented which is able to scan its beam in two dimensions. The antenna is based on the bifocal approach with phase angle adjustments on a top and on a bottom reflector. Seven feeds are used to switch between different beams in one plane, and the backside reflector is tilted to scan in the orthogonal direction. For good performance, top and bottom reflector are designed is a special way. A sample antenna has been built and tested at 77 GHz.**

Keywords-scanning antenna, reflectarray, mechanical scanning, automotive radar

I. Introduction

In the last years, a number of efforts have been spent to develop automotive radars in the 76 GHz - 77 GHz frequency range for autonomous cruise control or collision warning, [1 - 3]. Most systems presently are based on antennas with three or four beams to account for targets in neighboring lanes or in curves. For future systems with increased detection reliability, more beams will be required [3]. As these sensors have to be integrated into the front part of a car, very compact antenna arrangements are required which, at the same time, must be suited for a low-cost mass production. In [4], a radar sensor has been demonstrated using a folded reflectarray providing a rather low-profile, low-loss antenna which easily can be fabricated using planar technologies. Mechanical scanning in one direction has also been demonstrated. In [5], a multibeam antenna with a number of feeds and associated tilted beams based on an extended folded reflectarray principle has been presented. In this way, beam scanning can be achieved by switching between the different feeds of the antenna. With increasing functional requirements for automotive sensors, scanning is required also in elevation. Automotive radars should have the possibility to correct beam position in elevation, for example to correct mounting tolerances, misalignment of the antenna if the vehicle is severely loaded or for operation in a hilly area, and it would be desirable to detect not only cars on other lanes, but also bridges or traffic sign arrangements crossing the street. Electronic beam steering would be advantages, but solutions like phased array antennas or combinations of beam switching in both planes get quite complex, require large space, and are rather costly. In this paper, therefore, a combination of a multibeam reflectarray antenna in one plane combined with some amount of mechanical scanning in the orthogonal plane is described.

II. Basic principle of folded single and multibeam reflectarray antennas

The basic cross section of a planar folded reflectarray antenna [4] is sketched in Fig. 1, top. The radiation from the feed horn is polarized in such a way that it is reflected by a printed grid or slot array at the front of the antenna. Then the wave is incident on the reflectarray with printed rectangular patches. This array adjusts the required phase angles to transform the incident spherical wave into an outgoing plane wave and provides, at the same time, a polarization twisting of 90° (Fig. 1, bottom). To this end, the electric field is incident on the reflectarray at an angle of 45° with respect to the axes of the array elements. The electric field is decomposed into the two components parallel to the patch edges. If the reflection phase angle for these two components differs by 180° (Fig. 1, bottom right), the reflected electric field is twisted by 90°. As such an antenna with a relatively short focal lengths has a poor scanning performance, this type of antenna was modified to allow a wider range of beam scanning or multibeam arrangements.

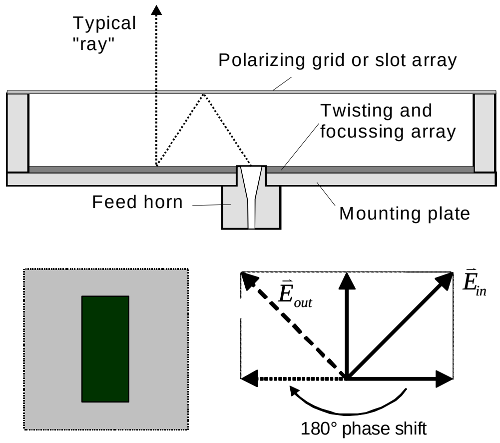

Figure 1: Basic principle of the folded reflector antenna (top) and single cell/patch and vector decomposition of incident and reflected electric field for 180° of reflection phase angle difference (bottom).

The design of a such a multibeam reflectarray antenna is based on the bifocal principle. In such antennas, the single focal point is replaced by two symmetrical feed points, or for axisymmetric configurations, a focal ring [5, 6]. This requires, however, a further degree of freedom for the design - in this case, another set of dipoles is integrated on the top substrate in parallel to the grid allowing an additional phase control for an electric field parallel to the dipoles and the grid (Fig. 2 top). This arrangement, on the other hand, is nearly transparent for a wave in the orthogonal polarization.

