PERIODIC AND QUASI-PERIODIC STRUCTURES FOR ANTENNA APPLICATIONS

Dietmar Pilz*, Wolfgang Menzel

Microwave Techniques, University of Ulm, PO Box, D-89069 Ulm, Germany
(* now with DaimlerChrysler Aerospace, D-89070 Ulm, Germany)
E-mail: menzel@mwt.e-technik.uni-ulm.de

***Abstract* – Printed periodic and quasi-periodic structures can be employed to control reflection and transmission properties of incident waves as a function of structure geometry. As this can be done mostly independently for both polarizations, different kinds of polarizers (reflection and transmission polarizer from linear to circular polarization or twist polarizers) can be realized. A local variation of element geometry allow the design of printed reflector antennas. Including the dual polarization properties for such antennas, dual function or dual frequency antennas can be built, or these properties can be exploited for the realization of compact, low-profile folded reflector antennas. Examples for these structures are presented, including antennas for 60 and 77 GHz with a diameter of 100 mm and a depth of 25 mm only.**

I. INTRODUCTION

In many cases, periodic structures are associated with frequency selective surfaces. Such structures, however, can also be used to manipulate reflection and transmission performance as a function of size of the periodic elements. Maintaining a periodic grid, on which the elements are arranged, but modifying the element geometry as a function of coordinates, quasi-periodic structures result which can be used to locally control reflection or transmission. An example for this is the manipulation of the reflection phase to focus a plane wave. Furthermore, such effects can be achieved mostly independently for both (linear) polarizations, leading to novel concepts of polarizers and printed antenna structures. Converters from linear to circular polarization as well as planar – even folded – reflector antennas are presented as examples.

For periodic structures, a theoretical computation can be restricted to a single elementary cell applying Floquet's theorem [1]. For quasi-periodic structures, the varying element geometries and current distributions have to be included, and the complete structure has to be calculated as a whole. Taking into account the large size of high gain antennas, this results in a considerable numerical effort. Up to now, this has been performed for moderate size, single polarization antennas only [2], applying a special method to evaluate the integration of the reaction integrals in the spectral domain method [3].

II. REFLECTION POLARIZER

The basic arrangements investigated in this contribution are quite similar to those well-known from frequency selective surfaces [1]; mostly, even rather simple elements like rectangular patches are employed. A first structure is a periodic array of rectangular patches printed on a dielectric substrate with backside metallization (Fig. 1). For all examples given in this contribution, the element cell size is approximately half a wavelength. An incoming plane wave will be reflected completely; the reflection phase angle, however, depends on the patch size - mainly on the dimension parallel to the electric field. A typical example for a quadratic element grid and broadside incidence of the wave is given in Fig. 2. The same diagram can be used here (quadratic grid) for the orthogonal polarization, simply interchanging patch width and length.

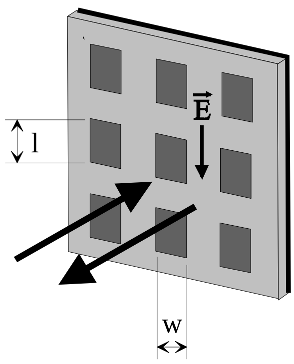

Fig. 1: Periodic arrangement of printed patches.

If the polarization of an incoming wave includes an angle of 45° with respect to the patch axes, the electric field can be decomposed into components parallel to the patch axes (Fig. 3). If the patch size now is adjusted in such a way that the difference of reflection phase angles between these two components is 90°, the outgoing wave has a circular polarization. If the phase difference is 180°, a twisting of the polarization of 90° occurs (Fig. 3). All this can be achieved with commercially available substrates – the substrate thickness needs not to be an eighths or a quarter of a wavelength, respectively.

