Entwurf und Optimierung von Reflectarray-Antennen mit Designer Planar EM

(Design and Optimization of Reflectarray Antennas using Designer Planar EM)

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Summary

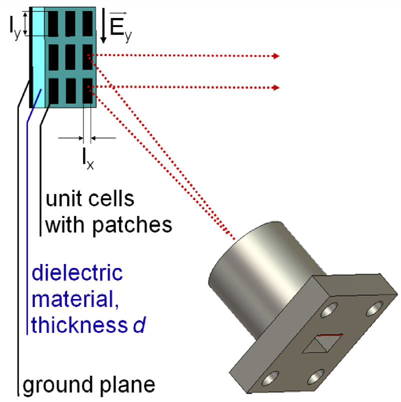
In this paper, design methods for reflectarray antennas by use of Designer Planar EM from ANSYS are introduced. This includes development, simulation and optimization of advanced reflection elements for these antennas. Additionally, an optimization routine for the whole antenna configuration using Designer Planar EM and applying Particle Swarm Optimization has been developed. The simulation methods and optimization routines are verified by far-field measurement of antennas, which have been designed with these principles, for 35 GHz and 77 GHz respectively.

Keywords

Reflectarray antennas, antenna design, and optimization, Designer Planar EM.

1. Introduction

Planar reflectarray antennas [1] have the advantages of easy, low-cost fabrication, high antenna gain, and low weight. Fig.1 (left) shows the principle of such kind of antennas: a feeding antenna illuminates the reflector, which consists of a backside-metalized dielectric material with printed metalized dipoles on top. Different sizes of these patches act as different phase shifters, and therefore, various reflection phase angles are possible to adjust. This is a method to compensate for free-space delay on the reflector and there is a multitude of antenna farfield-diagrams to be chosen from in the antenna design.
For determination of the reflection coefficients of the patches, Designer Planar EM from ANSYS [2] is a very powerful tool. A full-wave simulation of the whole antenna would need very high computational effort. Alternatively, here a full-wave Frequency Selective Surface (FSS) simulation is used, with the assumption of uniform cells which are repeated and form arrays of infinite size. In reality, the geometrical patch dimensions vary over the reflector position, however, as the variation is very small, the FSS assumption is accurate enough for the design process. Fig.1 (right) shows the simulation model of such an FSS unit cell from Designer Planar EM and the obtained reflection phase angle, as a function of the patch dimensions l_x and l_y.



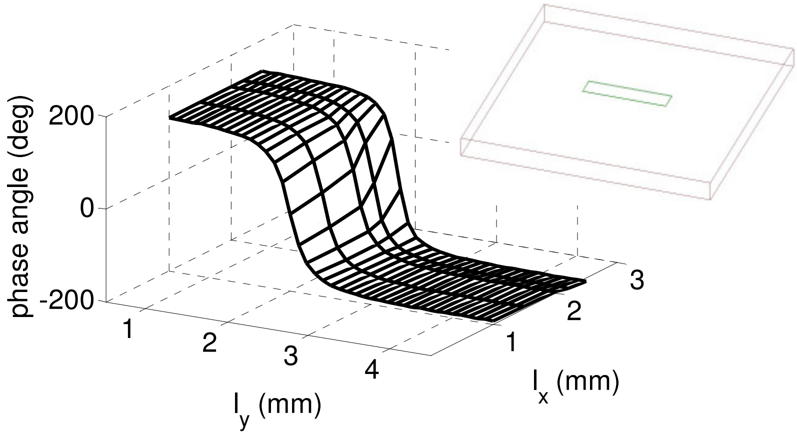
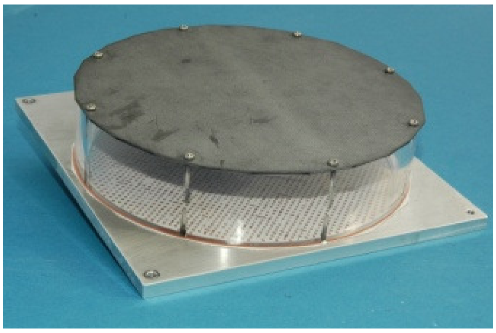


Fig. 1. Principle of a reflectarray antenna (left) and simulated reflection phase angle as a function of the patch dimensions (right).