The design of a bifocal folded reflector antenna is based on ray tracing analogue to [5, 6]. In the case of such an antenna, a relation is necessary between reflector properties of the reflectarray and angles of incident and reflected rays. In a single plane, this can be derived according to Fig. 2 (bottom) and equs. (1) and (2). Φ_1 and Φ_2 are electrical lengths representing the phase delay within the reflectarray. Equal overall electrical length (equivalent to equal phase angle) of the two rays requires

$$\Delta r \cdot \sin\Theta_{out} + \Phi_1 = \Delta r \cdot \sin\Theta_{in} + \Phi_2 . \qquad (1)$$

With $\Delta r \to 0$, this results in

$$\frac{\partial \Phi}{\partial r} = \sin\Theta_{out} - \sin\Theta_{in} . \qquad (2)$$

For rotational symmetry of the antenna, the detailed ray tracing procedure is given in [5].

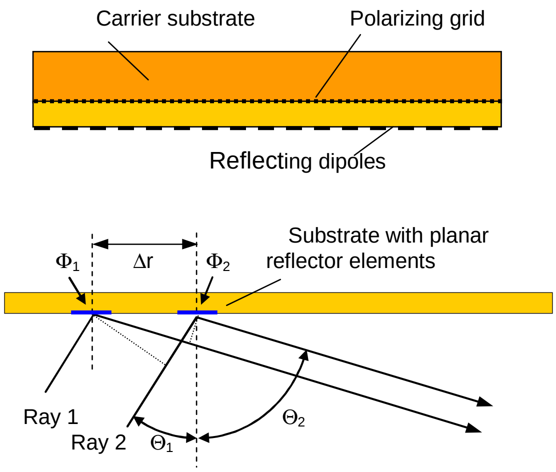

Figure 2: Cross section of top reflector for the multibeam antenna and sketch of ray configuration to derive the one-dimensional reflection relations.

As the antenna described in the following will have a different behavior of phase angle distribution in the two principal planes, the relation above has to be extended to two dimensions [7], leading to

$$\sin(\Theta_{out})\cos(\Phi_{out}) - \sin(\Theta_{in})\cos(\Phi_{in}) = \frac{\partial\Phi(x,y))}{\partial x} \qquad (3)$$

$$\sin(\Theta_{out})\sin(\Phi_{out}) - \sin(\Theta_{in})\sin(\Phi_{in}) = \frac{\partial\Phi(x,y))}{\partial y} \qquad (4)$$

where Φ and Θ are the respective angles in the two planes with indices "in" and "out" for the incident and reflected (output) angles, respectively.

III. Design of the Multibeam Antenna with Orthogonal Mechanical Scanning

For the antenna presented in this paper, the approach with multiple feeds/beams is selected for one plane (x-direction), a mechanical tilting of the lower reflector is employed for the orthogonal plane (y-direction) similar to [4]. The general scanning principles for the two planes are sketched in Fig. 3. To achieve a mostly independent diagram while tilting the lower reflector, the complete transformation from a spherical wave from the feed to a plane wave is performed in this plane by the upper reflector. Consequently, the lower reflector must not vary in phase in the y-direction.

According to the required performance, a ray-tracing is done using equs. (3) and (4) and the two scanning conditions as described above. As a result, two vector fields with the two ***derivatives*** of the required phase angle distribution with respect to x and y results. To determine the phase angles which have to be adjusted by the two reflectors, the two distributions as described above are approximated by 2D polynomials, and for each reflectarray element, the phase angle is calculated via the path integral from the antenna axis (x=0, y=0) to the respective element position. (For the approximation by polynomials, this integral is independent of the actual path).

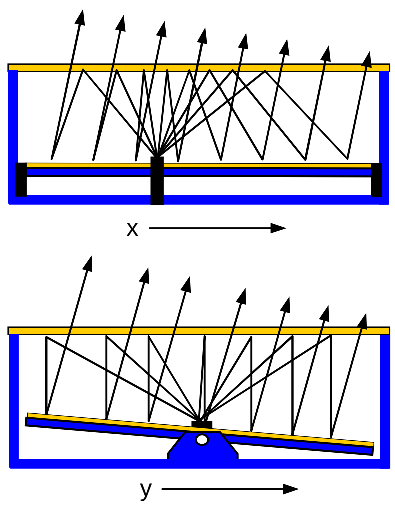

Figure 3: Scanning concepts in the two planes - a multibeam configuration in the x-z-plane (top) and reflector tilting in the y-z-plane (bottom).

