Folded Reflectarray Antenna Using A Modified Polarization Grid for Beam-Steering

S. Dieter*, P. Feil+, W. Menzel#

Institute of Microwave Techniques, University of Ulm
Albert-Einstein-Allee 41, 89081 Ulm Germany
** sabine.dieter@uni-ulm.de*
+peter.feil@uni-ulm.de
#wolfgang.menzel@uni-ulm.de

***Abstract*— This work proposes a novel version of folded reflectarray antennas that allows beam-steering by adjusting the reflection properties of the polarizing grid on top of the antenna. The necessary degree of freedom is introduced by combining the polarizing grid with narrow patches acting as reflection phase shifters. Hence, this approach is interesting for reconfigurable concepts based on RF MEMS or Liquid Crystal arrays. In many applications, only a one-dimensional beam scan is required. In this case, the complexity of such arrays can be significantly reduced, as a two-dimensional distribution of control or bias signals can be avoided. As a proof of concept the presented antenna designed for a frequency of 77 GHz is based on common RF substrates.**

I. Introduction

Folded reflectarray antennas [1] are a compact version of reflectarray antennas [2-3]. They have the advantages of reduced weight and profile, an easy, low-cost fabrication and high gain. The antenna principle can be seen in Fig. 1. The outgoing wave from the central feed is reflected at a polarizing grid on top of the antenna. Then, a second reflection occurs on the lower reflector consisting of a dielectric substrate with backside metallization and printed patches as reflection elements adding specific phase angles. They compensate for free-space delay, giving a pencil beam pattern or allowing to choose from a multitude of antenna diagrams in the design process. In a first approach, the lower reflector is designed for obtaining a pencil beam diagram. In addition to adjusting the phase angles, a polarization twist of 90° has to be achieved at the reflection on the lower reflector, so that the wave then can pass the grid. This is realized by choosing specific patch dimensions. The polarization twist of 90° for the outgoing wave is obtained by a 180° phase angle shift between the polarizations E_x and E_y for the incoming wave with polarization E_{in}, see Fig. 2.

II. Design of the Phase Shifting Grid Structure

Besides separation of the polarization components, within this work, the grid on top of the antenna is used for obtaining an offset beam diagram. To this end, a structure is integrated in the grid design which adds specific reflection phase angles. Two stacked substrates from Rogers (RT5880 with a dielectric constant ε_r=2.2) are connected together with a bonding foil. In Fig. 2, a unit cell of the layered structure is shown (with a cell size of 2 mm × 2 mm).

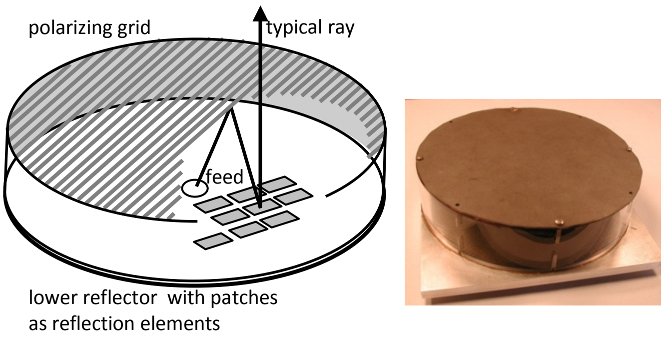

Fig.1 Antenna principle and fabricated antenna.

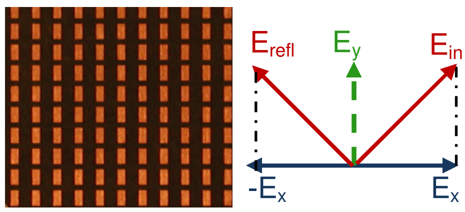

Fig.2 Principle of unit cells with polarization-twisting ability.

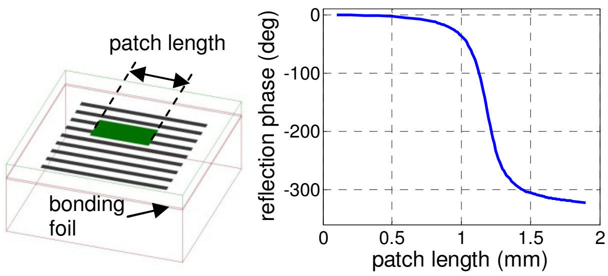

Fig.3 Reflection grid layout and simulated obtainable phase angles.