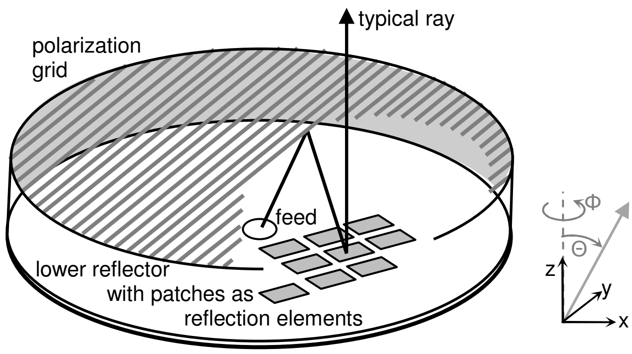


Fig. 2. Folded reflectarray antenna (left) and principle of the antenna (right).

Another, very compact version of these antennas are folded reflectarray antennas [3], as they are shown in Fig.2. The outgoing wave from the feed is reflected at a polarizing grid. Then, a second reflection occurs on the lower reflector. Here again, metalized patches act like phase shifters, the simulation method is analogue to other reflectarrays. The difference is, here only a selection of patch dimensions is possible for usage, those who obain a polarization twist. So the wave can pass the polarizing grid in the last step.

2. Advanced Reflection Elements for Reflectarray Antennas

One standard unit cell as shown in Fig.1 (right) uses a single metalized patch and just one substrate layer. The simple reflector construction based on such cells has the advantage of very easy fabrication. The drawback of this structure, however, is the reflection phase angle, which usually covers only a region of less than 360 degree. So not all necessary reflection phase angles are available for antenna design. An alternative is using coupled resonators instead of a single patch to increase the possible phase angle range for the phase shifter values. In order to keep the easy production method with a single-layer substrate, in this work, designs were developed with integration of the resonators into one unit cell [4]. Two planar EM simulation models are shown in Fig.3, as examples for such unit cells. With this applied simulation tool, the multitude of geometrical parameters can be optimized very effectively. So, a final design is developed, with optimum resonance lengths and coupling behaviour.

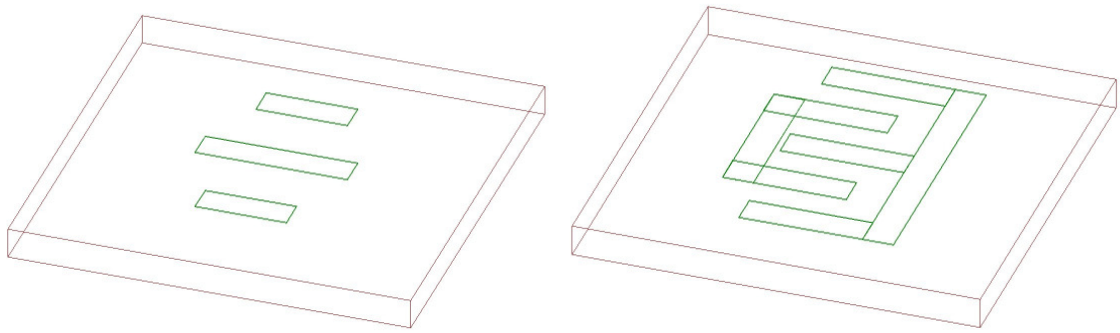


Fig. 3. Simulation models of novel reflection structures with several resonators per unit cell.

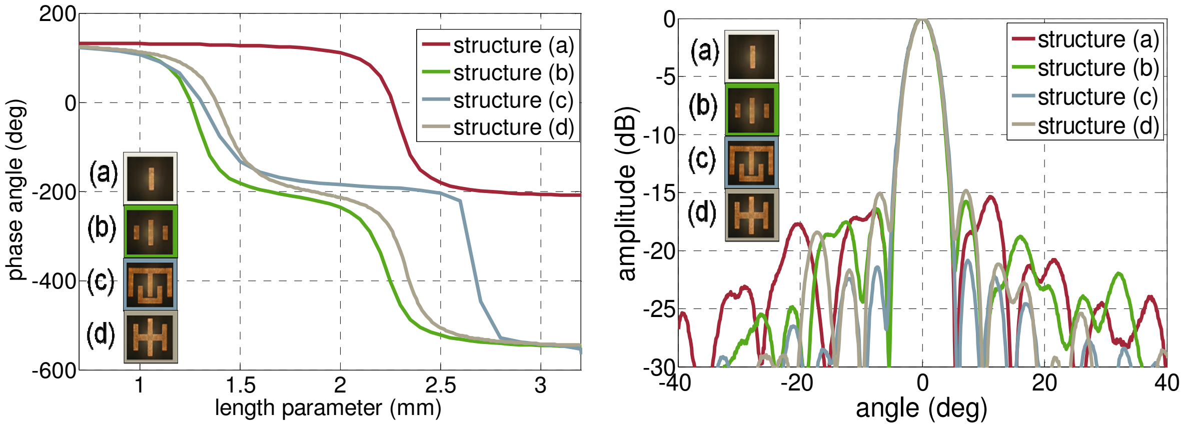


Fig. 4. Simulated reflection phase ange of the optimized structures (left) and correspondent measured antenna diagrams at 35 GHz (right).

