A 77 GHz Near-Field Probe with Integrated Illuminating Waveguide

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***Abstract*— In this paper, a near-field probe with integrated illuminating waveguide for frequencies around 77 GHz is introduced. For such high frequencies, alignment of transmitter and receiver in the near-field measurement setup are difficult. So the purpose is integrating both devices into one setup for an easy and reproducible measurement procedure. The measurement probe is used in order to characterize individual patches on the surface of reflectarray antennas, placing the device a few millimeters above the antenna surface. This requires a high spatial resolution and a insignificant influence of the probe on the examined structure. The ability of the developed probe has been investigated in simulations and has been verified in near-field measurements at reflectarray structures for 77 GHz.**

***Terms*— Near-field characterization, high resolution probe, reflecarray antenna.**

I. INTRODUCTION

Reflectarray antennas [1]-[3] have the advantages of easy, low-cost fabrication and high gain. Simulation tools for these antennas are usually based on Frequency Selective Surface Simulations (FSS), which assume infinite structures without geometrical variations.

In order to examine the realistic behavior of such antennas, including the necessary geometrical variations, finite dimensions, edge effects, and errors due to fabrication tolerances as well, different characterization methods [4] have been developed in recent time. These methods may also be applied within other measurement applications, e.g. for the characterization of reconfigurable antenna concepts [4] or for other setups in the microwave frequency range.

The problem with rising frequency, however, is the decreased size of both the examined structure and the measurement devices. Near-field measurement concepts introduced for frequencies around 35 GHz [5] are not easily applicable for higher frequencies, where the designer has to deal with problems of increased errors due to fabrication tolerances within the probe design. Another challenge in higher frequency regions is the alignment of the measurement devices in the near-field setup, leading to shadowing effects and multiple reflections.

In order to overcome these problems, a novel high-resolution near-field probe is introduced in this paper. This device combines both illuminating waveguide and detecting probe for 77 GHz, reduces the alignment problem, and offers reproducible measurement results.

II. PRINCIPLE OF THE PROBE

The probe design is based on a substrate integrated waveguide (SIW) [6]. This consists of a dielectric material metalized on top and bottom. In the other dimension two rows of metalized via holes are used as waveguide boundaries. An enlarged photograph of a SIW for 77 GHz is shown in Fig.1.

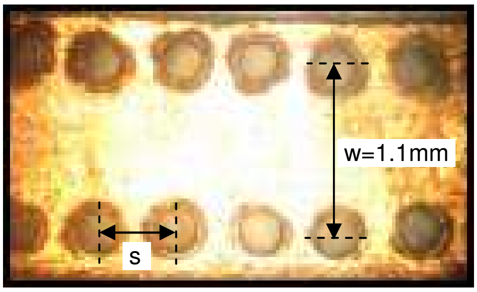

Fig. 1. Top view of a fabricated substrate-integrated waveguide (SIW).

The used substrate (Rogers RT Duroid 6010) has a high permittivity of ε_r=10.8, the substrate thickness is h=0.64 mm. This allows small waveguide dimensions and therefore leads to the desired high spatial resolution of the probe.

The geometrical parameters of the SIW also depend on the fabrication tolerances, such as increased deviations for the placement of the drill holes with smaller repetition distances s.

Here, the via hole diameter is chosen to d=0.3 mm, the via distance (SIW width) is w=1.1 mm, and the via repetition distance is s=0.5 mm.

The effective width w_{eff} of the waveguide was determined by simulations of a SIW with the parameters mentioned above, and compared to an equivalent waveguide model with electric walls as waveguide boundaries [7]. The result for the effective width obtained with this model was w_{eff} =0.914 mm. This result is consistent with the estimation from [8] for the SIW parameters from above, which leads to w_{eff} =0.9 mm.

The principle of a SIW probe design without integrated illumination is shown in Fig. 2. The probe consists of a regular waveguide with a transition to SIW. This reduces stepwise the height of the regular waveguide down to the substrate thickness h=0.64 mm. The substrate at the transition itself has the shape of an arrow, which leads to a slower change of the effective permittivity at the transition.

As mentioned above, the high permittivity of the substrate allows small effective waveguide dimensions and good spatial resolution of the probe. As a drawback of this high permittivity, one should mention the increased substrate losses and the high permittivity steps to air which lead to standing waves.