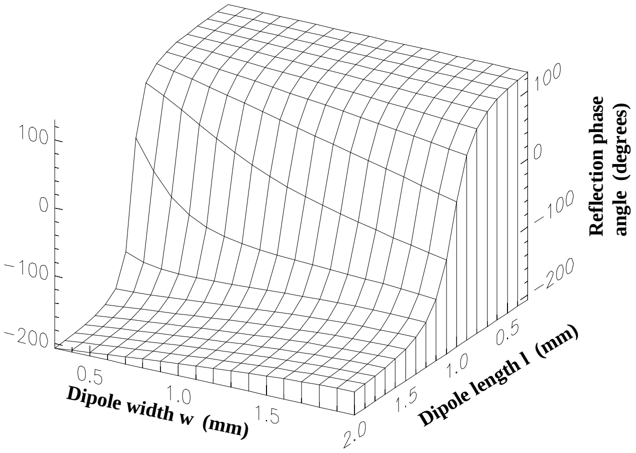

Fig. 2: Example of reflection phase angle of periodic arrangement of printed patches as a function of length and width. (Broadside incidence of plane wave, f = 76.5 GHz, substrate height 0.245 mm, ε_r = 2.22, cell size 2.2 by 2.2 mm).

Very similar results occur for a wave with a different angle of incidence; for 45° incidence for example, the axes orientation of the patches has to be modified to about 53°. On this basis, a circular polarizer was designed which, in addition, reflects the wave at an angle of 90° (Fig. 4). Fig. 4 shows the depolarization (ratio of undesired to desired amplitude) of the outgoing circular polarized wave. The computed performance (spectral domain method) and measurement agree very well.

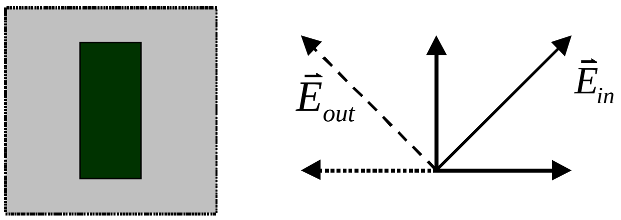

Fig. 3: Single cell/patch and vector decomposition of incident and reflected electric field for 180° of phase difference.

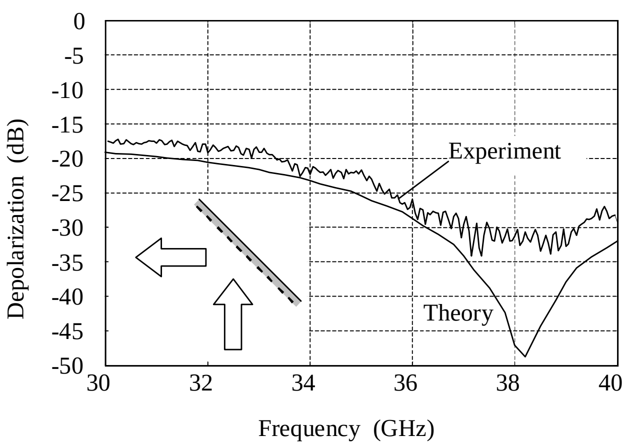

Fig. 4: Theoretical and experimental reflection performance of a reflection type circular polarizer. (Substrate height 0.76 mm, dielectric constant 2.5).

III. TRANSMISSION POLARIZER

In [4], a novel transmission type polarizer was presented consisting of a dielectric substrate with printed dipoles on both sides; the dipoles on one side being tilted with respect to the other ones (Fig. 5). With this polarizer, one linear polarization of an incident wave is transferred into a circular one, while the respective orthogonal linear or circular polarization is reflected. A typical performance of such a polarizer is shown in Fig. 6.

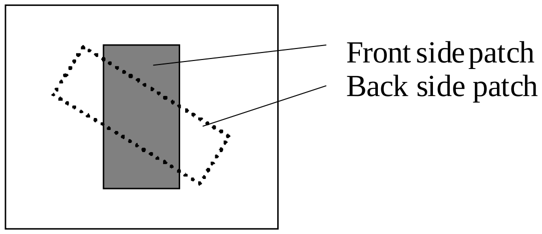

Fig. 5: Single cell of transmission polarizer [4].