IV. Results

A test antenna has been designed, fabricated and tested. Fig. 4 shows a photograph of this antenna. Antenna diameter is 100 mm, the distance between the two reflectors is 30 mm. Both reflector substrates are 0.254 mm thick. The carrier substrate for the front reflector is 1.02 mm thick. The dielectric constant of all layers is 2.2. Seven feeds with a circular waveguide diameter of 3 mm and distances of 4 mm between them are used. The antenna was designed in such a way that the center feed opening is in the reflector plane, the other ones protrude out of this plane for best performance.

Fig. 5 and 6 show the radiation characteristic at 76.5 GHz. All beams are normalized to 0 dB at the maximum of the main lobe. In Fig. 5, the diagrams for the seven different feeds are displayed (E-plane, no tilting of the lower reflector). Beamwidths are between 3.1° for the central beam and 3.75° for the outer beams, scan range is 16°, and sidelobe level is better than -16 dB in this plane. In Fig. 6, the H-plane radiation diagrams are plotted for the central feed and five different tilting angles of the lower reflector (tilting was limited by the specific mechanical construction of the test antenna, but in general, 20° are estimated to be possible instead of the 9° here). Beamwidth is around 3.3° for all beams, the sidelobe level is below -17 dB.

The gain of the central beam was measured to 29.7 dB. In the E-plane, due to the scanning and an increased beamwidth, the gain of the outer beams is reduced, while scanning in the H-plane leaves the gain nearly unchanged.

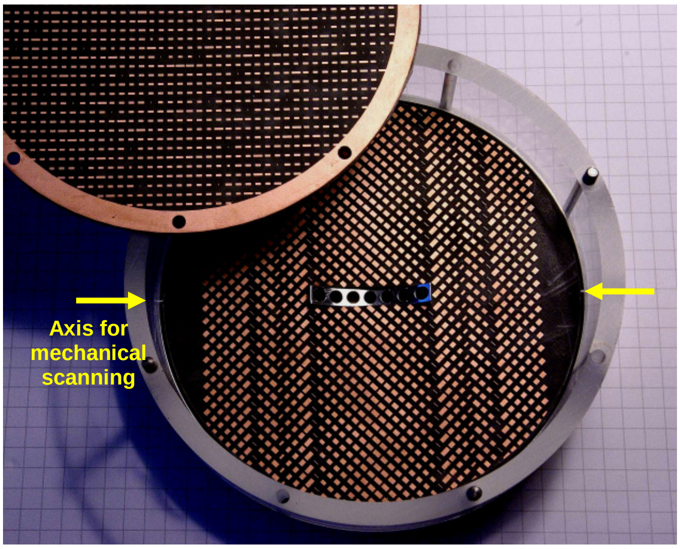

Figure 4: Photograph of the realized antenna with the front reflector top down to see the dipole elements. In the test antenna, the tilting angle is adjusted by a screw and a spring.

Other measurements were performed for a combination of offset feed and tilted reflector. A 3D plot of an example measurement is shown in Fig. 7 for a beam tilted to about 8° and using the first offset feed. While the diagrams in the main plane still are quite good, the 3D plot reveals that the main beam get a slightly triangular shape, and two symmetric sidelobes come up in diagonal planes. The reason for this was found in the fact that by tilting the lower reflector, the performance of the multibeam plane was disturbed. Nevertheless, for automotive applications, a sufficient horizontal beam scan by switching between the feeds and a limited scan by tilting the reflector can be achieved without severe distortion of the beam, enabling the detection of bridges over the street or adjusting the vertical alignment of the sensor.

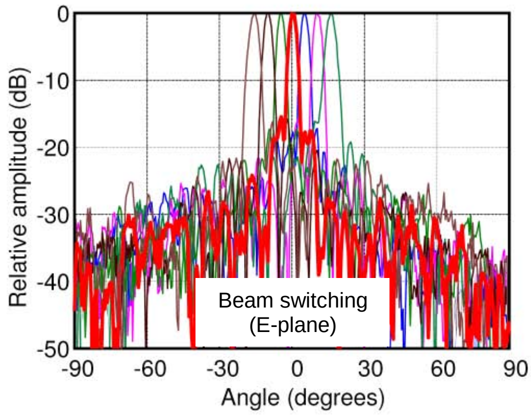

Figure 5: Radiation diagrams for the seven feeds (E-plane). In the respective orthogonal plane, the reflector is adjusted to the center position.