The thickness of the combined dielectric layer (d=1.25 mm) is designed to provide maximum transmission at the design frequency. All the printed copper structures are situated on the thinner substrate (d=0.254mm), with the dipoles facing the inner side of the antenna and a printed metal grid for polarization separation on its opposite side. The phase angles as a function of the dipole length are depicted in Fig. 3. These values are obtained by a FSS simulation tool [4]. The overall phase angle range for this structure is 320°.

III. Antenna Design

The antenna design for a first test of this novel principle is based on the standard design of a folded reflectarray antenna [1]. An additional phase adjustment then is done on the upper reflector to enable an offset beam of the antenna. The raytracing principle for this design is illustrated within the cross section of the antenna in Fig. 4. The process is executed considering an incident ray from the desired offset beam angle φ, and tracing it back to the feed of the antenna.

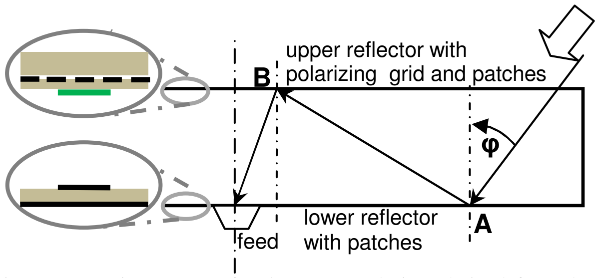

Fig. 4 Raytracing process for the antenna design, derived from the desired beam-steering angle φ.

In general, the relation between the angles of the incident and reflected rays depends on the local reflection phase gradient. This relation is described in detail in [5] and illustrated in Fig. 5.

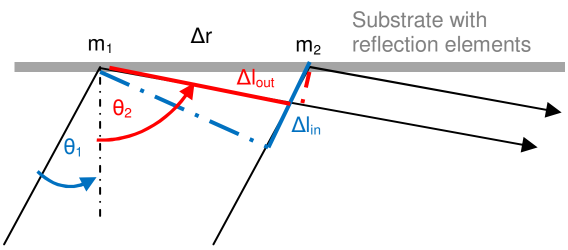

Fig. 5 Relation between the angles of the incident and reflected rays on a planar reflector.

The quantities m_1 and m_2 in this picture represent electrical lengths added by the reflection at the dipole structure and related to the reflection phase angle φ_i by

$$m_i = \varphi_i / k_0 \qquad (1)$$

In the limiting case $\Delta r \to 0$, the following relation results

$$\partial m / \partial r = \sin(\theta_2) + \sin(\theta_1)\,. \qquad (2)$$

These conditions are applied to the raytracing process sketched in Fig. 4 as follows. As the lower reflector's phase angle distribution is already determined by the pencil beam design of the antenna, the expression $\partial m / \partial r$ is known on the lower reflector. So the output angle at point A of the lower reflector can be calculated with (2). This again defines the input position and input angle of the upper reflector at point B. Here, the output angle is already fixed by the feed location. Using (2) again, the derivation $\partial m / \partial r$ can be solved for the upper reflector. Doing this step by step for different incident positions of the incoming rays, the upper reflectors' phase angle distribution and necessary reflection element dimensions are obtained.

In summary, the degree of freedom introduced by the new reflection grid is used to redirect the reflected ray to the feed location.

IV. Fabrication and Measurement

A grid structure with reflection dipoles has been designed for a pencil beam antenna at a frequency of 77 GHz. The desired offset beam location in this case is at an angular position of 14°. The lower reflector from [6] and the newly designed grid with reflection structures can be seen in Fig. 6.

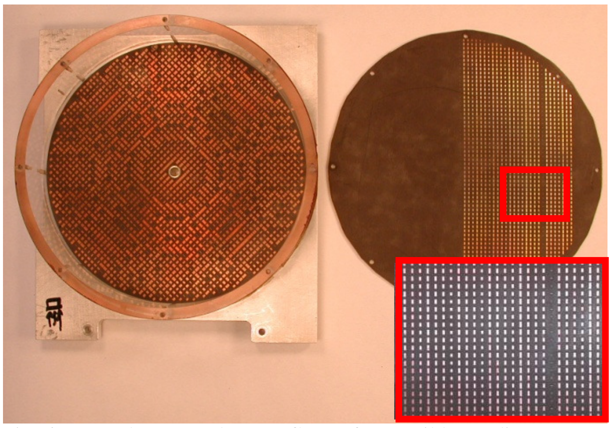

Fig. 6 Opened antenna: lower reflector for pencil beam diagram (on the left) and fabricated grid with reflection structure, designed for an additional offset beam (right). Very short dipoles cannot be seen on the photographs, resulting in the apparent gap in the dipole array.

