Influence of the Wafer Chuck on Integrated Antenna Measurements

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DOI: 10.1109/GEMIC.2016.7461609

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***Abstract*—For meaningful pattern measurements of integrated antennas the devices, which are required during the measurement process, need to be optimized to influence the measurement results as little as possible. In this paper the errors caused by reflections on the chuck are investigated and quantified. A plastic chuck was built to reduce sources of reflection and thus improve the overall accuracy of the setup. The new chuck causes less ripples over the scanning angle and over the frequency and therefore, increases the performance of the setup significantly.**

I. Introduction

Monolithic microwave integrated circuits (MMICs) are becoming increasingly popular to realize fully integrated radar sensors. For the measurement of these MMICs probe stations with chuck, positioners, and wafer probes are required to contact the chips and to prevent damaging the integrated circuits and connectors. For the same reasons integrated antenna measurements cannot be performed without these components. However, the design and the materials were optimized for MMIC measurements in terms of sturdiness, accuracy, minimal relative movement, and durability, rather than for electromagnetic properties, reflection coefficient, and size, which are important for antenna measurements.

The probe station consists of a wafer chuck, a microscope, and a positioner. The probe table is made almost solely of metal and presents a huge reflective surface in antenna measurements. The microscope is used to precisely land the probe tip on the 60 μm $\times$ 60 μm pads on the chip by adjusting the positioner. The positioner holds a converter module that extends the frequency range of the network analyzer and feeds the upconverted signals to the probe. The wafer chuck is required to mount the integrated antenna and to ensure a steady, defined position by using a vacuum pump to fixate the chip as minimal relative movement can damage the probe and the circuit. Microscope, positioner, probe tip, and wafer chuck are made of metal and cause reflections and scattering of the radiated fields, which leads to errors in the measurement results [1].

While the table can be sufficiently covered with absorbers or adjusted to suit the demands of antenna measurements better [2], other components like the positioner, the wafer probe, converter module, and the chuck are not dispensable.

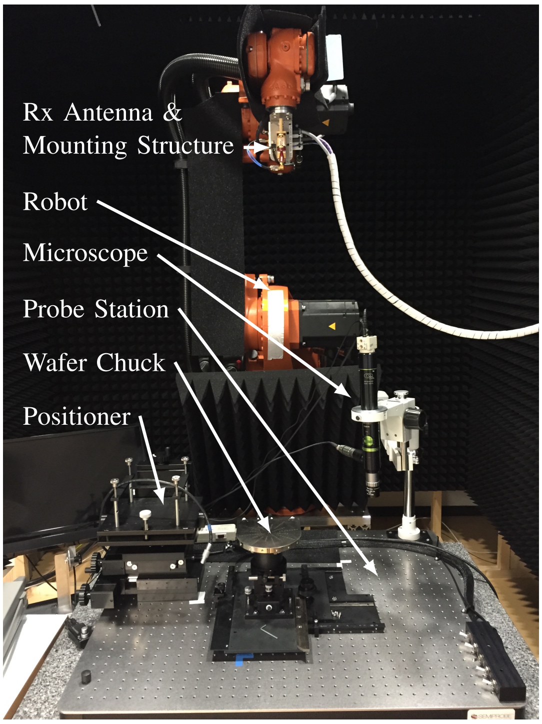
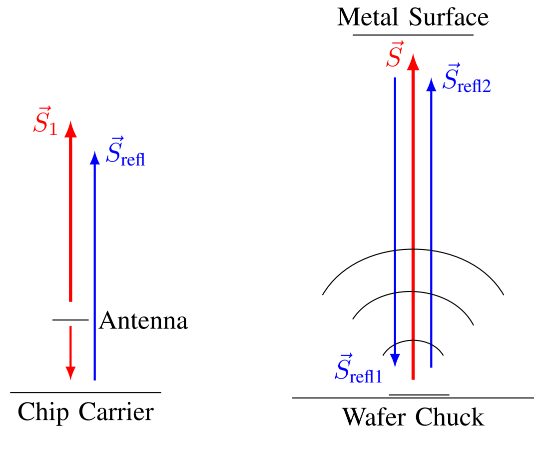


Fig. 1. Rx converter mount with reference antenna.

Both the probe and the chuck are in the immediate proximity of the antenna under test (AUT) and cannot be covered with absorbers completely. This makes their influence on the measurement result especially critical.

Optimized setups for integrated antenna measurements have been proposed, however, most of them at lower frequencies, e.g. [3], [4]. In [5] absorbers are used to cover most components of the probe station and a special probe is used to increase the distance to the antenna and reduce the scattering. [1] also uses absorbers to reduce reflections from the probe station and a cavity underneath the wafer to decrease the chuck influence. This approach, however, is not applicable when measuring single chips.

In order to reduce the effect of the setup on the measurements, a plastic chuck has been designed and the effects on different measurements were investigated. The setup allows



(a) Type 1 (b) Type 2

Fig. 2. Chuck reflections.

