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***Abstract*—In order to measure antenna properties precisely at frequencies above 100 GHz, elaborate measurement techniques are required. This is especially challenging for integrated antennas, as probes require a steady, rigid measurement setup to avoid damage. This paper introduces an antenna measurement setup that allows fast and reliable 3-dimensional antenna pattern measurements in a frequency range of 60 GHz to 330 GHz. The system consists of a probe station, a vector network analyzer (VNA) and an industrial robotic arm with six axes. The robot ensures highly repeatable and accurate measurements and allows high flexibility in terms of scan geometry and resolution. Using a probe station, this setup not only supports measurements of waveguide-fed antennas, but also integrated antennas. After explaining the basic setup, measurement results are shown to demonstrate the capability of the system.**

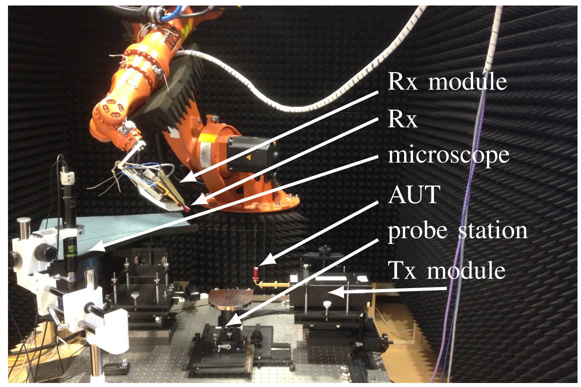

Fig. 1. Measurement setup with robot, VNA, and probe station.

I. Introduction

Advancements in semiconductor and RF technology have driven research to frequencies beyond 100 GHz and the first fully integrated radar sensors at frequencies over 100 GHz have been demonstrated, e.g. [1]. Numerous new applications for integrated antennas call for accurate measurement of gain, radiation pattern, and antenna efficiency in order to optimize the performance of the overall system.

Many different approaches on measurement setups for RF antenna measurements have been investigated, most of which are limited in their respective frequency range and can measure on limited planes around the antenna under test (AUT). More elaborate measurement setups allow 3-dimensional radiation pattern scans, but operate at a lower frequency range, are limited to spherical measurements with a specific radius, or cannot correct misalignments of the AUT [2], [3]. In both [4] and [5] industrial robots are used for antenna measurements. [4], however, works at frequencies around 1 GHz. [5] allows highly accurate near field measurements with arbitrary scan geometries for frequencies far beyond 100 GHz. This setup is designed especially for near field measurements and does not support the usage of RF probes to contact integrated antennas.

The presented setup features a six degrees of freedom (six DOF) industrial robot, which holds the receiving antenna (Rx). With six DOF the Rx position can be adjusted in x-, y-, z-direction and the orientation can be changed by rotation around the three different axes (Rot_x, Rot_y, Rot_z) thus making highly flexible scan geometries such as sphere sections and planar scans possible. The robot has a position repeatability of 50 µm and guarantees highly repeatable far field measurements.

In the following sections the measurement setup is explained, measurement results are shown, and the repeatability is discussed.

II. Measurement Setup

The measurement setup contains a VNA with converter modules for different frequency bands, a probe station, a six DOF robot, and a computer to control the measurement procedure. A picture of the installation with robot, probe station, and antennas is shown in Fig. 1.

After a measurement was initiated, the computer sends the required parameters to the VNA and the robot. The robot will move to the specified measurement points and trigger the VNA whenever a point is reached. The VNA measures the S-parameters at the desired frequencies. After the measurement was performed for all points, the VNA sends the results back to the control computer for further processing. The robot can adapt easily to changing Rx dimensions, AUT positions, measurement trajectories, and polarization changes by updating variables without the need for any rearrangements.

Both point-to-point (PTP) and on-the-fly (OTF) measurements are supported. For PTP measurements the robot will stop at every measurement point, initiate the measurement

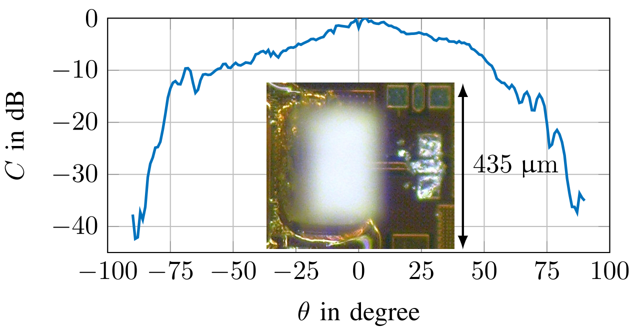

Fig. 2. Measurement of an integrated antenna at 280 GHz, H-plane.