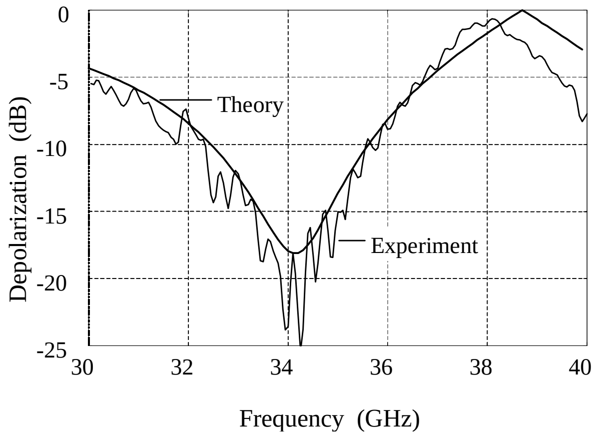

Fig. 6: Theoretical and experimental performance of transmission polarizer. (Substrate height 1.58 mm, dielectric constant 2.35).

IV. PLANAR REFLECTOR ANTENNA

If the elements in a periodic grid are locally modified in length, locally different reflection phase angles result (see Fig. 2). This can be utilized to realize a flat printed reflector focussing an incoming plane wave, i.e. acting like a reflector antenna [5], [6]. If, in addition, the width of the dipole elements is varied, too, an independent radiation characteristic can be achieved for the orthogonal polarization. For example, two different diagrams with the same or different feed points or antennas for two different frequencies in different polarizations are possible.

In Fig. 7, part of the layout for a dual frequency (24 and 60 GHz) printed reflector antenna is shown. On the one hand, the grid spacing should be λ_0, on the other hand, it should allow a maximum dipole length of half a guide wavelength as well. To cope with these requirement, a substrate with a dielectric constant of 6 and a non-quadratic grid was chosen for this antenna. The complete reflector possesses ca. 5000 printed patches, and it was offset fed from the same feed point at both frequencies.

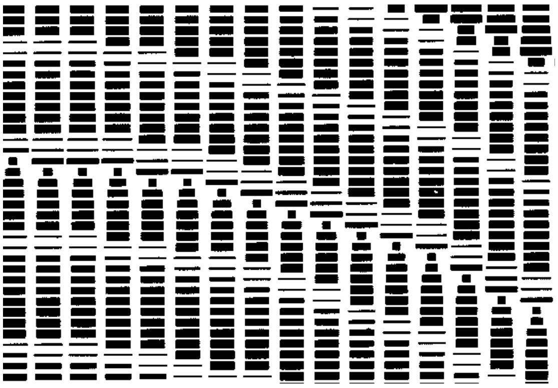

Fig. 7: Part of the reflector antenna layout for the 24/60 GHz dual frequency antenna.

Fig. 8 shows the azimuth radiation patterns of this antenna. At 24 GHz, a rather good performance can be stated, while the 60 GHz diagrams shows some side lobe shoulders around -15 dB.

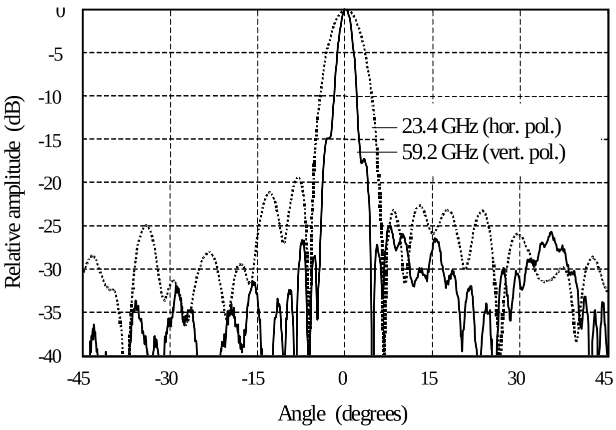

Fig. 8: Radiation diagrams of dual frequency printed reflector antenna.

V. FOLDED REFLECTOR ANTENNA

Based on the concept of planar reflector antennas as described above, the focussing array was modified to include a polarization twisting of the electromagnetic field. A first relatively small and low frequency antenna of this type was described in [7]; now high gain and high performance mm-wave antennas of this type have been realized.

