

Investigations of Advanced Folded Reflectarray Antennas

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Abstract – This paper reports on recent research on folded reflectarray antennas done at the University of Ulm. The first area of work deals with the investigations of reflector elements with improved phase angle range and the influence of different effects on bandwidth and antenna gain including cell type, size, or substrate layer structure. A second area of work is the precise characterization of reflector elements, both with respect to the phase angle as well as the polarization twisting. Two methods have been developed for such characterization at frequencies around 77 GHz, one based on a quasi-optical Gaussian beam setup, another one based on near-field probing.

1 INTRODUCTION

Printed planar reflectarrays [1-4] have gained increasing interest due to their low weight, design flexibility, or ease of fabrication. A more compact version of such antennas is provided by folded reflectarray antennas [3-4] which have already been implemented into an automotive radar. The cross section of a folded reflectarray antenna is shown in Fig. 1. This antenna consists of a circular feed, a polarizing grid printed on a dielectric substrate, and the specific reflectarray substrate with printed metal elements like rectangular patch elements, which, simply by their geometry, both can adjust the overall phase angle and twist the polarization of the incoming wave by 90° using a 180° phase shift between the two polarizations of the reflected wave. This dual function requires an independent adjustment of the reflection phase angles for both polarizations.

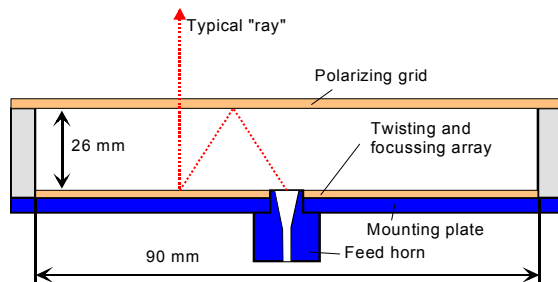


Fig. 1: Principle of a folded reflectarray antenna.

2 NOVEL REFLECTOR ELEMENTS

A disadvantage of simple rectangular patches for single-layer reflectarrays is a reduced phase angle range of only 300°... 320°. This problem may be overcome by dual or triple layer reflectarrays, e.g. [4].

The underlying principle are coupled resonances, thus doubling or tripling the available range of phase angles. For some application, however, like in automotive radars, such multilayer substrates with their increased fabrication effort and cost are not acceptable.

A solution of this problem could be the realization of coupled resonators on a single layer. In addition, in this case, a thicker substrate can be used resulting in a flatter phase curve. Recently, some modified structures have been proposed for an increased phase angle range for single polarization, e.g. [5-11], based on multiple elements, partly combined with slots. Losses now occur at both resonances, although losses may be lower. The two resonances should be close together to achieve a flat phase curve. For folded reflectarrays, phase adjustment is necessary independently for both polarizations requiring some degree of double symmetry.

Two of such elementary structures with dual resonances are shown in Fig. 2 top. The first one (*three fingers*) exhibits a double resonance based on different lengths of narrow strips, the second one (*crossed elements*) has different resonance frequencies based on two adjacent elements. To provide 180° phase shift and maintaining double symmetry, four substructures each are combined to one unit cell. The phase angle behavior of the left structure is given in Fig. 2 bottom; the right structure shows a similar performance; both with a phase angle range of more than 500°. A reference antenna with simple rectangular elements (on a 0.254 mm thick substrate) and one antenna each with the cells as shown in Fig. 2 were designed, fabricated, and tested. All three antennas result in similar radiation diagrams as shown in Fig. 3 for the reference antenna, where the two modified antennas exhibit slightly higher beamwidths.

Antenna losses also were tackled with another approach. With the usual PTFE substrates, the interface between substrate and metallization is roughened to ensure a good bonding strength of the metal, leading to increased losses from surface currents at the rough interface. In a new antenna approach, the metallization has been etched on a thin substrate ($h = 0.127$ mm, $\epsilon_r = 2.2$), this was then bonded face down on the main substrate. In this way, the main surface current is flowing on the much smoother top side of the metallization, reducing current losses [12].

