On-chip Antenna Pattern Measurement Setup up to 325 GHz

Bernhard Klein, Michael Jenning, Patrick Seiler, Klaus Wolf, Dirk Plettemeier
Chair for RF Engineering, Communications Lab, Faculty of Electrical and Computer Engineering
Technische Universität Dresden, Germany
bernhard.klein@tu-dresden.de

***Abstract*—This paper presents a setup for on-chip antenna pattern measurements built on a commercially available wafer-prober. Since the measurements are performed in the near-field, a near-field to far-field transformation is included. First validation measurements at 60 GHz show a high agreement with simulation data and the results of the ongoing measurements at 300 GHz with the measurement setup will be shown at the conference.**

***Index Terms*—integrated antenna, on-chip antenna, antenna measurement, fully-integrated system, near-field measurement**

I. INTRODUCTION

The integration of antennas and circuits on one chip show a huge potential as they avoid various problems in contrast to antenna in package systems. For on-chip antennas, connection parasitics, e.g. because of bonding wires, do not occur. Applications like active imaging arrays with high-efficient on-chip antennas coupled to CMOS SOI detectors at 300 GHz [1] or transmitters with an on-chip antenna at 245 GHz [2] are examples for the achievements when using fully-integrated systems in the 220 GHz to 325 GHz (WR3) band.

In order to build reliable fully integrated systems, it is important to know besides the matching also the radiation characteristics of the on-chip antenna. For the sake of computational effort, simulations of on-chip antennas cannot include all elements of a semiconductor process in detail (e.g. fill structures), there is the necessity of antenna pattern measurements. Therefore, in this paper an antenna pattern measurement setup for frequencies up to 325 GHz is shown. In contrast to measurement setups like in [3], this setup is based on a commercially available wafer-prober and does not require a special chip holder. This allows the usage of standard equipment available to circuit testing labs.

This paper is structured as follows. As the measurements are performed in the near-field, section II summarizes the necessary near-field to far-field transformation. Section III describes the setup for measurements up to 325 GHz and in section IV the measurement of a standard horn antenna at 60 GHz is shown. The results of the ongoing measurements between 220 GHz and 325 GHz, which could not be finished on time due to delays in the fabrication of the test chips and the availability of the lab, will be shown at the conference. Section V gives a short conclusion.

II. NEAR-FIELD TO FAR-FIELD TRANSFORMATION

For the near-field to far-field transformation the plane wave spectrum theory [4] can be applied. By measuring the tangential electric field components in the near-field on a plane, it is possible to calculate the x-component $f_x(k_x, k_y)$ and y-component $f_y(k_x, k_y)$ of the plane-wave spectrum of the antenna under test (AUT) [5]:

$$f_x(k_x, k_y) = \int_{-b/2}^{b/2} \int_{-a/2}^{a/2} E_{xa}(x', y', z' = 0) e^{j(k_x x' + k_y y')} dx' dy' \quad (1)$$

$$f_y(k_x, k_y) = \int_{-b/2}^{b/2} \int_{-a/2}^{a/2} E_{ya}(x', y', z' = 0) e^{j(k_x x' + k_y y')} dx' dy' \quad (2)$$

where a and b are the length and width, respectively of the measurement plane, E_{xa} and E_{ya} are the x- and y-component of the tangential electric field on the measurement plane as well as k_x and k_y are the x- and y-component of the wavevector. Having calculated this plane-wave spectrum, the θ-component E_θ and Φ-component E_Φ of the electric far-field can be calculated by a 2D fourier transform as follows [5]:

$$E_\theta(r, \theta, \Phi) \simeq j \frac{ke^{-jkr}}{2\pi r} (f_x cos(\Phi) + f_y sin(\Phi)) \quad (3)$$

$$E_\Phi(r, \theta, \Phi) \simeq j \frac{ke^{-jkr}}{2\pi r} cos(\theta)(-f_x sin(\Phi) + f_y cos(\Phi)) \quad (4)$$

where r, θ and Φ are the spherical coordinates and k is the wavevector. With these results the radiation characteristics of the antenna can be evaluated. The transformation is only valid upon a critical angle θ_{critical}, which is defined as follows:

$$\theta_{\text{critical}} = \pm \arctan\left(\frac{L - \frac{a}{2}}{d}\right), \quad (5)$$

where L is the length of the measurement plane, a is the diameter of the AUT and d the distance between AUT and the probe antenna. In the measurements described, the distance between AUT and probe antenna stays fixed at three wavelengths. Therefore, θ_{critical} can be varied by changing the size of the measurement plane.

