A 76 GHz multiple-beam planar reflector antenna

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Abstract* — A multiple-beam antenna based on the principles of a folded reflectarray antenna and a bifocal antenna is presented. Experimental results are given for a 76.5 GHz antenna with 90 mm diameter, a height of 26 mm, and a scanning range of ±13.5 as well as for an antenna with 130 mm diameter, a height of 30 mm, and a principle scanning range of ±30°. With its low height and potentially low fabrication cost, this antenna is an interesting candidate for next generation automotive radars.

INTRODUCTION

In the last years, a number of efforts have been spent to develop automotive radars in the 76 – 77 GHz frequency range for autonomous cruise control or collision warning, [1 – 3]. Most systems presently are based on antennas with three 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 has been demonstrated, too, over a ±10° range, and the use of three feeding points for this type of antenna is shown in [5]. Mechanical scanning, however, mostly is discarded due to reliability considerations, and the use of more feed points leads to a strong increase of coma lobes of the antenna diagram. Therefore, this antenna is modified to enable a wide angle scanning without abandoning its general principle and setup.

BASIC PRINCIPLE OF A PLANAR FOLDED REFLECTOR ANTENNA

The basic cross section of a planar folded reflector antenna [4, 5, 8, 9] is sketched in Fig. 1. The radiation from the feed 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 patches. The patch axes of this array are tilted by 45° with respect to the incident electric field. The electric field vector can be decomposed into the two components parallel to the patch axes (Fig. 2), and the reflection properties can be determined separately. The dimensions of the patches are selected in such a way that a phase difference of 180° occurs between the reflection phase angles of these two components. Superposition of the *reflected* field components then leads to a twisting of the polarization by 90° (Fig. 2). The necessary 180° phase angle difference between the two field components of the reflected wave can be achieved for a large number of combinations of length and width of the patches differing by their *absolute* reflection phase angle. This degree of freedom now is used to adjust the required phase angles to transform the incident spherical wave into an outgoing plane wave.

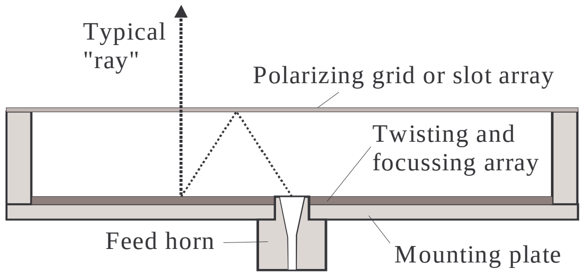

Fig. 1: *Basic principle of the folded reflector antenna.*

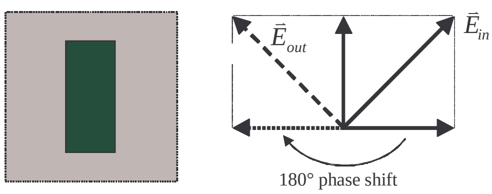

Fig. 2: *Single cell/patch and vector decomposition of incident and reflected electric field for 180° of reflection phase angle difference.*

MODIFIED PLANAR REFLECTOR ANTENNA

In order to maintain a low profile of the folded reflector antenna, the effective focal length is kept shot, resulting in poor scanning performance. On the other hand, as it is known from the design of lens or reflector antennas, bifocal antennas for wide angle scanning are possible. In such antennas, the single focal point is replaced by a focal ring [6, 7]. This requires, however, another degree of freedom for the design – selecting specific shapes of both surfaces of a lens [6] or both reflectors of a double reflector configuration [7].

As has been demonstrated in [8], a printed grid can be used as ground plane of a reflectarray, and in combination with narrow dipoles as reflecting elements, this reflectarray is nearly transparent for a wave in the orthogonal polarization. Thus, such a structure can be used as a second reflector in a folded reflector antenna, replacing the polarizing grid (Fig 3, top right). In this way, it is possible to apply the principle of a bifocal antenna to a folded reflector antenna.

