High-Resolution Probes for Near-Field Measurements of Reflectarray Antennas

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***Abstract*—This letter proposes three different near-field-measurement probes in order to characterize individual patches on the surface of reflectarray antennas, both in phase and amplitude. The first realized structure is a dielectrically filled waveguide probe, the second is a probe ending in a dipole structure, and the third is a substrate-integrated waveguide probe. Requirements for near-field probes in this application are high resolution and reduced influence of the probe on the examined structure. The ability of the presented probes has been investigated by simulations and validated with measurements at a frequency of 35 GHz at reflectarray structures, placing the probes a few millimeters above the antenna surface.**

***Index Terms*—High-resolution probe, near-field characterization, reflectarray.**

I. Introduction

REFLECTARRAYS have found an increasing interest due to their advantages of planar and low-weight antennas, which are simple and low-cost in fabrication [1], [2]. Compared to parabolic antennas, the phase corrections are performed by use of printed structures, e.g., rectangular patches of variable size. The benefits of this principle have also initiated the development of reconfigurable reflectarrays, e.g., based on tunable liquid crystal material [3]–[5].

Commercial software is available to examine the behavior of unit cells, where the assumption of an infinite array with uniform unit cells is made. Nowadays, not only the phase values, but also the corresponding amplitude variations due to dielectric and metallic losses, are of interest [6]. For measuring amplitude and phase, a prototype unit cell can be investigated in a waveguide simulator measurement setup [5]. An interesting method of near-field measurements as a basis for reflectarray antenna design has been introduced in [7] for frequencies around 15 GHz. In that work, a monopole probe with the length of $\lambda/16$ is penetrating from the metallic ground plane below the scatterer elements.

In this letter, near-field measurements a few millimeters above the antenna surface are used in order to characterize the reflection behavior of each unit cell individually. These investigations can be made on the surface of any reflectarray structure, not just on prototype cells. It could be useful for reflectarray characterization and design.

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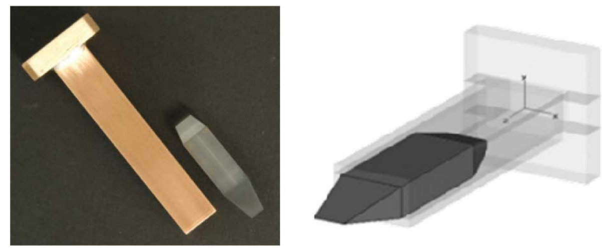

Fig. 1. Photograph and simulation model of the dielectrically filled waveguide probe (A).

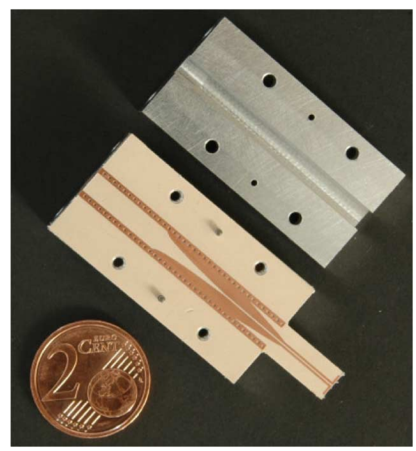

Fig. 2. Photograph of the dipole probe (B).

II. Developed Near-Field Probes

For the detection of the field components, near-field probes with high spatial resolution are needed in order to assign the measurement results to the individual patches. For this purpose, three different near-field probes have been developed using a full-wave simulation tool [8].

The first probe (A) is a waveguide filled with acrylic glass of permittivity 3.4. The structure and simulation model are shown in Fig. 1. The tip of the acrylic structure is tapered in order to decrease the probe dimensions to 3.6×0.5 mm^2 and, therefore, improve the resolution of the probe. The tapered transition from the waveguide to the dielectric-filled waveguide with its length of 4.8 mm was designed for better matching at the operating frequency around 35 GHz, as can be seen in Fig. 3. With this probe, first near-field measurement scans on a reconfigurable liquid crystal reflectarray have been made [9].

