# Low-profile folded reflectarray antennas for communication applications

Wolfgang Menzel, Maysoun Al-Tikriti, Ralf Leberer

Microwave Techniques, University of Ulm, D89069 Ulm, Germany
Tel: +49-731-502 6350, Fax: +49-731-502 6359, E-mail: wolfgang.menzel@ieee.org

**Abstract:** Printed reflectarrays are an interesting solution for high gain antennas, especially in the mm-wave range. They show low loss, and they are potentially low cost. This concept has been extended to folded reflectarrays, exploring the dual polarization properties of reflectarrays, resulting in a small depth of such antennas, too. Principles and results for such antennas in the millimeter-wave range will be shown, together with recent developments including improved double layer reflectors and antennas with modified radiation characteristics like sector antennas, omnidirectional antennas, or multi-beam antennas for point-to-multipoint applications.

## Introduction

Printed antennas are of great interest for all types of microwave applications. With increasing frequency and increasing antenna size, however, these antennas often exhibit unacceptable losses mainly caused by the feed network. Based on printed structures, planar reflector antennas (reflectarrays) have been developed [1 - 6]. With these antennas, feeding of the printed radiating elements is done quasi-optically; the necessary reflection phase angle is adjusted either by attaching some transmission line section acting as reflection phase shifter, or by adjusting the phase angle by a specific geometry of the reflecting elements. These antennas typically show low loss, but require a feed element at the focal point in front of the reflectarray. Exploiting the dual polarization properties of reflectarrays, a folded version of such reflectarrays has been proposed and realized [7 - 9]. In this way, a low profile of such antennas has been achieved, and the feed element now is placed at the backside of the antenna. In this contribution, some actual results and possible applications of such reflectarray will be described.

## Basic principle of a planar folded reflector antenna

For the antennas described here, the reflection phase angle for a plane wave incident on a periodic structure of printed dipoles is adjusted by the geometry of the patches, it mainly depends on patch length (Fig. 1). For a single layer substrate, a range of phase angles of about 320° is covered, but this has proven to give reasonably good antenna results.

The basic cross section of a planar folded reflector antenna [7 - 9] is sketched in Fig. 2, left side. The radiation from the feed 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. For the folded reflector antenna as described here, the patch axes of the array are tilted by 45° with respect to the incident electric field (Fig. 2, right side). The dimensions of the patches are selected in such a way that a phase difference of 180° occurs between the reflection phase angles of the two field components parallel to the axes, leading to a twisting of the polarization by 90°. This 180° phase angle difference 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 which now can pass the polarizing structure in front of the antenna.

If a phase difference of 90° is adjusted between the two components of the electric field, circular polarization results which can be used in other antenna arrangements as will be described later on in this paper.

The calculation of the reflection phase angles is done based on a spectral domain method, and the antenna design is done assuming the incidence of a plane wave on a periodic structure. Although these assumptions are not really true and lead to phase errors, the antenna results mostly are quite acceptable.

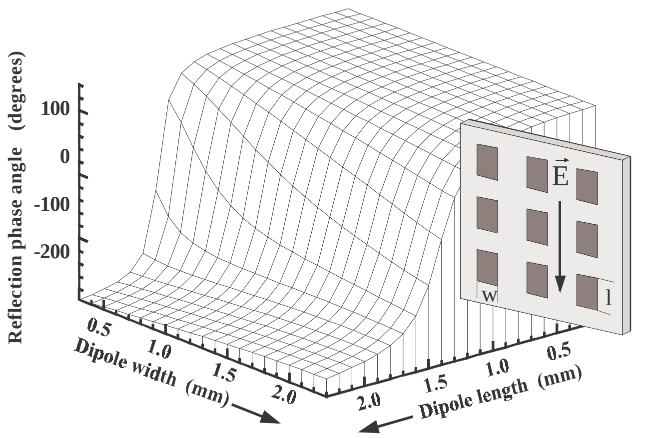


***Fig. 1**: Reflection phase angle of a plane wave reflected from a periodic array of printed dipoles. (Frequency 58 GHz, substrate thickness 0.254 mm, dielectric constant 2.22, dipole grid spacing 2.4 mm, normal incidence of the wave).*

