

Probe Influence on Integrated Antenna Measurements at Frequencies Above 100 GHz

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Abstract—When measuring integrated antennas the signal has to be fed to the antennas with wafer probes. Wafer probes are commonly used to contact integrated circuits for on-chip measurements. As integrated radar and communication chips with radiating elements are a fairly recent development, the wafer probes were not optimized for size and reflective properties (characteristics which are important for antenna measurements), but rather for their return loss, insertion loss, and mechanical stability. This resulted in metal probes that are relatively large compared to the wavelength. In this paper, two probes are compared with regard to their performance in integrated antenna measurements. The first probe is a standard commercially available probe. The second one is a modified probe with an extended coaxial probe tip to increase the distance between probe and antenna, which decreases the distortion and reflection caused by the probe significantly.

I. INTRODUCTION

The development of integrated radar and communication chips requires integrated antennas with well defined radiation characteristics depending on the specific application. Integrating the RF components on a chip reduces the losses and mismatches that occur when using bond wires for off-chip RF components and facilitates the usage for the end-user as only low frequency signals have to be handled.

For the development of integrated antennas accurate measurements are necessary as unknown material parameters can result in faulty simulation results especially at high frequencies. Furthermore, the effects of production tolerances need to be analyzed. Different setups have been proposed for antenna measurements at frequencies above 100 GHz in general and for integrated antennas in particular.

In [1] an antenna measurement setup is presented for frequencies of up to 500 GHz. The setup is capable of measuring electrically large antennas through near field scans, which is why a laser tracking system is used to ensure position accuracy and minimal error for the near field to far field transformation.

The setup used in [2] contains a wafer chuck to hold an integrated circuit and a positioner to hold a micro probe for chip contact. This makes it possible to measure integrated antennas. In [2] some error sources such as probe radiation and interaction of the radiated fields with both chuck and probe are discussed for measurements at 60 GHz. Two methods to decrease the effect of probe radiation are described. However, the probe still blocks part of the signal and the pattern cannot be measured in the shadow of the probe.

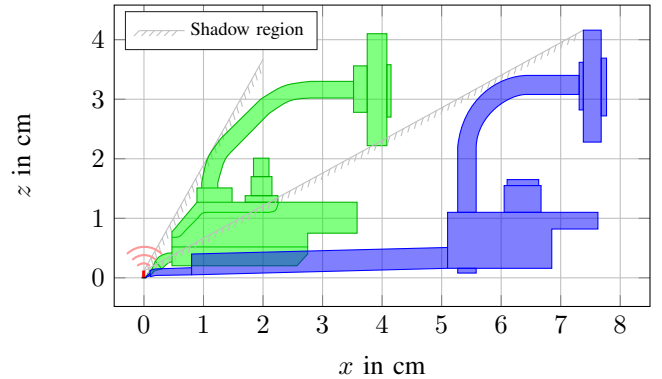


Fig. 1. Comparison of a standard wafer probe (left) and a dedicated antenna probe (right).

A different approach is taken in [3], where a 74 GHz integrated antenna is measured in the near field to reduce blocking of the radiated signal behind the wafer probe and scattering from the probe.

In [4] the influence of the probe on antenna measurements in the same frequency range, around 60 GHz is analyzed. To reduce the scattering and signal blocking of the probe during a measurement a special probe was designed, which can contact an antenna from below the chuck. The probe is therefore not in the immediate vicinity of the antenna, which reduces the distortion in the radiated near field of the antenna under test (AUT) and prevents signal blocking. For the measurements a patch antenna on a printed circuit board (PCB) was used. The probe was contacted with a flexible coaxial cable. At frequencies above 100 GHz waveguides are usually used for the RF connection, which make such a measurement setup more difficult to achieve. When measuring integrated antennas the probe is closer to the AUT compared to PCB antennas, as the chips are usually smaller than 2 mm, and therefore it is not possible to increase the distance with long microstrip feeding lines.