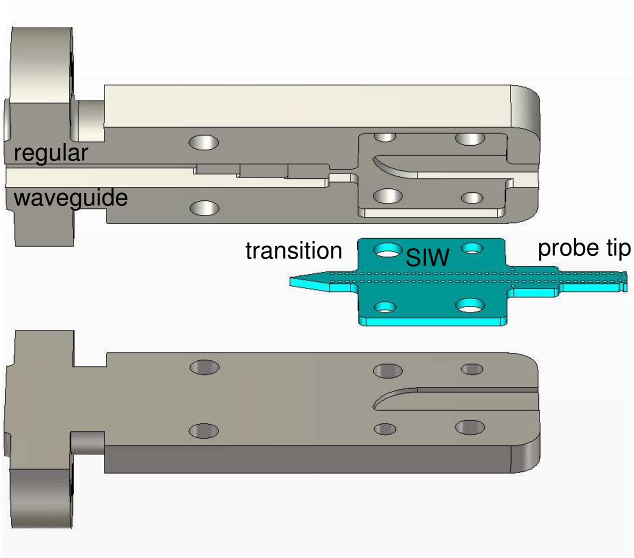

Fig. 2. Open simulation model of a near-field probe for detection.

III. Measurement Setup and Integration of the Transmitting Waveguide

The measurement setup with such a probe is shown in Fig.3. An open waveguide (TX) is illuminating the device under test (DUT), which here is a reflectarray surface. The reflected field component is detected by the probe (RX), a few millimeters above the DUT's surface.

Although Fig.3. only shows the measurement principle, it is easy to imagine the problems of alignment of the devices in the near-field measurement setup, possibly leading to shadowing effects, multiple reflections, and a slant angle of incidence.

The alternative probe design proposed in this paper is shown in Fig.4. It combines both illuminating waveguide (TX) and detecting probe (RX) within one design and therefore reduces the alignment problem and allows reproducible measurement results.

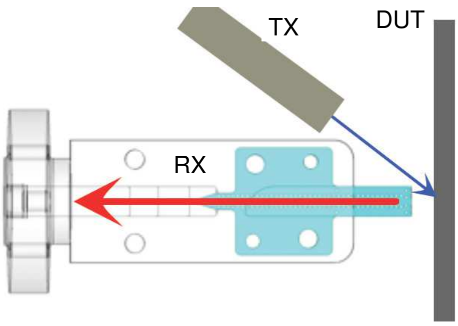

Fig. 3. Near-field measurement principle with separated waveguide for illumination (TX) and detecting probe (RX).

IV. Simulation and Fabrication of The Probe

In order to obtain the overall model of the probe, simulation models of the single parts have been built, and their parameters have been optimized separately according to [7]. All sub-models have been combined to the final probe version, as it can be seen in Fig.4. This includes a model for the SIW, one model for the RX-transition between waveguide and air, and for the behavior of the probe tip in front of an electric wall. With respect to the transmitting waveguide (TX), the purpose is to both illuminate the DUT from above and below the probe, but in a bigger distance than the probe tip. So the height of the tramitter waveguide is increased stepwise, and finally, the waveguide is separated into two parts at the junction. To prevent the transmitted wave from leaking into the side wings of the SIW substrate, an additional via row was added in the substrate at the junction point, see Fig.5, showing the opened fabricated arrangement.

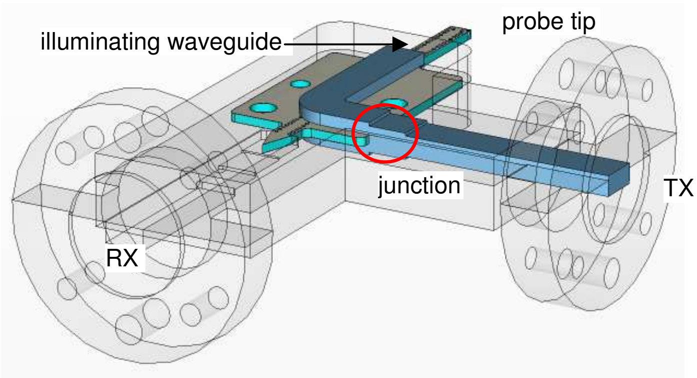

Fig. 4. Simulation model of detecting probe with integrated illuminating waveguide for 77 GHz.