Another developed near-field probe (B) is based on a waveguide with a suspended substrate in the E-plane, as shown in

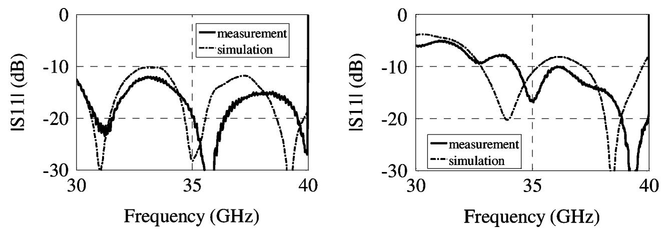

Fig. 3. Return loss for probes A and B in measurement and simulation.

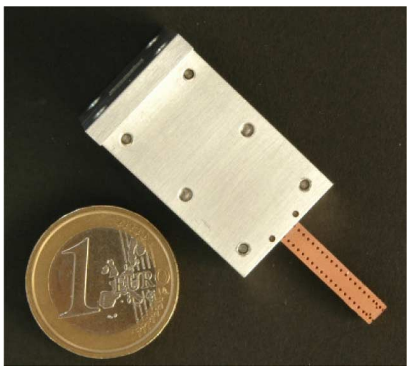

Fig. 4. Photograph of the substrate-integrated waveguide probe (C).

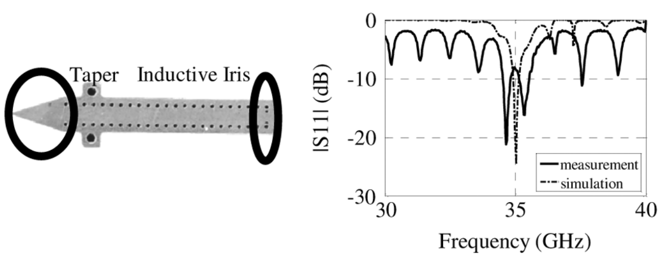

Fig. 5. Matching improvement for probe C (left) and measurement and simulation results (right).

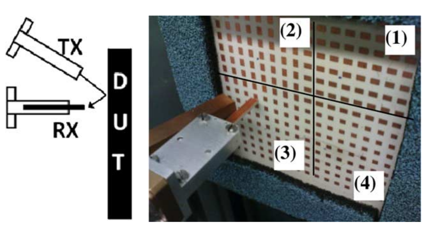

Fig. 6. Near-field measurement setup for reflectarray characterization with a 16 × 16 reflectarray as DUT, with its four subarrays 1 to 4.

Fig. 2. The substrate material is Rogers 3003 with a dielectric constant of 3.0 and a thickness 0.254 mm. At the maximum field strength in the center of the waveguide, the field is guided in a finline with a transition to a dipole, which is optimized for 35 GHz. The dipole length is 3.8 mm, and the slot width is 0.25 mm. The measured and simulated return loss is shown in Fig. 3.

Fig. 4 shows the third probe, a substrate-integrated waveguide probe (C). It consists of a metal waveguide with a transition to a substrate-integrated waveguide [10], metallized on the top and bottom and enclosed with vias.

The used substrate (Rogers RT 6010) has a thickness of 1.27 mm and a high permittivity of 10.8. The high dielectric