In this paper, the probe influence on measurements of integrated antennas is analyzed for frequencies above 100 GHz. The measurement results of a custom probe are compared to a standard probe in return loss, polarization, gain, and radiation pattern measurements of the same integrated antenna at 160 GHz (Sections II to IV).

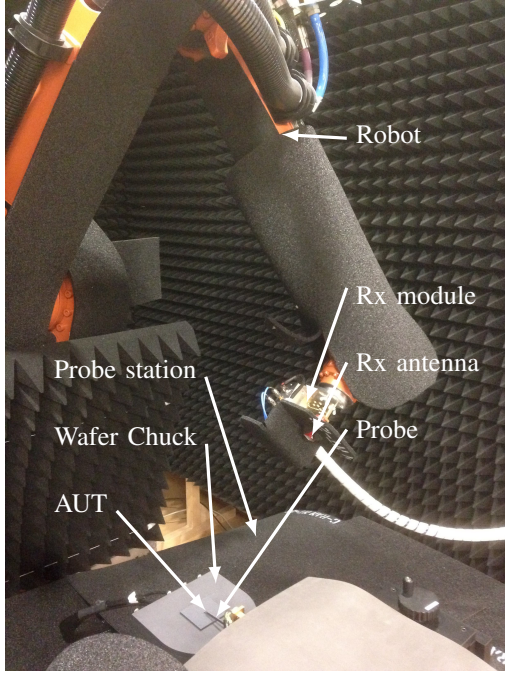


Fig. 2. Measurement setup with robot, converter module, and probe station.

Fig. 1 shows both the standard wafer probe (left) and the dedicated antenna measurement probe (right), which was fabricated for antenna measurements between 140 GHz and 220 GHz (WR5.1). The long coaxial feed of the custom probe increases the distance to the AUT and thus minimizes distortions of the radiated fields. The signal blocking in the probe shadow during far field measurements is also reduced significantly. For future probe optimization, the most sensitive areas and sources of reflection are analyzed at 160 GHz (WR5.1 model of custom and standard probe) and at 280 GHz (WR3.4 model of standard probe) in Section VI. The WR3.4 model operates at frequencies between 220 GHz and 330 GHz.

The used measurement setup contains a probe station and an industrial robotic arm with which the radiated fields of the AUT can be scanned on arbitrary trajectories. The setup is described in [5] and shown in Fig. 2. The integrated antenna that was used for the measurements is a dielectric resonator antenna fed by a cavity resonator based on [6]. A microstrip line feeds a substrate integrated cavity resonator, which then couples through a slot to a dielectric resonator that is glued to the chip.

II. RETURN LOSS

The return loss was measured with a one port deembedding technique similar to the open-short-load technique used in [7], but instead of using an open, a short, and a load standard, three short standards of different length were used to get three reflection coefficients at different locations in the Smith chart.

The custom probe has approximately 2 dB higher conversion loss due to the attenuation of the extended coaxial feed. The measured return loss of the AUT with both probes showed

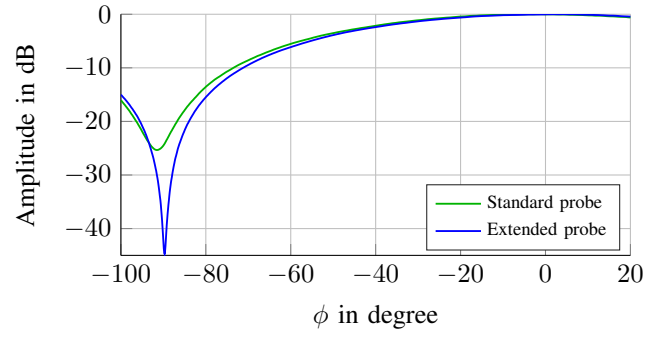


Fig. 3. Polarization measurement of the integrated antenna at 160 GHz.