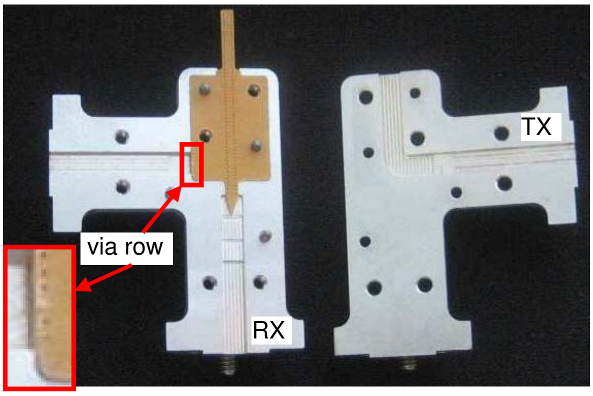

Fig. 5. Opened integrated probe for 77 GHz.

The simulated and measured return loss of the critical RX-path is shown in Fig.6. Obviously the SIW structure suffers from high losses due to increased electrical length of the high-permittivity substrate, especially for the integrated probe, which has increased dimensions compared to the detect-only probe, see Fig.7. Due to the high computational effort for the simulation of the whole model, the substrate losses were neglected in the simulation. Another drawback of the probe is the resonant length leading to standing waves, due to high permittivity steps at the interfaces to air.

However, the probe is still able to detect signals in the near-field. So the advantages of small waveguide dimensions are settling the choice of the substrate type.

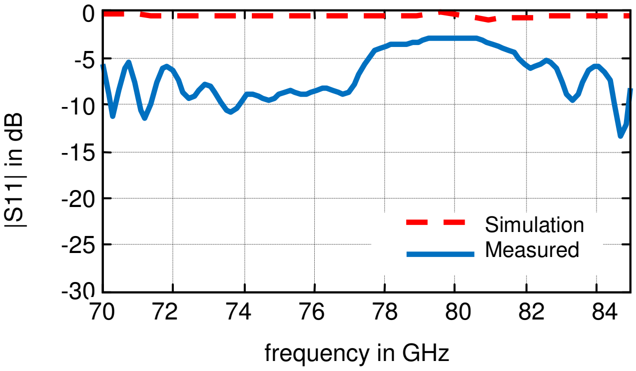

Fig. 6.Simulated and measured return loss of the fabricated probe.

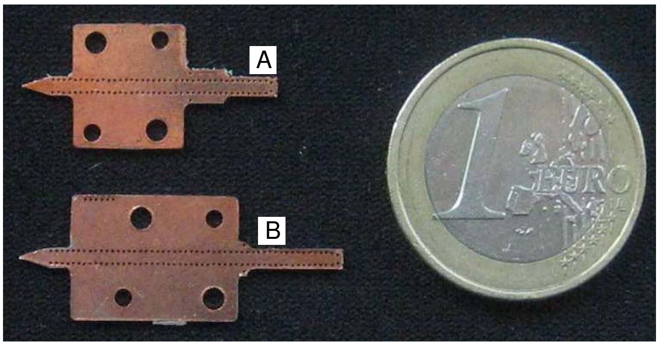

Fig. 7. Fabricated substrate-integrated waveguides for the detect-only probe (A) and for the integrated probe (B).

V. Near-Field Measurement Results

For the verification of the probe, a test reflectarray has been fabricated as a DUT and examined in the near-field setup. The test structure includes four sub-regions on the array, all consist of patch arrays with the same dimensions, but rotated by 90° respectively (see Fig.8). The dimensions of the patches are chosen in such a way that there is a phase angle difference of 180° between both orientations.

The patch positions and the phase angle differences should be verified in the measurement setup, which can be seen in Fig. 9. The illumination of the DUT occurs in the far-field, from above and below the probe. The probe tip itself is situated in the near-field of the array, detecting the reflected signal components from the test array. During the measurement, the location of the array is controlled automatically via an x-y-table.

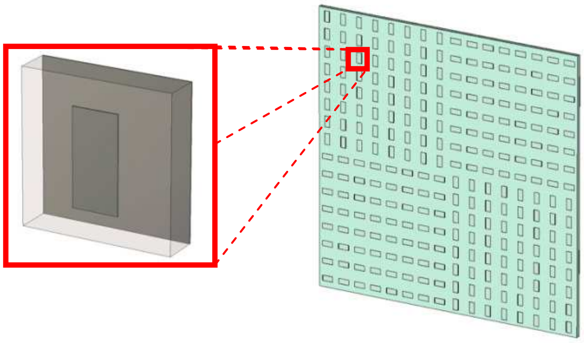

Fig. 8. Model of the test reflectarray for verification of the probe.