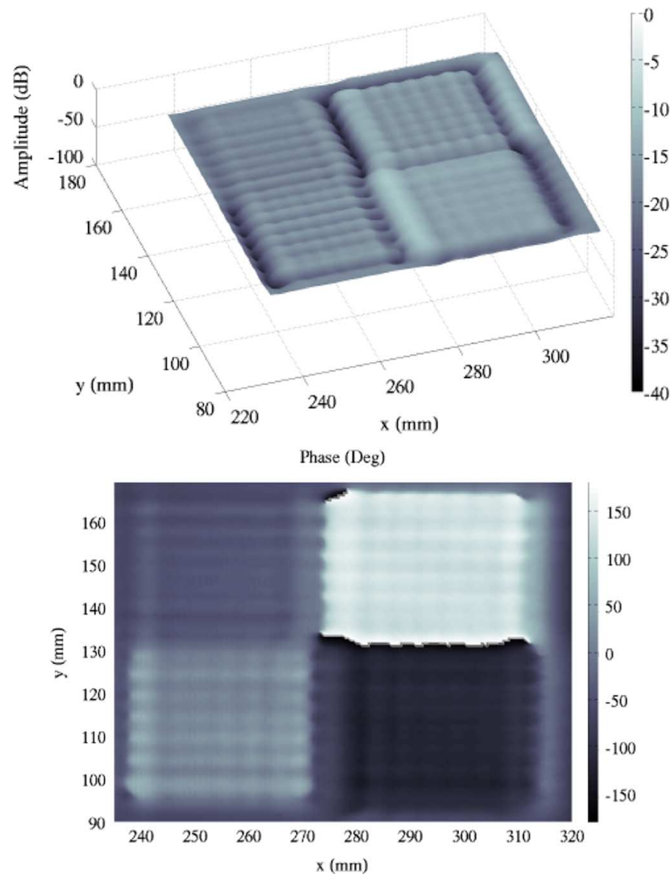

Fig. 7. Measured amplitude and phase characteristics of a 16 × 16 reflectarray with four different regions of identical patch sizes, scanned with the dielectrically filled waveguide-probe (A).

constant allows very small waveguide dimensions, and, therefore, a very small tip dimension of less than 2 mm, which leads to a very high near-field resolution.

This substrate implicates, however, a high-permittivity step, both at the inner waveguide transition and at the tip of the probe. This leads to high reflections, and, therefore, further modifications on the design have been made in order to improve matching. As it can be seen in Fig. 5, a tapered transition, with a length of 6 mm, from waveguide to substrate-integrated waveguide was used. A further modification is an inductive iris, located at the tip of the probe in order to improve matching on this side of the probe. This is realized by adding two vias at a distance of 1.2 mm from the tip of the probe, as illustrated in Fig. 5. With this method, matching could be improved for the frequency range from around 34 to 36 GHz, as seen in Fig. 5.

III. Near-Field Measurement Results

Near-field measurements at a reflectarray have been performed with all three probes in order to compare their resolution characteristics and to validate their function for this purpose.

The measurement has been performed at a near-field measurement x-y-table. The setup can be seen in Fig. 6. An open waveguide (TX) is used to illuminate the reflectarray patches (DUT), and the reflected field components are detected with the near-field probe (RX). The DUT position is controlled automatically during measurement. The step width of the scan has been