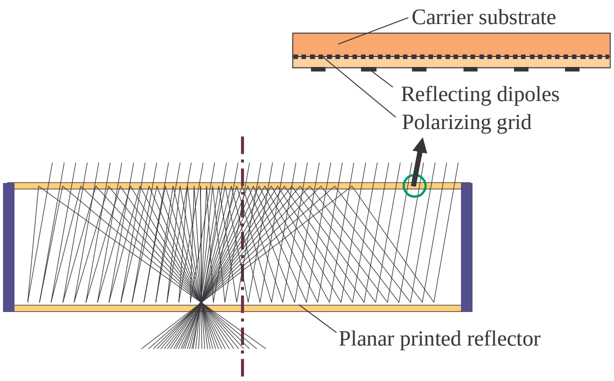

Fig. 3: *Cross section of bifocal folded reflector antenna and bundle of incident rays.*

The design of a bifocal folded reflector antenna is based on ray tracing analogue to [6] and [7]. For the design of a standard reflectarray according to Fig. 1, simply the reflection phase angle is required at the point of incidence of a ray. In the case of a bifocal antenna, however, a relation is necessary between reflector properties of the reflectarray and angles of incident and reflected rays. This can be derived according to Fig. 4. Two parallel rays separated by a small distance Δr are incident on the planar structure at an angle Θ_1. They are reflected by the array structure suffering a delay described by electrical lengths Φ_1 and Φ_2, respectively, and leave the structure (approximately parallel) at an angle Θ_2. This requires the same path lengths for both rays:

$$\Delta r \cdot \sin\Theta_2 + \Phi_1 = \Delta r \cdot \sin\Theta_1 + \Phi_2 . \tag{1}$$

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

$$\frac{\partial \Phi}{\partial r} = \sin\Theta_2 - \sin\Theta_1 . \tag{2}$$

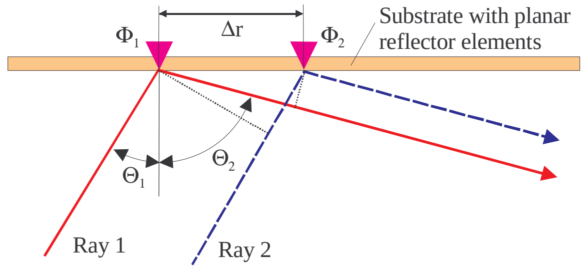

Fig. 4: *Principle of determining the relations between angles of incidence and reflection and planar reflector properties.*

Based on prescribed feed position and beam angle, taking into account the symmetry of the antenna, and using equ. 2, a ray tracing procedure according to Fig. 4 can be applied. The upper substrate is a composite structure as shown in Fig. 3 (top right), the lower substrate a reflectarray including the twisting performance as described in the previous section. A ray (1) is incident on the lower reflector at the axis of the antenna. The incident beam angle is as desired; polarization of the wave is such that it can pass the top substrate. Due to symmetry, it is reflected at the bottom substrate at the same angle while the polarization is twisted by 90°. Back on the top structure, it has to be reflected such that it ends at the feed point. From the known angles of incidence and reflection, the reflector properties ($\partial\Phi/\partial r$) can be calculated at the reflection point according to equ. 2. Exploiting symmetry, these properties must be the same on the opposite side of the antenna. Consequently, the reflection of a ray (2) starting at the feed point can be traced up and down to the lower reflector. Knowing the angle of incidence and the angle of the outgoing ray, the properties of the lower reflector can be determined at this point, and consequently, at the point symmetric to this one. The whole procedure is continued until the edge of one of the reflectors is reached. A second set of data can be derived in the same way starting with a ray from the feed point to the center of the upper reflector.