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Two antennas based on this approach have been realized, one with interleaved rhombs as elements, one based on the structure as shown in Fig. 2, top left. Fig. 4 compares the gain behavior of all realized antennas.

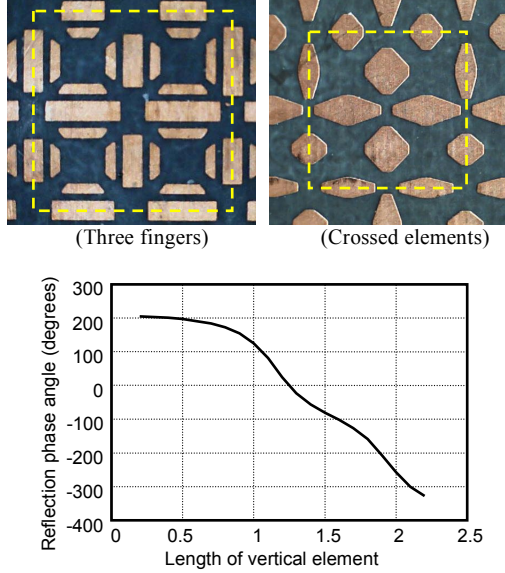


Fig. 2: Cell structures for two modified twist reflector (top) and reflection phase angle of the left structure on top for vertical polarization as a function of the vertical length L_{vert} of the sub-structure. ($L_{\text{hor}} = 1.2$ mm, substr. thickness 0.5 mm, $\epsilon_r = 2.22$, $f = 76.5$ GHz).

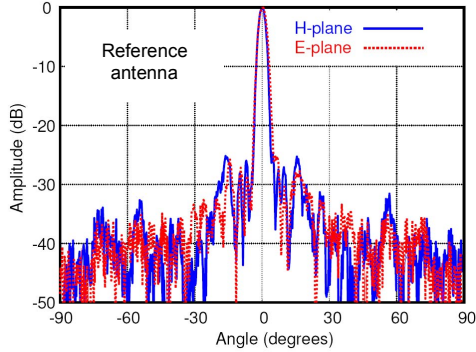


Fig. 3: E-plane and H-plane radiation diagrams of the reference antenna at 76.5 GHz.

The reference antenna and that with the covered rhombs show the best gain with a maximum of about 33 dB and a 3 dB bandwidth of 10 ... 11 GHz. The element cell size of the antennas with the three finger patches and the crossed patches are quite large with phase angle errors, especially towards the antenna edges (slant incidence of the waves), resulting in wider beamwidths and reduced gain. An improvement for the covered three finger patch antenna can be observed; this one has smaller element cells having dielectric material on both sides of the metallization and the improved metal losses.

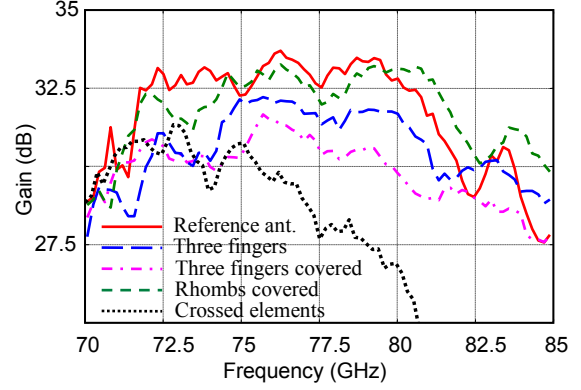


Fig. 4: Gain of reference and four test antennas.

3 CHARACTERIZATION METHODS

Besides simulation results of prototype unit cells, it is important to investigate the reflection behavior of reflectarray structures experimentally including deviations due to fabrication tolerances. In this chapter, two characterization methods for unit cells with a polarization twist are introduced, investigating their absolute reflection phase angles and their ability of polarization twisting as well.