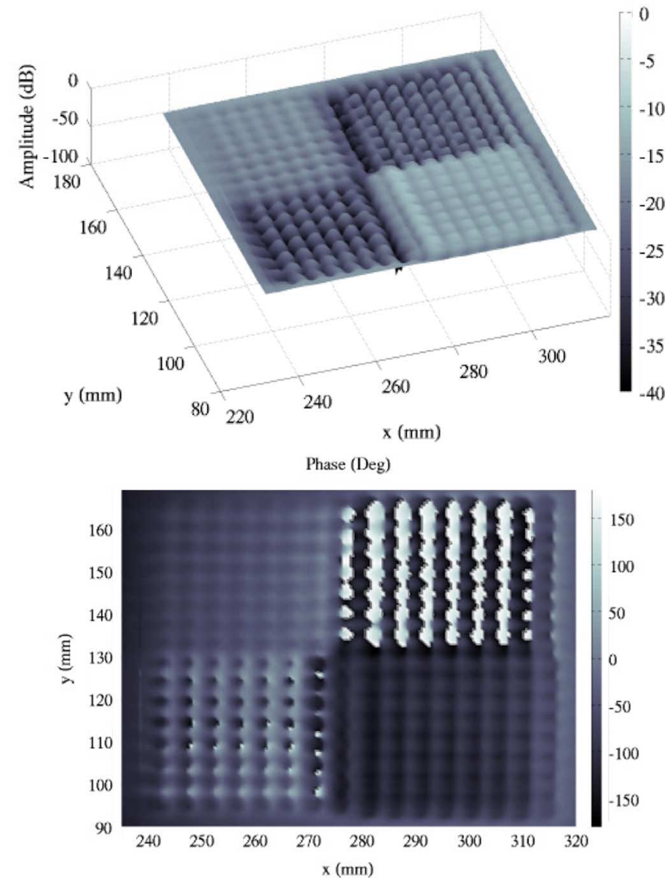

Fig. 8. Measured amplitude and phase characteristics of a 16 × 16 reflectarray with four different regions of identical patch sizes, scanned with the dipole probe (B).

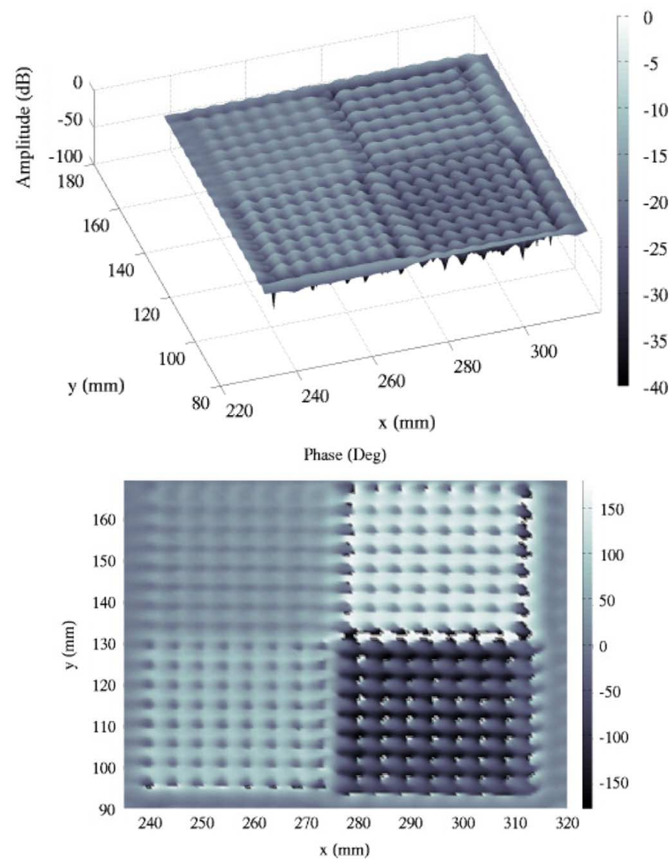

Fig. 9. Measured amplitude and phase characteristics of a 16 × 16 reflectarray with four different regions of identical patch sizes, scanned with the substrate-integrated waveguide-probe(C).

chosen to be 0.5 mm, both in the x- and y-direction. The probe is situated in the near-field of the DUT, a few millimeters above the reflectarray surface. The transmitter waveguide is installed at a bigger distance, more than one wavelength away from the DUT, so far-field conditions are assumed for the incident wave.

The device under test is a reflectarray with 16 × 16 patches. Both unit cell dimensions are $0.55\lambda 0 = 4.71$ mm. It has been produced for validation of the near-field measurements of the reflectarray with the presented probes. This test array includes four subarrays 1 to 4, each consisting of 8×8 patches. The elements in each subarray have the same size and, therefore, the same reflection phase angle. They are designed in such a way that there is a phase angle difference of 180°, both between patches in regions 1 and 2 and between regions 3 and 4. In reality, these values may differ slightly due to etching tolerances, especially for the patch sizes chosen close to the resonant length. No absolute calibration is done in this method, so the absolute phase angle may vary between the different measurements. Therefore, besides the probe resolution, the measured phase angle difference between the patch regions is the significant result.