The principal function of this antenna is indicated in Fig. 9. The radiation of the feed is reflected by a printed grid or slot array at the front of the antenna. Then the wave is incident on a special array of rectangular metal patches printed on a standard microwave substrate with full backside metallization. The patch axes are tilted by 45° with respect to the incident electric field. The dimensions of the patches are designed in such a way that, on the one hand, a phase difference of 180° occurs between the two components of the reflected wave – giving the twisting performance (Fig. 3). On the other hand, an overall phase shift is adjusted according to the focussing (phase shifting) requirements. The outgoing plane wave then can pass the grid or slot array. The original design of this antenna is done on the basis of *periodic* structures. For varying patch dimensions, the reflection phase angles are calculated for both principal polarizations. The optimum combination of phases then is selected from this set of data according to both twisting and focussing requirements. If the polarizing grid or slot array is replaced by the circular polarizer as described in section III [4], even circular polarization can be achieved with this type of antenna.

A photograph of the twisting and focussing array of a 60 GHz antenna is shown in Fig. 10.

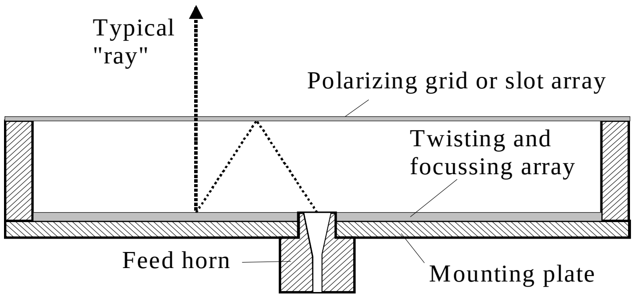

Fig. 9: Principal set-up of the folded reflector antenna based on planar printed structures.

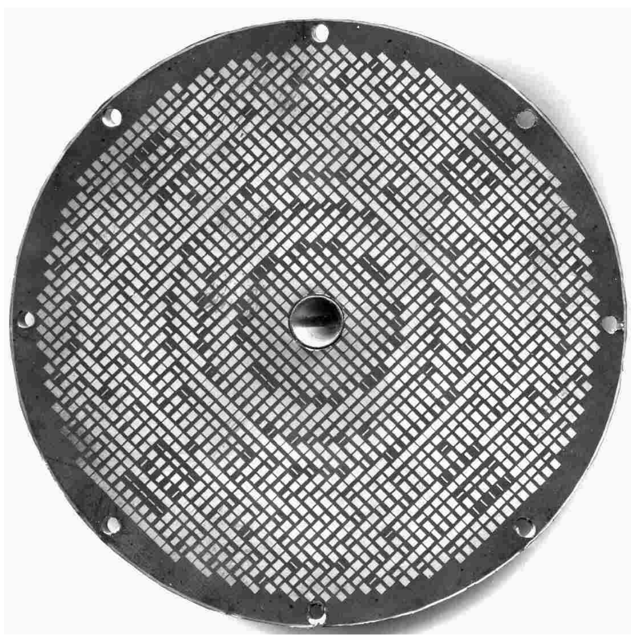

Fig. 10: Photograph of the printed twisting and focussing reflector for the 60 GHz antenna.

This type of antenna has been designed for communication applications at 28.5 and 60 GHz and for an automotive radar at 77 GHz [8].

The Ka-band antenna has a rectangular shape of 270 mm by 250 mm and a depths of 50 mm. Its radiation diagram is plotted in Fig. 11. Beamwidth is 2.7° in E-plane and 2.5° in H-plane.

Both the antennas at 60 and 77 GHz have a diameter of 100 mm and a depth of 25 mm, and the reflectors are printed on a Duroid substrate of 0.254 mm thickness. For 60 GHz, a grid printed on a Duroid substrate (h = 1.58 mm, ε_r = 2.35) is used, while for the 77 GHz antenna, a slot array (TMM4 material, h=1.02 mm, ε_r = 4.5) was used instead of the grid. The antennas are fed with small circular waveguide feed horns.