The simulated reflection phase angles of these optimized novel structures (b to d) are compared with the behaviour of a standard single patch cell (a). Fig.4 (left) shows the obtained reflection phase angle curves dependent on the geometrical resonator length. The novel structures (b to d) show the advantage of an almost doubled phase angle range compared to the single patch (a). Based on these simulation results and a quasi-optical raytracing process, four offset-fed antennas (with the principle shown in Fig.1 left) have been designed and fabricated for 35 GHz. The measured far-field diagrams are shown in Fig. 4 (right). Compared to the others, the antenna based on structure (c) has the best sidelobe supression of 20.9 dB and the highest antenna gain of 27 dB, followed by the antenna based on structure (d).

3. Optimization Routine for the Reflector Configuration of a Folded Reflectarray Antenna

For the optimization of such antennas, a routine has been implemented, which is based on Particle Swarm Optimization (PSO), a very powerful optimization algorithm presented in [5]. The principle of the developed routine, which was introduced in [6], is shown in Fig. 5:

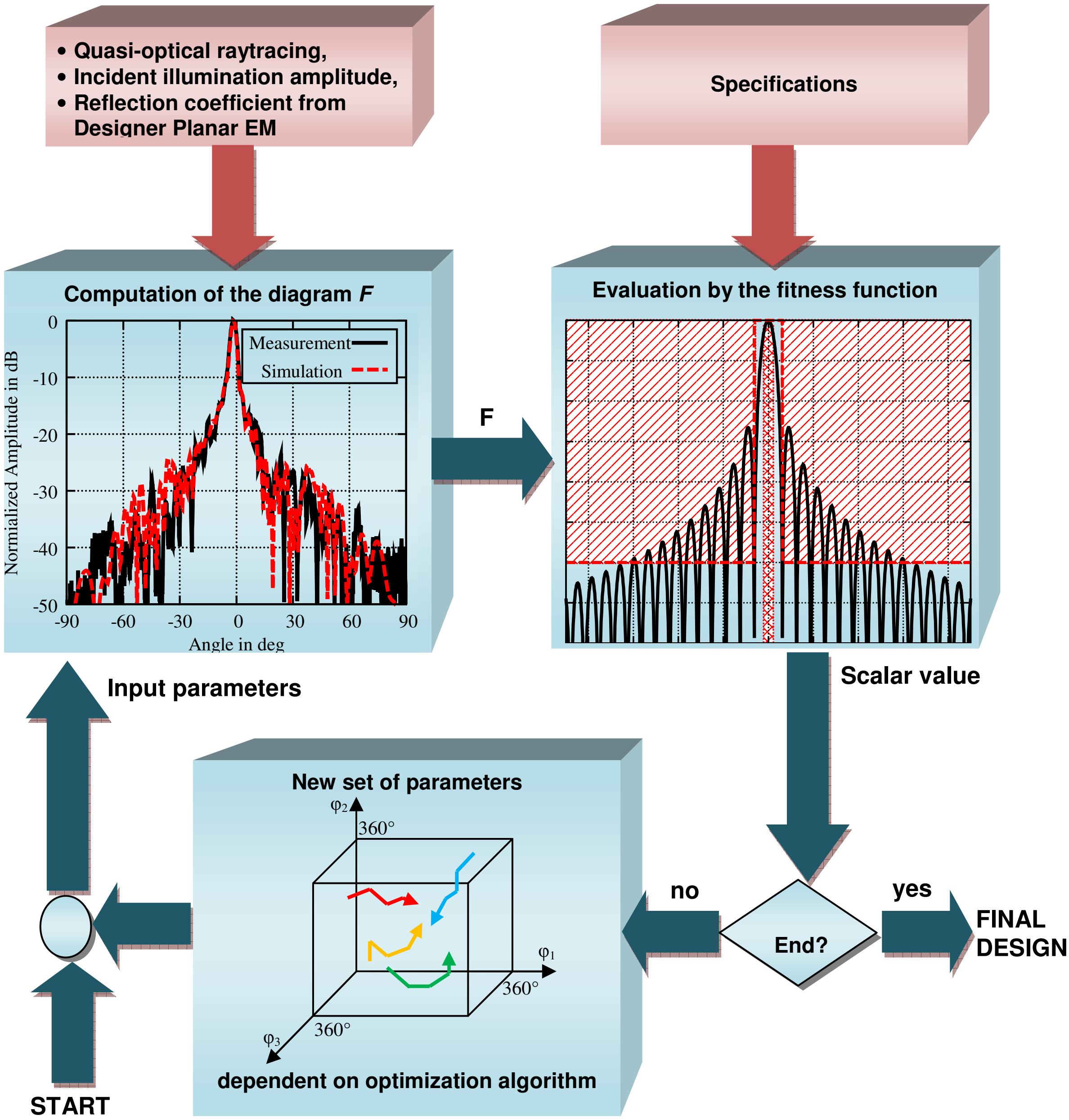


Fig. 5. Developed Particle Swarm Optimization for the antenna, using Designer Planar EM.