The first characterization method is based on a quasi-optical Gaussian beam setup with polarization separation, the second one is based on near-field probing using special, very compact probes developed for this application. First investigations have been made around 35 GHz ([13], [14]), now measurements are possible also in the 77 GHz frequency range.

Fig. 5 shows a periodic array of patches designed by use of [15] as a test structure for the characterization measurements at 77 GHz. The Rogers substrate RT5880 ($\epsilon_r = 2.2$) with printed patches is backside-metallized; substrate thickness is 0.5 mm. Unit cell size is $2.14 \text{ mm} \times 2.14 \text{ mm}$. The specific dimensions of the chosen patch size ($0.735 \text{ mm} \times 1.56 \text{ mm}$) lead to a reflection phase angle difference of 180° between the two field components E_x and E_y . An incident electric field with polarization E_{in} , tilted by 45° against the patches' axes, results in a polarization twisting of the reflected wave E_{refl} by 90° .

3.1 Quasi-optical measurements

According to Fig. 5, a decomposition of the reflected components into the two polarizations E_x and E_y helps to characterize their reflection phase angle difference and therefore to verify the polarization twisting. A quasi-optical Gaussian beam setup with polarization separation is shown in Fig. 6. The setup consists of three horn antennas h1 to h3, the device under test (DUT), and two square arrangements of lenses. Square I – with a diagonal dielectric sheet – is acting as a quasi-optical directional coupler for the incident

signal and the signal reflected from the DUT. The horn antenna h1 transmits under an angle of 45° , therefore including both field components E_x and E_y . Part of the wave is reflected at the dielectric sheet in square region I and guided to the DUT, which is located at the waist of the Gaussian beam. The reflected wave passes the dielectric sheet and enters region II. There, a horizontally orientated grid separates the two polarization components E_y and E_x , which then are detected via horn antennas h2 and h3. The grid is realized on a Rogers RT5880 substrate ($\epsilon_r = 2.2$) with a thickness of 1.143 mm, the polarization separation is better than 20 dB in the considered frequency region from 76 GHz to 79 GHz, [15].

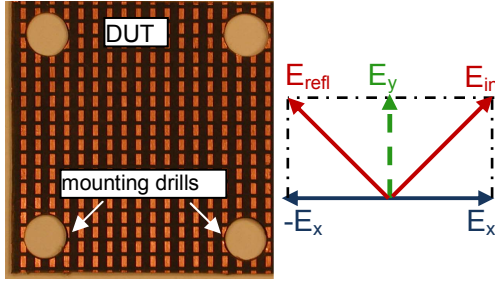


Figure 5: Test structure with polarization twist.

The reflection phase angles of the separated field components E_x and E_y using this quasi-optical setup are shown in Fig. 7. Their phase angle difference is consistent with the simulated results from [15]. The reason for a slight deviation between measurement and simulation can be explained by a low ripple over frequency for the measurement of E_y due to a standing wave in that path. This effect was reduced by adding some absorbing material.

3.2 Near-field characterization

Another experimental method is the examination of the test array (DUT) in a near-field measurement setup as shown in Fig. 8. The patch array is illuminated by an open waveguide (WG), and the reflected field is detected in the near-field using a probe with high spatial resolution. For this purpose, a special probe has been developed for 77 GHz. Its design is based on substrate-integrated waveguide with a high- ϵ_r substrate, metalized on top and bottom; the sidewalls are realized with rows of vias.

The test array (DUT) includes patches with the same dimensions as those investigated in the quasi-optical setup. This time, patches are printed on the array in regions with both orientations, as it can be seen in Fig. 8.

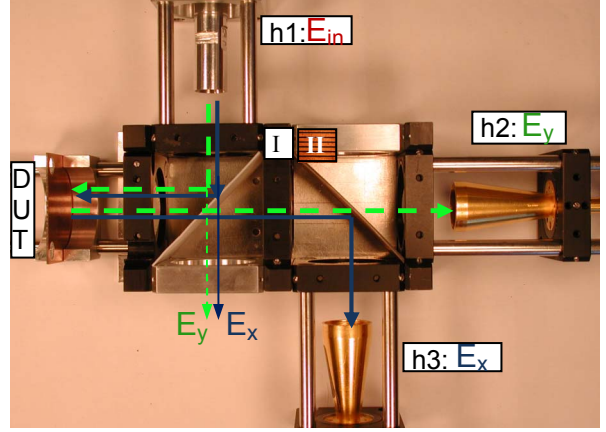


Figure 6: Quasi-optical measurement setup.