It should be noted that there are some regions on the reflection grid, that are not hit during the raytracing process. The locations and sizes of those areas depend on the desired off axis angle.

The measured radiation diagrams of the antenna are shown in Fig. 7. The green center curve shows the original on-axis pencil beam antenna with a uniform grid (without additional reflection structures).

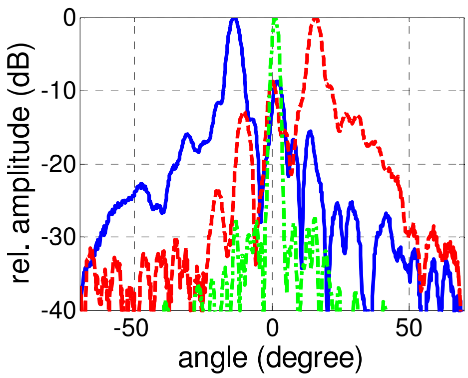

Fig. 7 Measured antenna diagrams at 77 GHz. Two diagrams with beam-steering grids for angular offsets of ±14° are plotted in comparison with uniform grid diagram (green center beam).

The offset-beam diagrams at angular positions of ± 14° verify the principle functionality of the designed grid. The sidelobes at 0° in the two off-axis diagrams are due to rays reflected at grid regions without additional phase shifter elements, as can be seen at the non-metalized parts of the grid in Fig. 6. As explained before, these regions cannot be considered during the design process. However, the feed is illuminating the complete reflection grid. As the blank areas behave like a simple polarizing grid, there is a residual lobe in boresight direction. To overcome this effect, a second design method for the grid is described in section V.

V. Alternative Antenna Design

In [5], multibeam antennas have been designed based on the principle of bifocal lenses or reflectors. In the case of the realization as a folded reflectarray antenna, symmetrical phase angle adjustment is done both on the lower and upper reflector resulting in a configuration with two symmetrical focal points in one plane, or in the case of a rotational symmetric antenna, with a focal ring. A typical ray diagram of an antenna from [5] is shown in Fig. 8. The distance between the two reflectors is 30 mm, the design diameter is 120 mm. Parallel incoming rays focus in an offset feed point; due to the symmetry of the reflectors, this works equally perfect for the mirrored case. Good radiations diagrams result for such antennas not only for the two focal points, but also for feed positions within and some distance outsides the design feed positions. Accordingly, such an antenna is quite well behaved with respect to different angles of incidence, and also rays appear all over the upper reflector, so a modification of such an antenna according to Fig. 4 will avoid the empty areas and the drawback of the previous antenna design.

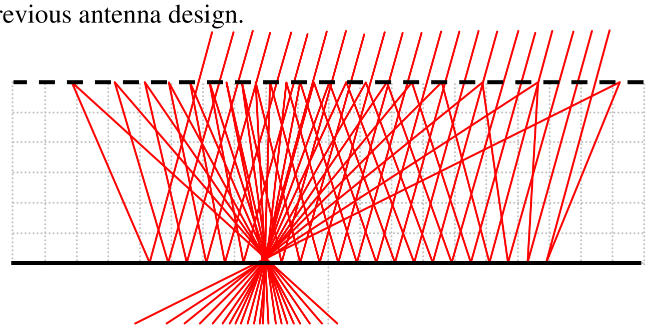

Fig. 8 Ray performance for a multibeam folded reflectarray antenna [5].

The new design now starts with an antenna as described in [5]; the lower reflector will be unchanged, and the upper reflector is modified according to the procedure described in section III. As a first example, the rays for an antenna based on those indicated in Fig. 8 are shown in Fig. 9. The incident, tilted rays are reflected at the lower array in the same way as in Fig. 8, only the upper array is modified such that the rays now all cross in the array center. There is, however, a further modification concerning the phase angle design of this antenna in the orthogonal plane. As a constant reflection phase angle is intended on the upper array in the plane orthogonal to the plane shown in Fig. 8 and 9, all the focussing has to be done on the lower reflector. As a consequence, the lower reflector will have, in the plane shown in the figures, a phase angle distribution according to the bifocal antenna configuration, and a parabolic phase angle distribution normal to this plane with respective transitions in between. This design procedure similar to that in [7] is still going on; results will be presented at the conference.