Fig. 7 shows the measurement results of a near-field scan with the dielectric-filled waveguide probe (A). In the amplitude result, the patch rows can be distinguished, but the curve is still very smooth, which indicates that the resolution of the probe is still not high enough to sample the characteristics of each single patch. As in this case, all patches within the four subarrays have the same size. The measured phase result in Fig. 7 indicates reasonable results for the four phase values.

The near-field scan of the reflectarray antenna with probe B shows better results with respect to the resolution. Each patch can be identified separately in amplitude and phase, as seen in Fig. 8.

The substrate-integrated waveguide probe (C) shows the best resolution of all, as seen in Fig. 9. The phase angle differences between the patch regions of the reflectarray are consistent with each other in all three measurements. As the three measurements all have different reference planes, only the phase differences can be measured. Thus, there is one degree of freedom, a constant offset phase that can be added to all phase values in each measurement in order to fit the absolute values in the diagrams.

For better comparison of the probe's resolution, cuts through the amplitude diagrams from Figs. 7–9 are plotted in Fig. 10. The chosen patch row consists of five patches and is in the middle of a subarray, where no edge region effects occur. All five patches can be identified separately, probes B and C show the best resolution.

As another test, some measurements over frequency also have been made with each probe, focusing one single patch of the reflectarray. These results are compared to simulation results of an

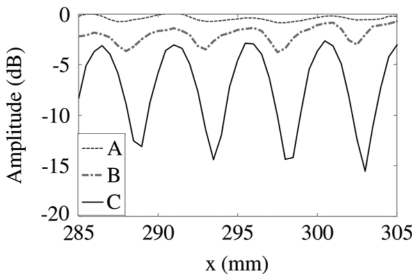

Fig. 10. Amplitude measurement evaluation of a row of patches for resolution comparison of probes A to C.

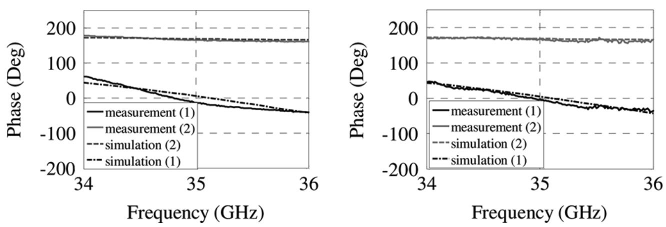

Fig. 11. Phase measurement results over frequency using probes A and C for two patch types (1 and 2) on the reflectarray compared to the simulation results.

infinite array of patches with the same dimensions. The best results were obtained with probes A and C, shown in Fig. 11. Also, the expected phase difference of 180° at 35 GHz between the two patches of regions 1 and 2 on the reflectarray is confirmed by these measurement results. This accordance of measurement and simulation results validates the measurement setup with the assumption of an incident plane wave and the negligible influence of the probes on the setup.

IV. Conclusion

This letter reports three near-field probes to measure the reflection characteristics of individual reflectarray elements both in amplitude and phase with high spatial resolution. The presented probes are a dielectrically filled waveguide probe (A), a dipole probe (B), and a substrate-integrated waveguide probe (C). Probes B and C show a very good resolution, allowing the assignment of the measured characteristic to single patches on the reflectarray. The measured phase was confirmed by comparison with simulation results. Probes A and C show the most accurate phase results.

This method allows the examination of reflectarrays without the assumption of uniform and infinite arrays as well as the investigation of edge regions on the reflectarray, geometrical patch variations, and effects of etching tolerances.

The obtainable phase and amplitude values can be used as input for complex antenna synthesis, especially with respect to new methods for reconfigurable antennas.

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