E- and H-plane radiation diagrams are shown in Fig. 12 for 58.4 GHz, and in Fig. 13 for 77 GHz, respectively. Side lobe levels of the antennas are below -24 dB. At 60 GHz, beamwidth is 3.6° in E-plane and 4.4° in H-plane. This is slightly higher than expected from the antenna diameter, but in this case, the feeding horn was too big, resulting in an edge taper of –15 dB. Gain was measured to 33 dB, in the same order as computed from the familiar equation

$$G \approx \frac{27000}{\Delta\Phi/_{\text{degrees}} \cdot \Delta\Theta/_{\text{degrees}}} . \qquad (1)$$

The 77 GHz beamwidths amount to 2.7 °, gain to about 35 dB, showing a loss of 0.5 ... 1 dB compared to the value according to equ. (1). These slightly increased losses are caused by the resonant slots in the polarizer. Overall, however, the losses of this type of antenna are extremely low compared to planar antennas. With their comparably low profile and ease of fabrication, they show an interesting alternative to conventional antennas.

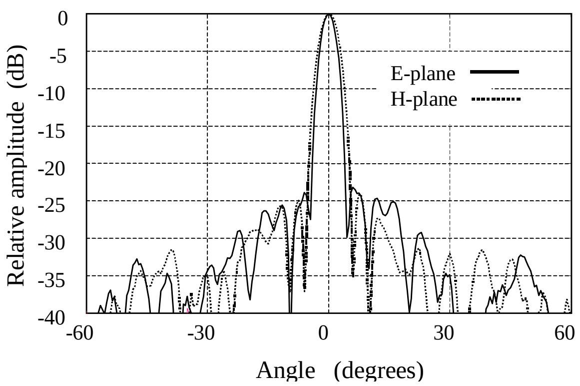

Fig. 12: Radiation diagram of 60 GHz folded reflector antenna.

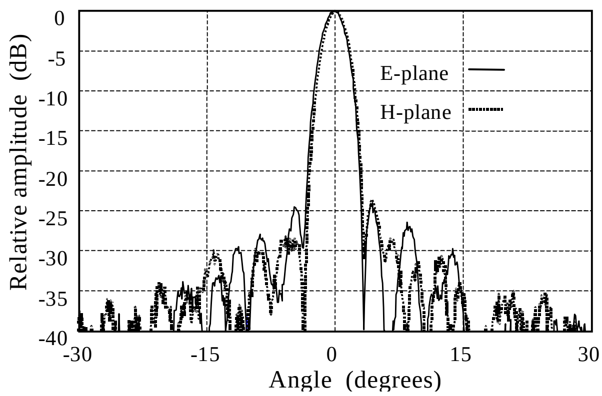

Fig. 13: Radiation diagram of 77 GHz folded reflector antenna.

VII. CONCLUSION

The application of printed periodic and quasi-periodic structures to the design of polarizers and printed (folded) reflector antennas has been demonstrated. To this end, use is made of the dual polarization properties of the printed structures. As examples, a transmission and a reflection type polarizer from linear to circular polarization, a dual frequency printed reflector antenna and folded reflector antennas for different applications have been presented.

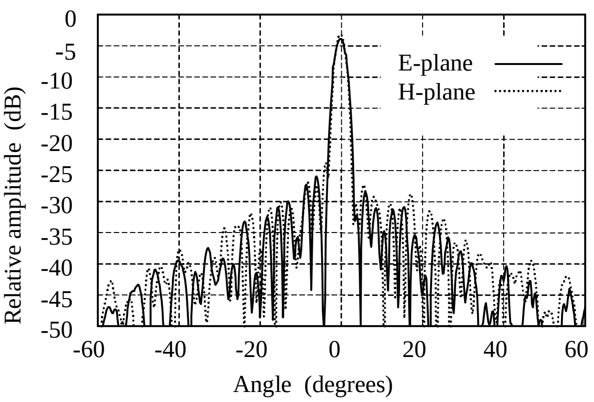

Fig. 11: Radiation diagram of 28.5 GHz folded reflector antenna.

VII. REFERENCES

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