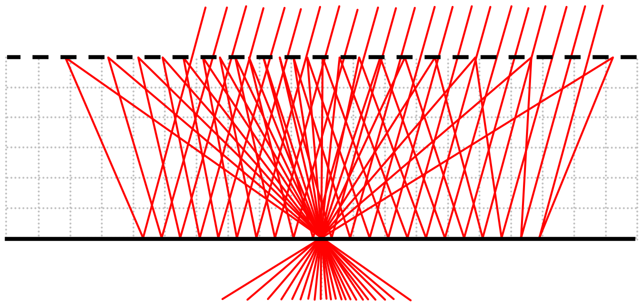

Fig. 9 Ray performance for a modified folded reflectarray antenna.

VI. Application to a Reconfigurable Antenna

To demonstrate the principle using common RF substrates for both lower and upper reflector, modified grids have to be designed and exchanged for each desired offset beam angle. The benefit of the proposed design method, however, becomes evident using reconfigurable concepts for the modified grid, so beam-steering is possible with a one-dimensional control of the upper reflector array.

As an example for a reconfigurable concept, a grid design for a Liquid Crystal (LC) array has been investigated. The unit cell for such a reconfigurable modified grid is shown in Fig. 10.

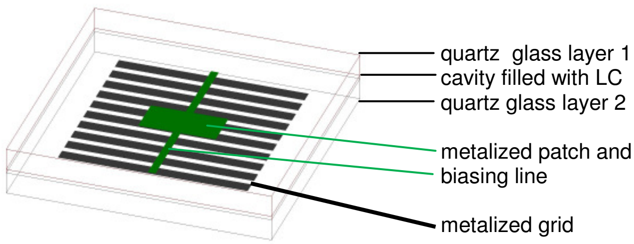

Fig. 10 Principle of a Liquid Crystal (LC) unit cell of a polarizing grid for a reconfigurable folded antenna.

The layer topology is very similar to a reflectarray cell for 77 GHz [8], where a cavity is formed between two quartz glass carrier substrates. At the inner surfaces of these carriers, metalized structures are evaporated, facing the cavity. In this design, the upper metal layer is a patch structure, the lower one a printed grid, similar to the layout in Fig. 3. The cavity itself is filled with liquid crystal (LC) material, changing its effective permittivity when applying a control voltage between the neighboring metal layers of patch and grid. With this, the reflection phase angle of the patch varies with the effective permittivity, and the reflection phase angle can be adjusted with the control voltage between patch and grid. As just one-dimensional controlling of the patch rows is needed for the modified grid design, just a single common biasing line is enough connecting the dipoles of one row each.

The obtainable reflection phase angle for such structure, has been simulated with [4] for possible permittivity values of the LC material filled in the cavity, see Fig. 11.

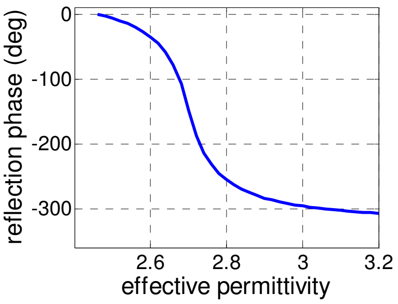

Fig. 11 Simulated obtainable reflection phase angles of the LC polarizing grid.

The obtainable phase angle range is 300°, similar to that of the unit cell based on common RF substrates (Fig. 3). So the performance of a reconfigurable grid is expected to be suitable to the design shown in the previous chapters. Such a folded antenna, with a reconfigurable grid structure and a lower reflector based on RF substrates, then will allow beam-steering by controlling the reconfigurable array in one dimension.

VII. SUMMARY

This paper presents a folded reflectarray antenna concept for beam-steering by using a reconfigurable polarizing grid with reflector elements.

By adjusting the grid structure of the antenna while keeping the lower reflector as before, different offset beam diagrams are possible using this approach. The grid adjusts the respective reflection phase angle in only one dimension. This makes the process interesting for reconfigurable arrays, e.g. based on MEMs or Liquid Crystal technology.

As with the first concept, a relatively high sidelobe occurs at broadside, a modified design procedure has been described which is presently under investigation.

ACKNOWLEDGMENT

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