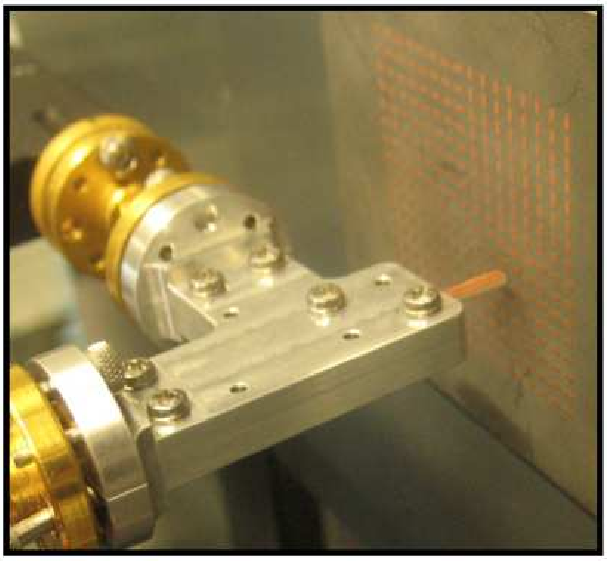

Fig. 9. Measurement setup with integrated probe and test reflectarray.

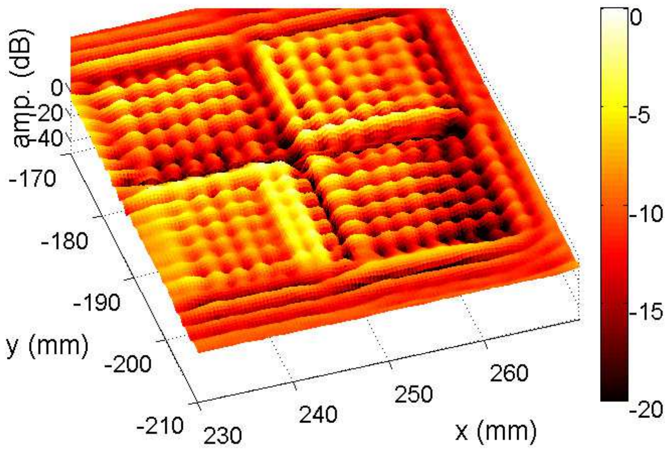

Fig. 10. Measured amplitude result of the test structure in the near-field setup.

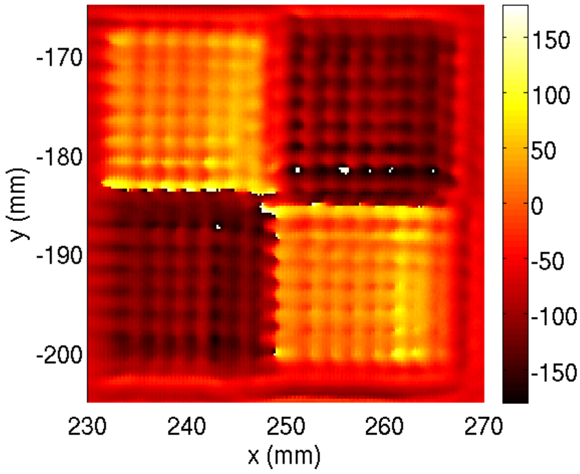

Fig. 11. Measured phase angle result of the test structure in the near-field setup.

The respective measurement results in amplitude and phase of the near-field of the scanned array are shown in Fig.10 and Fig.11. In the amplitude scan (Fig. 10), one can see that the resolution of the probe is high enough to separate each single patch on the reflector. The correspondent phase angle result obtains the expected phase angle difference of 180° between the patch regions.

VI. Conclusion

In this paper, a high resolution near-field probe with integrated illuminating waveguide is proposed. The probe design and near-field measurement setup have been shown for 77 GHz and verified for a test array at this frequency. The measurement setup using this probe reduces the alignment problem and allows reproducible measurement results. Due to the high resolution and the small influence of the probe, the patches could be detected separately, and the designed phase angle differences between the patch regions could be verified.

Acknowledgment

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