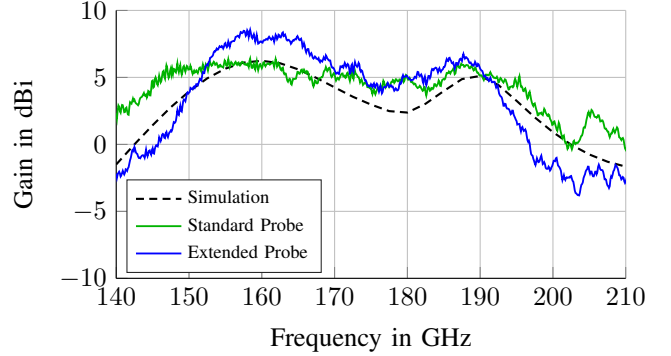


Fig. 4. Measured gain of an integrated antenna at 160 GHz.

good agreement and a -6 dB bandwidth of approximately 20 GHz.

III. POLARIZATION

A comparison of the measured polarization of the antenna is shown in Fig. 3. For this measurement the Rx antenna is centered over the AUT ($\theta = 0^\circ$; θ as shown in Fig. 8) and the received field is measured over ϕ to find $\phi_{\text{co-pol}}$ and $\phi_{\text{cross-pol}}$. ϕ is in the x - y -plane, starting from the x -axis.

The probe with the extended coaxial feed disturbs the radiated field of the AUT less than the standard probe, which is why the polarization of the antenna is not impacted as much, resulting in a deeper cross-polarization notch.

IV. GAIN

Fig. 4 shows the gain of the AUT with both probes. The measured gain at 160 GHz is 7.6 dBi and 5.8 dBi for the extended and the standard probe respectively. The minimum discussed in Section V causes a lower measured gain with the standard probe at 160 GHz. As the interference of the direct and the reflected signal changes with the distance at which the measurements are being taken, the measured gain changes over the distance when measuring with the standard probe, whereas it stays fairly stable when using the extended probe.

The simulated gain is 6.23 dBi at 160 GHz. Reasons for deviations can be false material parameters used in the simulation and fabrication tolerances of the dielectric resonator and its

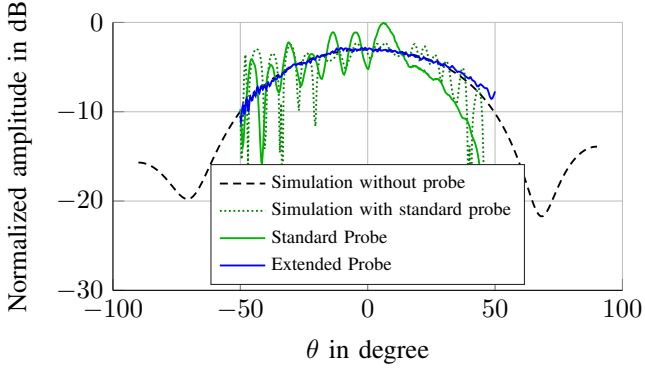


Fig. 5. Measured E-plane of the integrated antenna at 160 GHz.

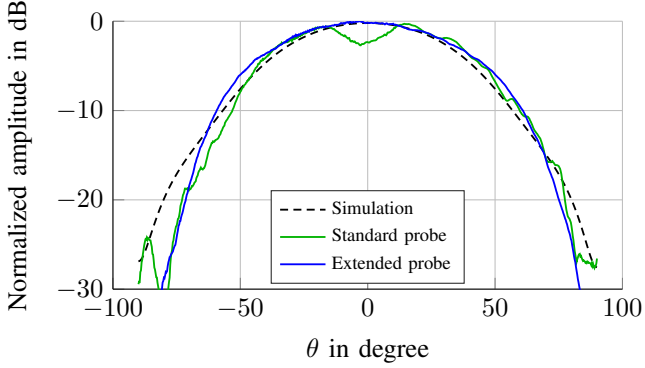


Fig. 6. Measured H-plane of the integrated antenna at 160 GHz.

positioning, which has a significant effect on the performance of the antenna.

V. RADIATION PATTERN

The radiation patterns were measured in the E- and H-plane. For this AUT the E-plane is in probe direction, which would be the x - z -plane in Fig. 1. The H-plane is therefore in the y - z -plane. The measurements in both planes were normalized to the same maximum after calibrating for the different insertion losses of the probes.