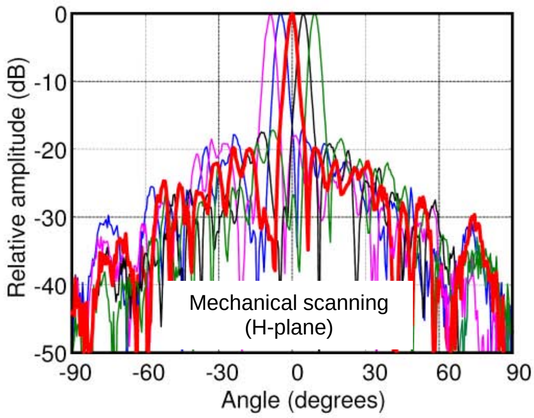

Figure 6: Radiation diagrams for five tilting angles of the lower reflector (H-plane) using the center feed.

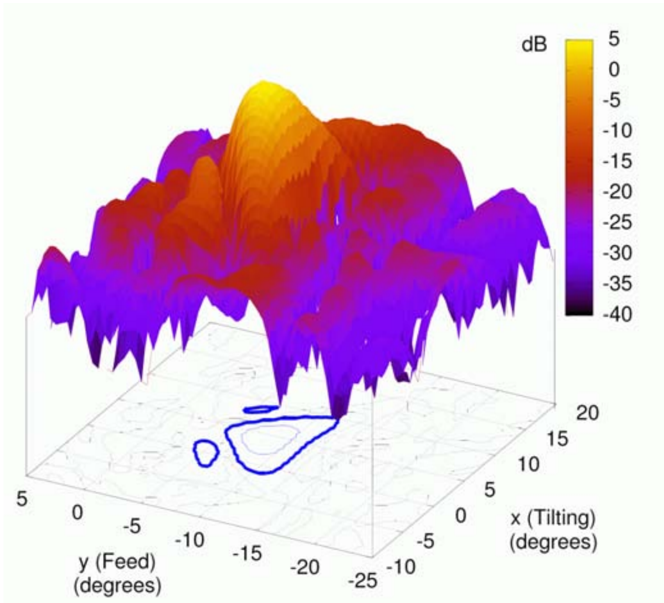

Figure 7: 3D radiation diagram of the antenna for the first offset feed and a mechanical tilting of the beam of about 8°.

V. CONCLUSION

A novel antenna configuration based on a planar folded reflectarray has been presented. This antenna is designed as a bifocal antenna with seven feeds in one plane, while in the other plane, only the upper reflector transforms the spherical wave from the feed horn to a plane wave, and tilting of the lower reflector simply redirects the fields. In that way, the antenna beam direction can be controlled in both planes - switching between different feeds in the E-plane and scanning in the H-plane by tilting the lower reflector. Beam control of 9° in the H-plane and 16° in the E-plane have been demonstrated by the test antenna at 76.5 GHz.

REFERENCES

[1] H. H. Meinel, "Automotive Millimeterwave Radar," *28th European Microwave Conf., 1998, Amsterdam, Netherlands, Vol. 1*, pp. 619 - 629.

[2] I. Gresham et al., "A compact manufacturable 76-77-GHz radar module for commercial ACC applications," *IEEE Transactions on MTT, 2001,* pp. 44 - 58.

[3] R. Schneider and J. Wenger, "System aspects for future automotive radar," *1999 MTT-S International Microwave Symposium Digest, Vol. I*, pp.293-296.

[4] W. Menzel, D. Pilz and R. Leberer, "A 77-GHz FM/CW radar front-end with a low-profile lowloss printed antenna," *IEEE Transactions on MTT, 1999,* pp. 2237-2241.

[5] W. Menzel, M. Al-Tikriti, R. Leberer, "A 76 GHz multiple-beam planar reflector antenna," *European Microw. Conf., Milano, Italy, Sept. 2002,* pp. 977 - 980.

[6] P.S. Holt, A. Mayer, "A design procedure for dielectric microwave lenses of large aperture ratio and large scanning angle," *IRE Trans. on AP-5 (1957)*, pp. 25 - 30.

[7] R. Leberer, W. Menzel, "A Dual Planar Reflectarray with Synthesized Phase and Amplitude Distribution," *IEEE Trans. on AP, Nov. 2005*, pp. 3534 - 3539.