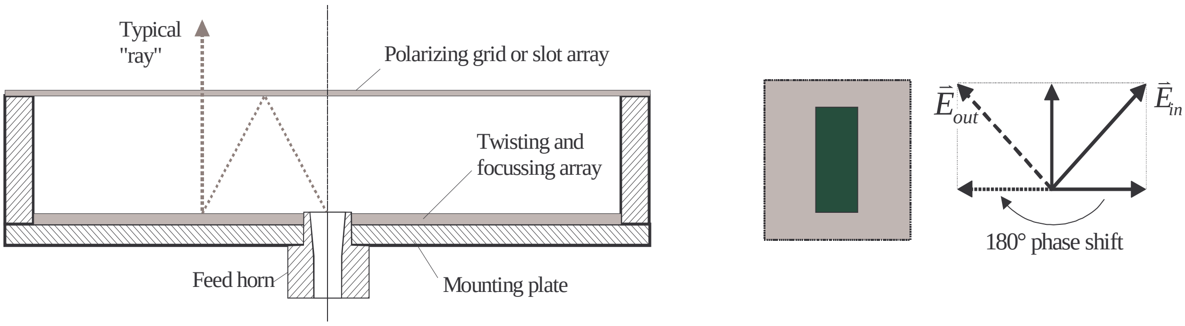


***Fig. 2:*** *Basic principle of the folded reflector antenna (left) and single patch with vector decomposition of incident and reflected electric field for 180° of reflection phase angle difference (right).*

## Pencil beam folded reflector antennas

Based on the principle explained above, a number of antennas have been designed and tested. Fig. 3 shows the radiation diagram of a folded reflectarray antenna at 61 GHz with a diameter of 100 mm and a depth of 25 mm. Beamwidths are 3.2° and 3.4° in E- and H-plane, respectively, and sidelobe level is better than –24 dB. Gain is about 34 dB at 61 GHz and better than 31 dB in a 7.2 GHz bandwidth (Fig. 4, solid line). An antenna of this kind even can be integrated into a 900 MHz patch antenna resulting in a dual frequency antenna [10].

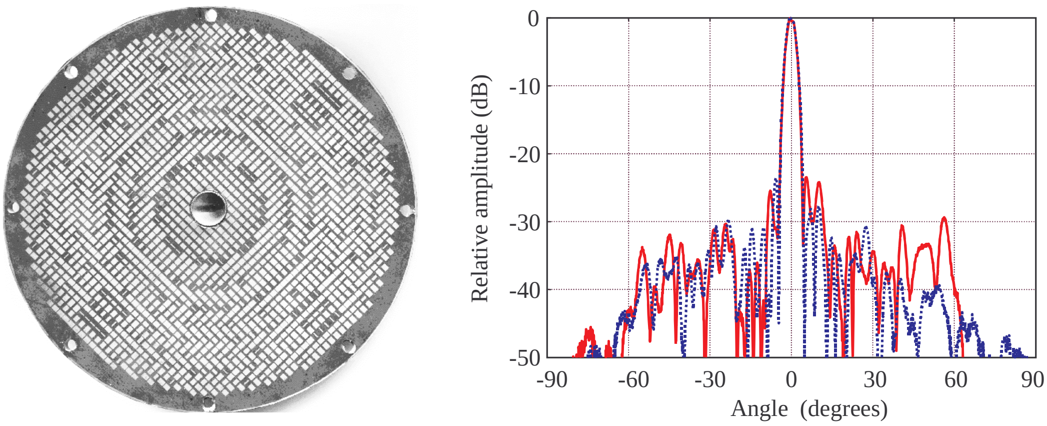


***Fig. 3:*** *Photograph of the reflector substrate and E- and H-plane radiation diagrams of a folded reflector antenna at 61 GHz.(solid line: E-plane, dotted line: H-Plane).*

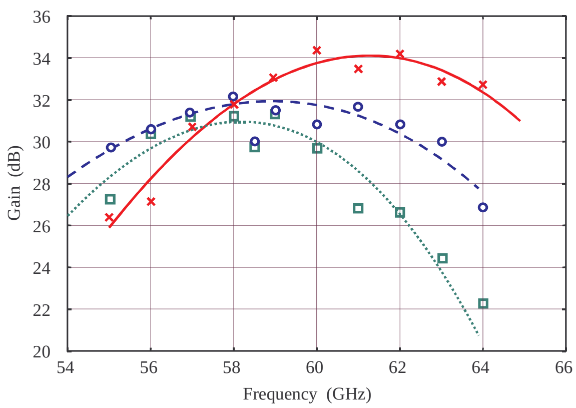


***Fig. 4:*** *Gain of different folded reflector antennas (dots: measured values; lines: approximation of the measured values by polynomials;*
**X**, ———: *25 mm depth, design frequency 61 GHz;*
**O**, – – – –: *20 mm depth, design frequency 58 GHz;*
□, ··········: *20 mm depth, design frequency 58 GHz)*