The probe influence can clearly be seen in the E-plane measurement with the standard probe shown in Fig. 5. The probe reflects part of the signal and causes ripples with an amplitude of up to 5 dB over the angle θ . For angles larger than 30° , the probe starts blocking the radiated signal. When using the extended probe, this shadowing effect does not occur for angles up to 60° . The probe reflection and ripples are reduced significantly and the agreement with the simulation is very high up to the maximum measured angle of $\theta = 50^\circ$.

The measurement in the H-plane is less critical as the probe is orthogonal to this plane and therefore less reflections occur. The measurement results with both probes show good agreement with the simulation results as shown in Fig. 6. Only for $\theta = 0^\circ$ the measurements differ, which is again due to

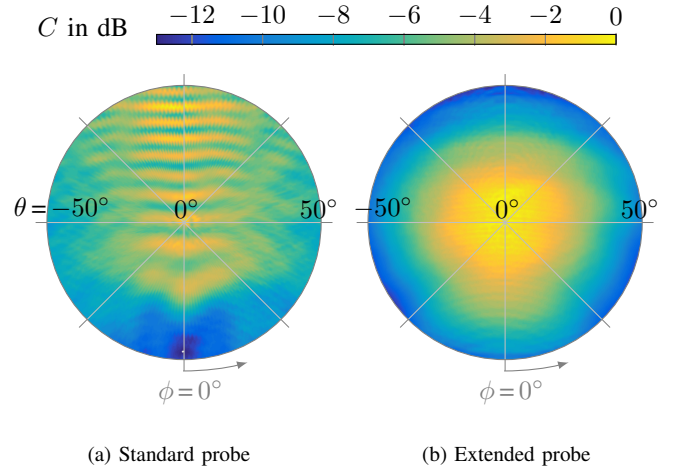


Fig. 7. Measured radiation pattern of the integrated antenna at 160 GHz. The probe is located in $\phi = 0^\circ$ direction.

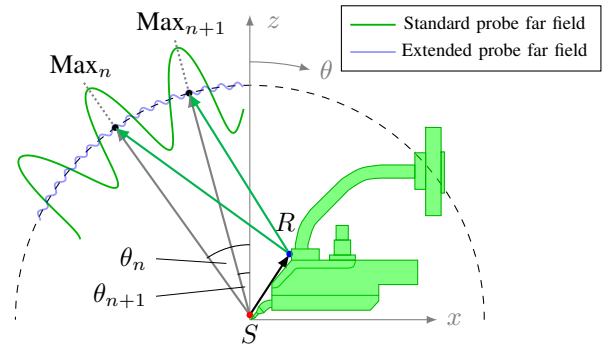


Fig. 8. Location of the maxima in the far field pattern depending on the path difference.

interference that caused a minimum at $\theta = 0^\circ$ when measuring with the standard probe.

In Fig. 7 a 3D radiation pattern measurement of the integrated antenna for both probes is displayed. Fig. 7a shows that the measurement with the standard probe is highly disturbed by probe reflections, whereas the radiation pattern measured with the extended probe in Fig. 7b shows a clear main lobe around $\theta = 0^\circ$ and significantly less ripples.

VI. PROBE SCATTERING CENTERS

The amplitude variations in the E-plane measurements with the standard probe shown in Fig. 5 can be used to calculate the scattering centers of the probe. When reflected, the phase of the signal changes by π , so when the path difference of the direct and reflected signal is $(2n - 1) \cdot \lambda/2$, a maximum is measured in the far field. As the AUT is in the center of the measurement surface, the direct path ($S \rightarrow \text{Max}_n$ in Fig. 8) is constant. Therefore, the length of the reflected signal path l_n ($S \rightarrow R \rightarrow \text{Max}_n$) has to change by λ between two adjacent maxima. To find the scattering region all points R , for which the path difference condition $|l_n - l_{n+1}| = \lambda$ is met, were calculated for the different maxima pairs ($\text{Max}_n, \text{Max}_{n+1}$). For each pair of maxima this results in a line, on which all possible