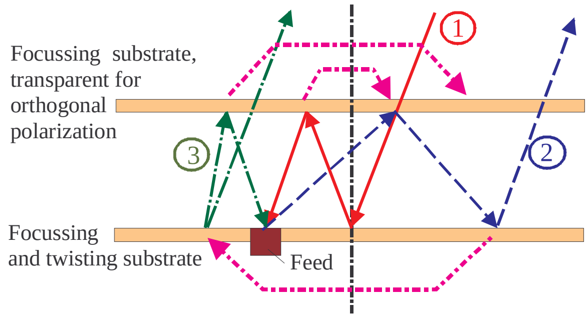

Fig. 5: *Ray tracing procedure.*

These two sets of data are merged and approximated by two polynomials for both upper and lower reflector. Integrating the polynomials gives the required delay length and the reflection phase angles, respectively, of the two reflectors. Furthermore, on the basis of these polynomials, a tracing of arbitrary rays is possible to check the design procedure, and even some optimization for best performance of offset as well as central beam is possible. In Fig. 3, the paths of a bundle of incident parallel rays are plotted, showing an excellent focus of the antenna.
The resulting reflection phase angles for the two reflectors then are transferred into the respective patch dimensions. The front reflector is realized as a double-layer structure to improve stability; the front substrate, at the same time, can act as a radom (Fig. 3, top right).

RESULTS

A number of these antennas have been designed, fabricated, and tested. Fig. 6 shows the photograph of a folded bifocal reflector antenna with the front substrate removed. Antenna diameter is 90 mm, the distance between the two reflectors is 26 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 diameter of 3 mm and distances of 4 mm 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. 7 shows E- and H-plane radiation characteristic at 76.5 GHz for the central beam (top) as well as the E-plane beams for the seven feeds (bottom). All beams are normalized to the same amplitude value. Beamwidths are between 3° and 3.3°, scan range is ±13.5°, and sidelobe level – except for the outer beams – is better than –18 dB. Very similar performance is found over a bandwidth of at least 76.5 ± 1 GHz.
Another antenna of this type (diameter 130 mm, height 30 mm) was designed for a ±30° scanning range. A scan angle of ± 24.5° has already been measured (Fig. 8); with additional feeds at the sides, ±30° should be possible, too. The central beams in both planes are 4° wide; in this antenna with wide scanning range, only part of the aperture is used actively. Sidelobe level for the central beam in the E-plane is better than -18 dB, in the H-plane, some unsymmetry leads to higher values. With a few exceptions, sidelobe levels of all scanned beams are below -15 dB.
In a future automotive radar, this antenna could be applied in two different ways. The first one resembles the conventional principle; a switching network may connect either of the feeds to a single radar front end. Low loss performance of the switches should be available soon using MEMS type switches [10]. An alternative approach consists in connecting separate receivers to each feed to allow a parallel processing of all channels. The transmitter then must illuminate the complete detection range which typically is done using a separate transmit antenna [11, 12].