In the first step, the antenna diagram is computed for a certain reflector configuration. This computation uses quasi-optical raytracing, the illumination pattern of the feed, and the reflection coefficients of the reflection structures, obtained by Designer Planar EM. With this, a very realistic preview on the resulting antenna diagram is computed within a few seconds. This diagram is evaluated by the fitness function, which compares this respective diagram with a specification mask. The output of the fitness function is a scalar value, which stands for the deviation between the optimum diagram mask and the actual farfield diagram. Dependant on this evaluation, the design could be chosen to be the final one, this would terminate the process. Otherwise, the next iteration starts with a new set of parameters, so with another diagram computation for another reflector configuration. This parameter selection depends on the results from previous iterations. The method, how new parameters based on this knowledge are chosen, depends on the optimization algorithm. In the Particle Swarm Optimization, a set of particles, standing for respective solutions, are moving through the solution space, trying to find an optimum solution. During their movement, the particles use the knowledge about their own best solution and the best solution of all particles. The overall process resembles that of a swarm, moving towards the optimum solution.

Two antenna designs have been optimized with this method and fabricated at frequencies around 77 GHz. The measured farfield patterns of the antennas are shown in Fig. 6. The left figure shows the measured cosec^2-antenna diagram, compared to the specification mask of the optimization routine. The other presented antenna has an offset beam characteristic. The measured and simulated results are shown in Fig. 6 (right) and fit very well. These measured antenna designs verify the performance of the powerful developed tool.

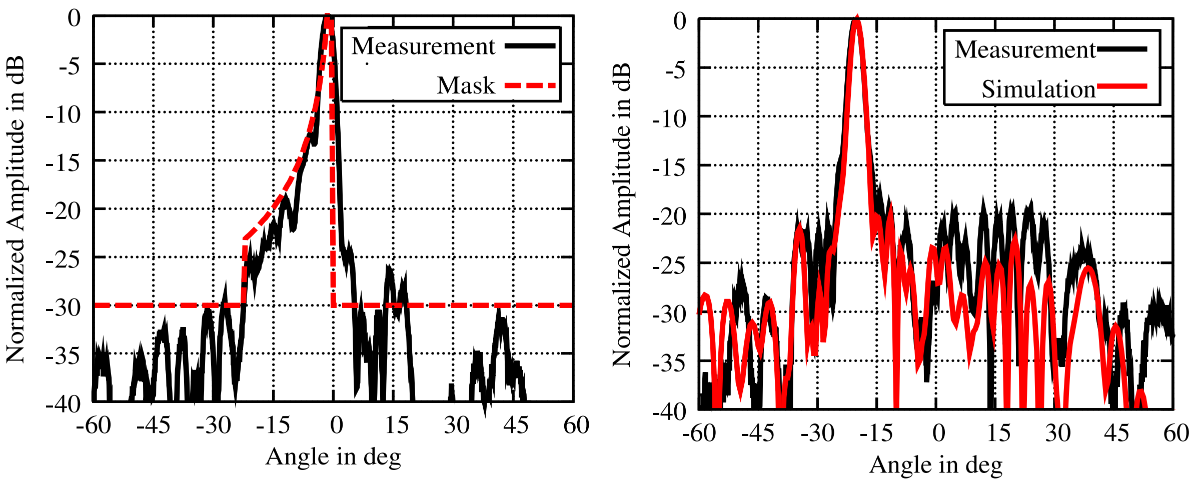


Fig. 6. Measured farfield diagrams for two optimized antennas for 77 GHz, using cosec^2-characteristics (left) and offset beam diagram (right).

4. Conclusions

The software program Designer Planar EM from ANSYS is a very efficient tool for the design and optimization of reflectarray antennas. This includes development, simulation, and optimization of advanced reflection elements for these antennas. Additionally, an optimization routine for the whole antenna configuration by use of Designer Planar EM and Particle Swarm Optimization has been developed. The simulation methods and optimization routines are verified by farfield measurements of antennas, which have been designed with these principles, for the frequencies 35 GHz and 77 GHz respectively.

5. References

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