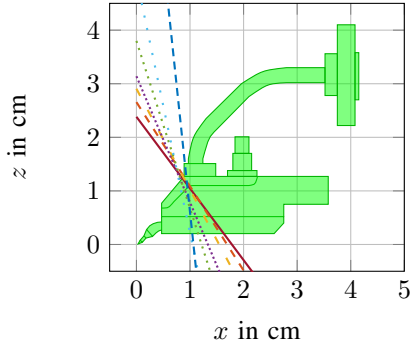


Fig. 9. Determination of the scattering center location for the standard probe (WR3.4) at 280 GHz. Similar results were obtained with the WR5.1 model at 160 GHz.

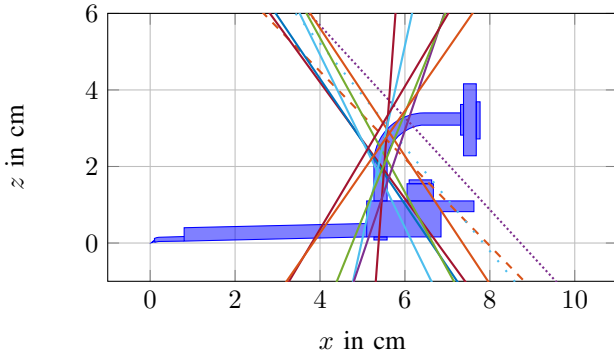


Fig. 10. Determination of the scattering center location for the extended probe at 160 GHz.

reflection points R that satisfy the path difference condition are located. Scattering occurs, where those lines intersect with each other and the probe surface.

This calculation was done for the standard probe at 160 GHz (WR5.1 model) and 280 GHz (WR3.4 model). Fig. 9 shows the calculated lines of possible reflection locations for the measurement at 280 GHz. The locations, where the different lines intersect with each other and the probe surface, are close together, which indicates a clear scattering center. The same calculation was performed with the WR5.1 model at 160 GHz, which resulted in a scattering center at the same location.

When measuring with the standard probe the amplitude of the ripples caused by reflection is much higher than other influences that cause ripples on the measured far field pattern. The locations of the maxima can therefore be determined with high accuracy, and the intersections of the calculated scattering lines are close together. When measuring with the extended probe the peak-to-peak amplitude of the ripples is way below 0.5 dB, which makes it more difficult to determine the exact location of constructive interference. The bigger path difference between the direct and reflected signal increases the number of maxima as the path difference changes faster over θ . This leads to a higher number of reflection lines, which are displayed in Fig. 10. The smaller amplitude of the ripples

decreases the accuracy of the scattering location determination. Because of that the reflection lines do not intersect in one location anymore, but it can still clearly be seen that most of the reflections occur on the waveguide bend of the probe.

VII. CONCLUSION

Because of the small chip size, probes are in close proximity to the AUT when measuring with standard probes. This causes disturbances that result in deviations in both polarization, radiation pattern, and gain measurements. The probe reflection causes ripples with a peak-to-peak amplitude of up to 5 dB when measuring the far field pattern in probe direction. The effect was less in the plane orthogonal to the probe, but can still be seen for angles around $\theta = 0^\circ$, depending on the measurement distance and frequency. Therefore the measured pattern changes with the distance at which the measurement is being taken and with the measurement frequency.

This effect is reduced significantly when using the dedicated antenna measurement probe, which was designed to move the probe body away from the AUT and to minimize the field disturbance. This improved the measurement results for all measured parameters. The cross-polarization was deeper, the ripples for radiation pattern measurements were reduced, and the measured gain does not change over the measurement distance. The insertion loss, which is about 2 dB higher compared to the standard probe, has only little effect on the measurement results as the received signals are way above the noise floor for both probes.

The scattering centers were determined by calculating possible points of reflection based on the location of the maxima in the far field pattern. This showed the critical areas of the standard probe at 160 GHz (WR5.1 model) and 280 GHz (WR3.4 model) and of the extended probe at 160 GHz.

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