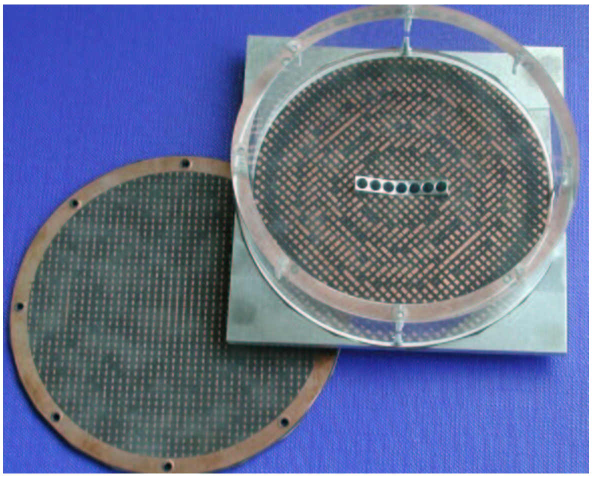

Fig. 6: *Photograph of a bifocal folded reflector antenna.*

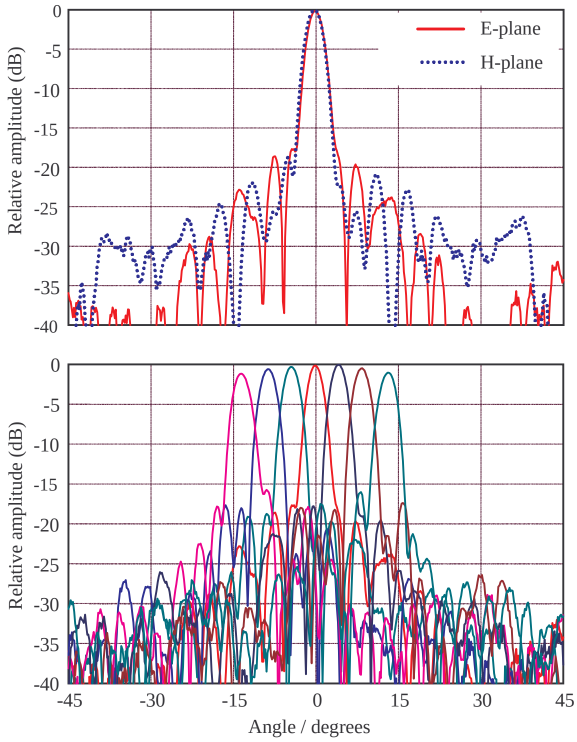

Fig. 7: *E- and H-plane radiation diagrams of central beam (top) and E-plane diagram for the seven feeds (bottom) of an antenna with 90 mm diameter and ±13.5° scanning range .*

CONCLUSION

A novel configuration of a bifocal planar folded reflectarray has been presented. This antenna has a low depth, low weight, and consists basically of two planar structures only. To increase the stabilty of the front substrate, it can be fixed to the antenna radom or to another carrier substrate. Results of two antennas of this type with diameters of 90 mm and 130 mm, heights of 26 mm and 30 mm, and scanning ranges of ±13.5° and ±24.5° at 76.5 GHz have been demonstrated.

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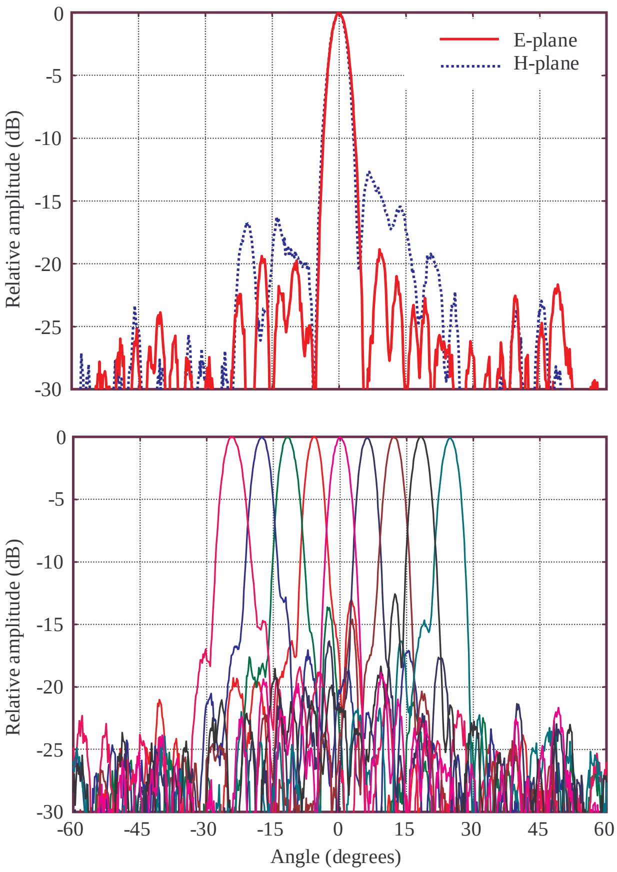

Fig. 8: *E- and H-plane radiation diagrams of central beam (top) and E-plane diagram for the nine feeds (bottom) of an antenna with 130 mm diameter and ±24.5° scanning range.*

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