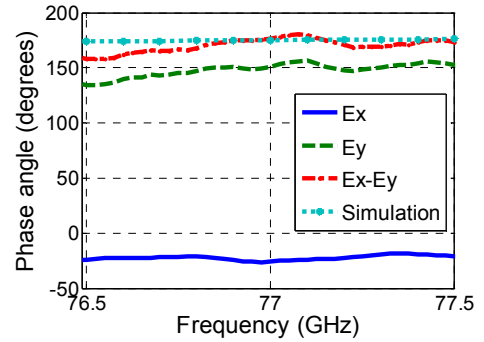


Figure 7: Measured phase angles with the quasi-optical measurement setup.

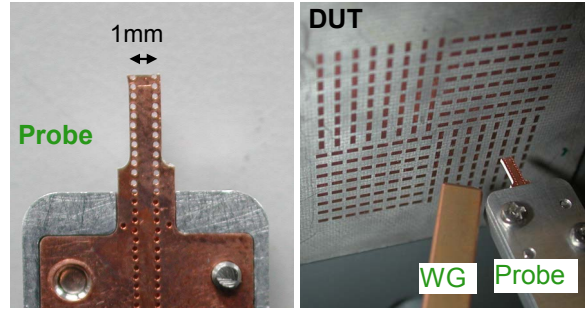


Figure 8: Probe and measurement setup.

As the polarization directions of both the illuminating waveguide and the probe are oriented in the same direction (E_y), the other component (E_x) can be measured in another array region with the patches rotated by 90° . Fig. 9 shows the phase angles of a near-field scan with this measurement setup, using a step width of 0.2 mm. The measured phase angle difference of the patches with the two orientations is almost 180° .

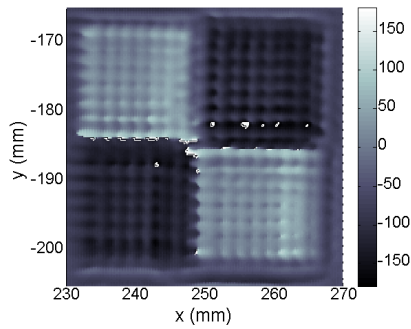


Figure 9: Measured phase angle result of a near-field measurement scan of the test array.

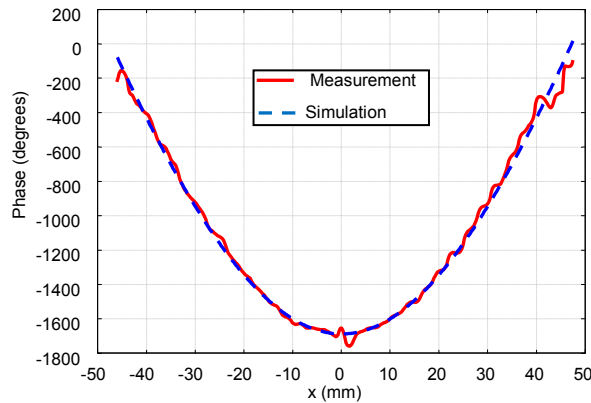


Figure 10: Measured reflection phase angle of a folded reflectarray antenna compared to ideal phase angle values.

Another test with the given setup is a radial scan at the center of a reflectarray antenna, see Fig. 10. In this case, the polarizations of feeding waveguide and probe were oriented orthogonal to each other. The measured (and unwrapped) curve of the absolute reflection phase angle and the theoretical results agree in an excellent way.