In a next step, effort were made to further reduce the antenna depth. To this end, two antennas with the same diameter, but only 20 and 15 mm in depth were tested. Radiation diagrams were very similar to those given in Fig. 3, except for some slightly increase level of the far-off sidelobes. This results in a decrease of the gain, and in addition, bandwidth is lower, too (Fig.4). The reason for this are the approximations made for the antenna design, together with the limitation of the available reflection phase angle to 320°. The variation of phase angle for an antenna with a short focal length is larger, thus the remaining phase angle gap appears more often for lower profile antennas.
This problem should be reduced using a dual layer substrate with two layers of patches; in this way, a phase angle range of more than 600° can be adjusted [6]. Furthermore, the dependence of phase angle on patch length is less steep resulting in less critical tolerances for the patch dimensions. A folded reflector antenna with such a double-layer reflector and a depth of 20 mm has been designed and tested. (Far-off) sidelobe level was found to be 3 ... 5 dB lower, but gain and bandwidth were not improved remarkedly.

## Sector antennas

For point-to-multipoint communication links, antennas with sector or omnidirectional characteristics in azimuth are required. For a sector antenna, a folded reflector antenna was redesigned such that a suitable non-planar phase distribution in azimuth results [11]. As a first test, an antenna with a sector width of 90° was built and tested. Fig. 5 shows layout as well as desired and achieved azimuth (H-plane) radiation diagram. Requirements for low phase errors are quite high in this application; nevertheless, the results look quite good. In elevation, a beamwidth of about 3° is achieved; sidelobe level, however, rises up to –8 dB; here some reoptimization is necessary.

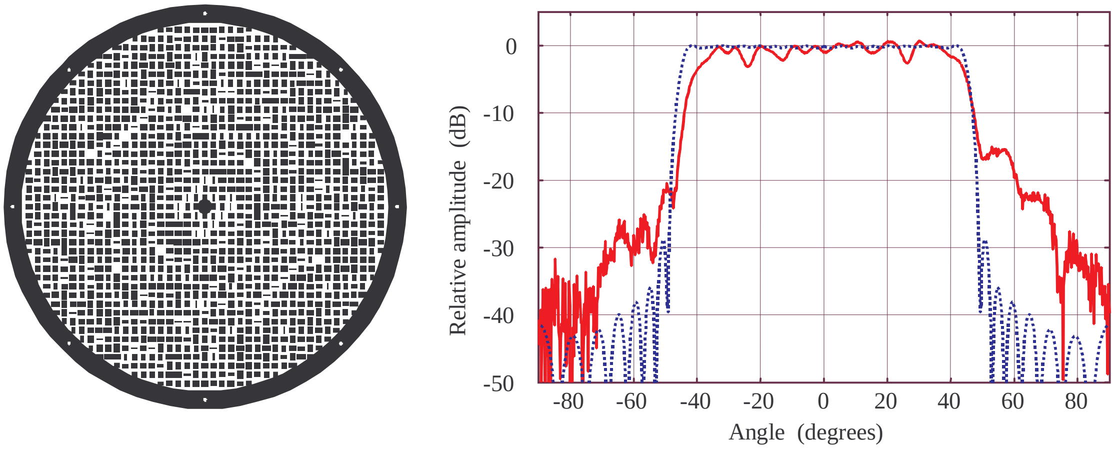


***Fig. 5:*** *Layout and azimuth (H-plane) radiation diagram of a folded reflectarray sector antenna (dotted line: designed diagram; solid line: experiment. In the antenna, the orientation of the layout is twisted by 45°).*

## Omnidirectional antennas

A possible solution to realize antennas with a constant azimuth diagram is the combination of a focussing reflector with a cone reflector. If the feeding waveguide, for simplicity, is excited with the $TE_{11}$ mode, antenna polarization is depending on the radiation direction; a way out of this problem is the use of circular polarization. Two of the necessary functions – focussing and generation of circular polarization – now are combined in a planar reflector. The basic function of the reflector is the same as for the folded reflectarray, except that in this case, the two field components incident on the reflector undergo a differential phase shift of 90° only. The overall setup of this antenna is shown in Fig.6, left side. If the polarization of the field in the feed is changed, the sense of the circular polarization is reversed. Elevation and azimuth radiation diagrams of such an antenna at 60 GHz are plotted on the right side of Fig. 6. A fairly constant radiation could be achieved in azimuth, combined with a narrow beamwidth (6.2°) in elevation. Due to the specific amplitude distribution in that plane (maximum amplitude at the upper edge), a sidelobe level of only -12 dB is achieved.