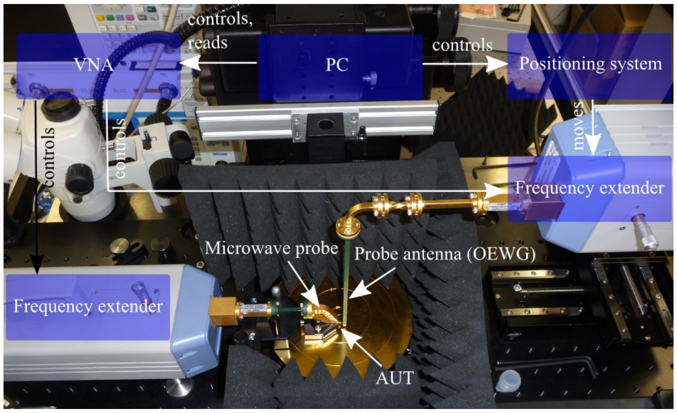


Fig. 1. Picture of the measurement setup for frequencies between 220 GHz and 325 GHz (For better visibility, some absorbers have been removed.)

III. Measurement Setup

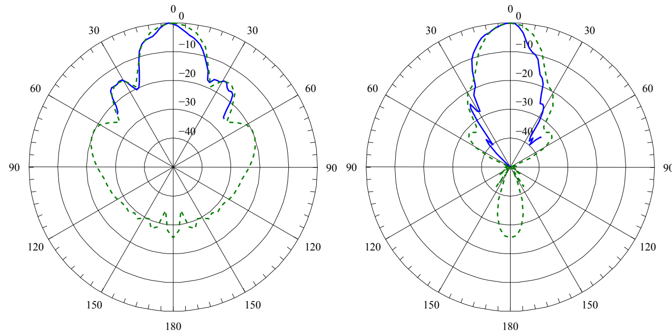
A picture of the proposed setup is shown in Fig. 1. The AUT stays fixed on the wafer chuck and is contacted by a microwave probe. The probe is connected to a frequency extender, which enables measurements between 220 GHz and 325 GHz. An open-ended waveguide (OEWG) is used as probe antenna, since it disturbs the electric field only to a very small extent [6]. The OEWG and the corresponding frequency extender are placed on a mechanical xyz-stage, which moves both on the measurement plane. For the measurement of the second electric field component necessary for the transformation, a WR-3 twist is placed between OEWG and the frequency extender. A computer controls the positioning system and reads the data of the network analyzer.

In Fig. 1 the absorbers, which reduce the influence of reflections, can be seen as well. Nevertheless, reflections, e.g. at the probe mounting, cannot be avoided completely. The measurement of S_{21} is performed in the radiating near-field of the AUT, with a distance of the measurement plane to the AUT of three wavelengths and with a spatial sampling of half a wavelength. The step resolution of the positioning stages is sufficient for the closer measurement points at 325 GHz in comparison to 60 GHz. For the validation measurements at 60 GHz shown, the frequency extenders are not required in the setup and the WR-3 waveguides are replaced by WR-15 waveguides.

IV. Verification Measurement

To verify the correct operation of the proposed measurement, a standard horn antenna with 20 dBi gain is used as AUT. The AUT is mounted on a probe holder. Absorbers are enclosing the measurement area with the exception of the probe mounting station. The measurement is performed at 60 GHz.

The size of the measurement plane is 5 cm x 5 cm. Therefore, the critical angle θ_{critical} is approximately 46°. In order to be able to verify the measurement results, a simulation of the horn antenna used has been carried out with FEKO [7]. A comparison of the measured and simulated E- and H-Plane of the horn antenna is shown in Fig. 2. The simulation data



(a) Horn E-Plane (Simulation (– –), Measurement (—))

(b) Horn H-Plane (Simulation (– –), Measurement (—))

Fig. 2. Measurement versus simulation results for horn antenna (all data normalized)

is shown for all θ angles, the measured data only up to θ_{critical}. Simulation and measurement data show a very good agreement. There is a small unsymmetry in the measured E- and H-Plane. These differences are assumed to occur due to reflections at the probe mounting.

All in all, this measurement shows, that the realized measurement setup is able to measure radiation patterns correctly by measuring the tangential electric field in the radiating near-field and a subsequent transformation into the far-field.

V. Conclusion and Outlook

This paper presented an antenna pattern measurement setup for frequencies up to 325 GHz built on a commercially available wafer-prober. First validation measurements at 60 GHz have been shown, as well as the measurement setup for frequencies up to 325 GHz. As each element of the measurement setup is capable up to 325 GHz and the validation measurements have shown a high agreement to the simulations carried out, ongoing measurements in the frequency band 220 GHz to 325 GHz will be available and presented at the conference.

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