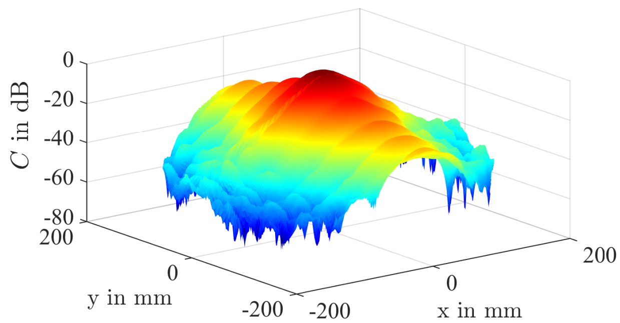

Fig. 3. Full 3D measurement of a horn antenna at 180 GHz.

after a specified wait time, and will not continue with the movement until the measurement is performed. For OTF measurements the robot will move the Rx antenna continuously along the selected trajectory with constant speed.

III. Measurements

Figure 2 shows a probe contacted integrated antenna and the measurement results at 280 GHz. The white area is a resonator that was mounted on the chip. In order to avoid reflections and radiation at the edges, attenuators were placed on the chuck, which caused the attenuation for angles over $80°$. In order to have a well defined AUT, a standard gain horn antenna is used as Rx for the following measurements.

In Fig. 3 a 3D radiation pattern measurement of a standard gain horn antenna for an azimuth angle of $\phi = 0° \ldots 180°$ and an elevation angle of $\theta = -40° \ldots 40°$ at 180 GHz is shown.

For the following comparisons two OTF (OTF_1 and OTF_2) and one PTP (PTP_1) measurement were taken. The angular speed was $4°$/s, the wait time for the PTP measurement was 1 s, and the radius 30 cm. In Fig. 4 the solid line displays the amplitude difference between PTP_1 and OTF_1. The dashed line shows the repeatability of OTF measurements. The mean difference $\overline{||\mathrm{R}_1|-|\mathrm{R}_2||}$ between two measurements R_1 and R_2 is 0.11 dB, when comparing two OTF measurements and 0.146 dB for the comparison between OTF and PTP measurement. The maximum difference between two measurements was smaller than 0.8 dB. The highest deviations occur at angles >$40°$, where the signal was more than 30 dB lower than the main lobe and therefore the absolute difference is small for all θ. A possible error source is an inaccurate robot position, which can cause phase shifts and amplitude changes. Other error sources are reflections at the robot and the probe station, inaccurate trigger positions for fast OTF measurements, and cable movements. Reflections are minimized by an anechoic chamber and attenuators on reflecting surfaces.

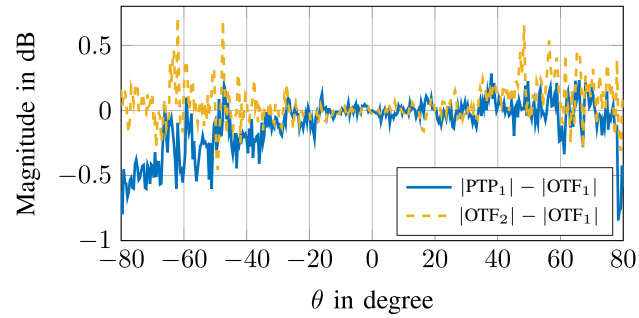

Fig. 4. Amplitude comparison between three measurements, normalized to OTF_1, E-plane.

The biggest deviations occur at local minima of the radiation pattern, for example at $\theta{=}-62°$ and $\theta{=}-48°$. As the robot does not stop for OTF measurements, the result is the integral of the received signal over a certain distance. Therefore, small and narrow extrema are not as sharp as in PTP measurements.

IV. Conclusion

A highly reconfigurable mm-wave measurement setup was described, which allows precise antenna measurements at frequencies from 60 GHz to 330 GHz on arbitrary planes and trajectories. Measurements of radiation pattern, gain, directivity, radiated power, and efficiency are possible. Using a probe station, the setup also allows measurements of integrated antennas. The deviations between different measurements depend on the radiation pattern of the antenna. Differences are higher (≈ 0.5 dB) for narrow changes in the pattern, because of the integration for OTF measurements. The differences between consecutive measurements for flat patterns are smaller.

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