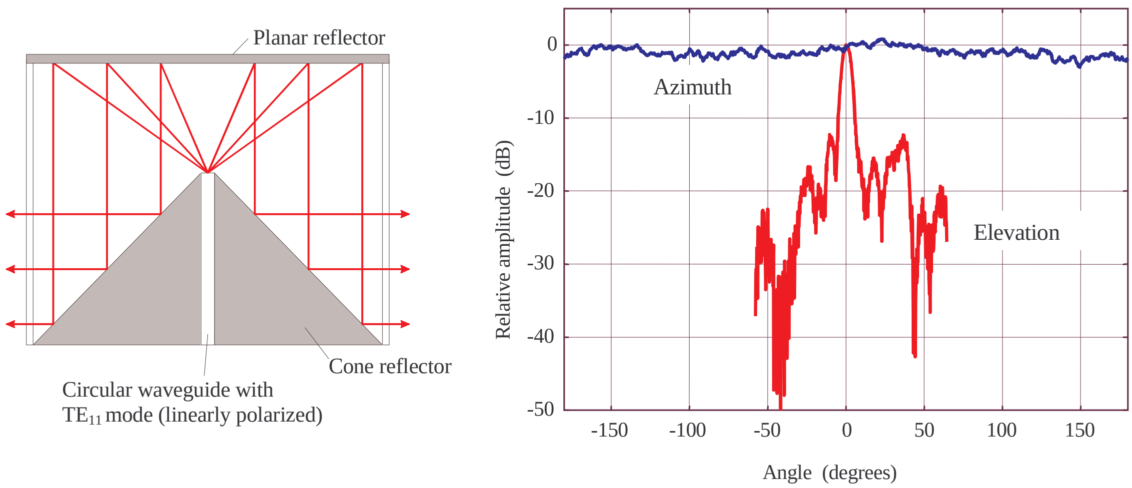


***Fig. 6:*** *Basic principle and radiation diagram of an omnidirectional antenna with planar reflector and circular polarization.*

## Multibeam antennas

As the folded reflector antennas basically are reflector antennas with a short focal length, only a small offset of the feed is possible to allow beam scanning or multi-beam operation. A way out of this problem is the extension to a bifocal type of reflector antenna. To this end, another phase adjusting structure is added to the top substrate of a folded reflector antenna (Fig. 7). It consists of a polarizing grid on one side and narrow dipoles parallel to the grid on the other side of the substrate; a second substrate serves for stabilization and as a radom. For an electric field parallel to the grid, the dipoles act as phase adjusting elements, for the orthogonal field direction, the dipoles and the grid are nearly transparent. The design of both reflectors is done using a ray-tracing procedure [12, 13]. As an example, different E-plane radiation diagrams for nine different feed positions are plotted in Fig. 8 for an antenna of 130 mm diameter and a depth of 30 mm. Frequency is 76.5 GHz, but the antenna equally can be scaled to other frequencies. With the available feed structure, a range of ±24° is covered; according to simulations, ±30° should be possible. Beamwidths are 4° ... 4.5°; this is wider than the antenna diameter would imply, but only part of the aperture can be used due to the beam scanning. Sidelobe level is between –15 dB ... –13 dB.

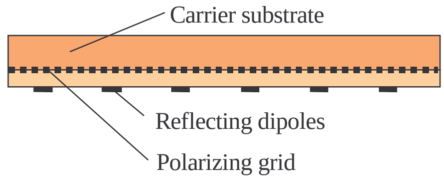


***Fig. 7:*** *Double-layer substrate acting as reflectarray in one polarization. For the orthogonal polarization, it is transparent.*

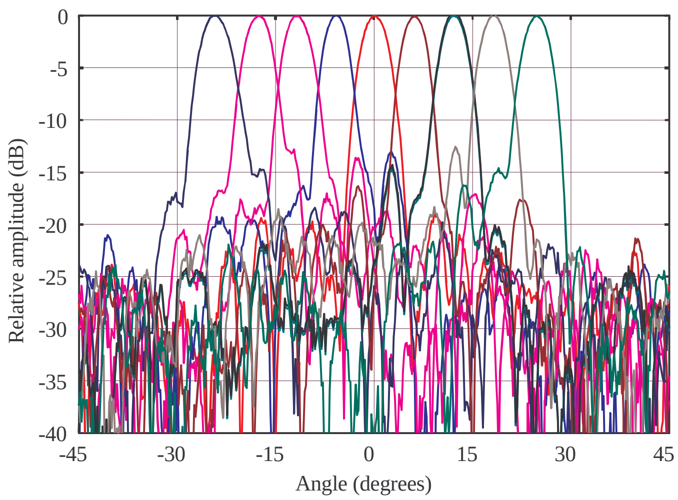


***Fig. 8:*** *E-plane radiation diagrams of a multi-beam planar reflectarray (76.5 GHz).*


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