4 CONCLUSION

This paper reports on recent research on folded reflectarray antennas. Investigations of novel reflector elements have been shown, antenna designs and measurements based on these structures are presented. In the field of characterization of polarization twisting elements for reflectarray antennas, two measurement setups have been introduced and verified by measurement results: one is based on a quasi-optical Gaussian beam setup, the other one uses near-field measurements with high-resolution probes developed for this purpose.

Acknowledgments

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References

- [1] J. Huang, "Microstrip reflectarray," IEEE Antennas and Propagation Society International Symposium, 1991. AP-S 1991, pp. 612-615.
- [2] D. M. Pozar, S. D. Targonski, H. D. Syrigos, "Design of millimeter wave microstrip reflectarrays," IEEE Trans. on Antennas and Propagation, Vol. AP-45 (1997), pp. 287-296.
- [3] W. Menzel, D. Pilz, and M. Al-Tikriti, "MM-Wave Folded Reflector Antennas with High Gain, Low Loss, and Low Profile," IEEE AP Magazine, June 2002, pp. 24-29.
- [4] J. A. Zornoza, R. Leberer, M. Moraga, J. A. Encinar and W. Menzel, "A folded 3-layer printed reflectarray with shaped pattern for LMDs central station sector antenna," IEEE Int. Symposium on Antennas and Propagation, Monterey, USA, July 2004, Vol. 1, pp. 5-8.
- [5] M. R. Chaharmir, J. Shaker, M. Cuhaci, and A. Ittipiboon, "Broadband reflectarray antenna with double cross loops," Electronics Letters, vol. 42, no. 2, pp. 65-66, Jan. 19, 2006.
- [6] M. R. Chaharmir, J. Shaker, M. Cuhaci, A. Ittipiboon, "A Broadband Reflectarray Antenna with Double Square Rings as the Cell Elements," 1st European Conference on Antennas and Propagation (EuCAP), Nice, France, 2006.
- [7] D. Cadoret, L. Marnat, R. Loison, R. Gillard, H. Legay, and B. Salome, "A dual linear polarized printed reflectarray using slot loaded patch elements," in Proc. Second European Conference on Antennas and Propagation EuCAP 2007, Nov. 11-16, 2007, pp. 1-5.
- [8] K. H. Sayidmarie and M.E. Bialkowski, "Investigations into Unit Cells offering an increased Phase Range for Single Layer Printed Reflectarrays," Microwave and Optical Technology Letters, Vol. 50, No. 4, April 2008, 1028-1032.
- [9] M. E. Bialkowski, A. M. Abbosh, and K. H. Sayidmarie, "Investigations into phasing characteristics of printed single and double cross elements for use in a single layer microstrip reflectarray," in Proc. IEEE Antennas and Propagation Society International Symposium AP-S 2008, Jul. 5-11, 2008, pp. 1-4.
- [10] S. Dieter, C. Fischer, W. Menzel, "Single-Layer Unit Cell with Optimized Phase Angle Behavior," Third European Conference on Antennas and Propagation, 2009, Berlin.
- [11] W. Menzel, J. Li, and S. Dieter, "Folded reflectarray antenna based on a single layer reflector with increased phase angle range," in Proc. 3rd European Conference on Antennas and Propagation EuCAP 2009, Mar. 23-27, 2009, pp. 2757-2760.
- [12] G. Fischer, University of Erlangen, Germany, personal communication.
- [13] S. Dieter, and W. Menzel, "High-Resolution Probes for Near-Field Measurements of Reflectarray Antennas", in IEEE Antennas and Wireless Propagation Letters, 2009, Vol. 8, pp. 157-160.
- [14] S. Dieter, A. Moessinger, S. Mueller, W. Menzel, and R. Jakoby, "Characterization of Reconfigurable LC-Reflectarrays Using Near-Field Measurements", in Proc. Of 4th German Microwave Conference GEMIC, 2009, Mar. 16-18, pp.1-4.
- [15] Ansoft Designer 5.0.2, ANSYS Inc., Canonsburg, PA, 2010.