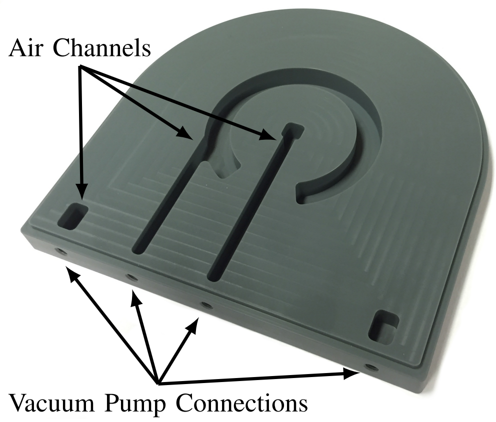


Fig. 3. Bottom part of the PVC chuck.

for two port calibration methods, which are not possible with many custom sample holders [5]. The measurements were taken with the setup shown in Figure 1. A detailed description can be found in [6].

II. Chuck Influence

Commercially available wafer chucks are commonly of metal for its durability and precision in production. However, the metallic surface of the chuck reflects almost the entire intensity of incoming electromagnetic waves. These reflections superimpose with the fields that are being radiated directly from the AUT and interfere with one another at the receiver antenna (Rx). The relative phase between the signal causes ripples in the result over frequency for gain measurements and over location for radiation pattern measurements.

In antenna measurements two types of chuck related distortions can be identified. Figure 2a illustrates reflections that are caused by the back radiation of the AUT. The waves are being reflected from the metal surface and at mm-wave frequencies this small path difference causes a phase difference between the direct signal $\vec{S}_1$ and the reflected signal $\vec{S}_{\text{refl}}$ that causes interference and measurement deviations.

The second type of distortion that is caused by the wafer chuck are signals that bounce back and forth between chuck and the mounting structure of the Rx antenna (see Figure 1).

III. Design of the Wafer Chuck

To decrease the reflections during measurements and thus the interference and ripples, metal parts have to be reduced as much as possible. For non metallic chucks the fraction of the wave that is reflected at the air-chuck-interface can be calculated using the Fresnel equations with the refractive indices n_x of PVC and air. For a perpendicular incident wave the reflectance is

$$R = \left| \frac{n_1 - n_2}{n_1 + n_2} \right|. \tag{1}$$

Aside from a low reflectance, the material needs to be easy to manufacture. As the chuck is used to fix the AUT with a vacuum pump, it needs holes to connect the pump and holes underneath the AUT to create a suction. The surface of the chuck has to be flat enough to prevent any air from getting in the vacuum system.

Different materials were considered and PVC was chosen for its workability, durability, and low reflectance. With a relative permittivity of $\epsilon_r \approx 3$, the resulting reflectance for a PVC chuck is 7.2 % and therefore, significantly lower than the reflectance of a metal chuck.

Two PVC parts were produced for the chuck and then glued together. The lower part with the required air channels is shown in Figure 3. It has four channels for two different chip sizes and calibration structures in the corners. The upper part has small holes over the air channels to suck air in.

The final chuck can be seen in Figure 4. In the bottom of the picture the four vacuum pump connectors are shown. When the vacuum pump is connected, the negative pressure sucks the chip carrier, on which the chip with the integrated antenna is glued, to the surface of the chuck to ensure a steady position.

IV. Radiation Pattern Measurements

Measurements of the radiation pattern with a metallic chuck resulted in ripples especially around the axis perpendicular to the chuck. The presented measurements were performed at 280 GHz with a scaled version of the antenna presented in [7], where a microstrip line couples in an substrate integrated resonator. The resonator then couples through a slot to a magnetic resonator that is glued on the chip. A picture of the antenna is shown in Figure 5.

A. Measurements in the H-plane

Figure 6 shows the comparison of an radiation pattern measurement of the H-plane. The measurement with a metal chuck shows a ripple of up to 4.7 dB compared to a much smaller ripple of 1.2 dB when using the plastic chuck. The

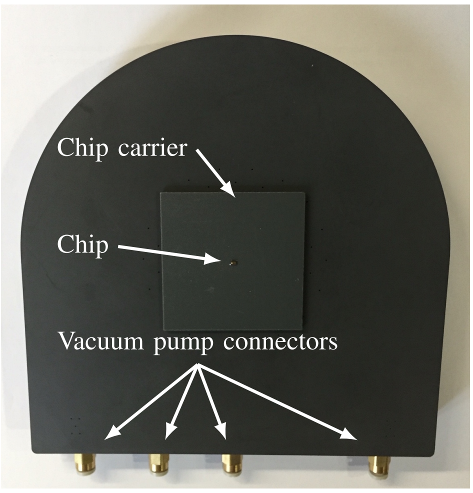


Fig. 4. PVC chuck with vacuum pump connections and chip.

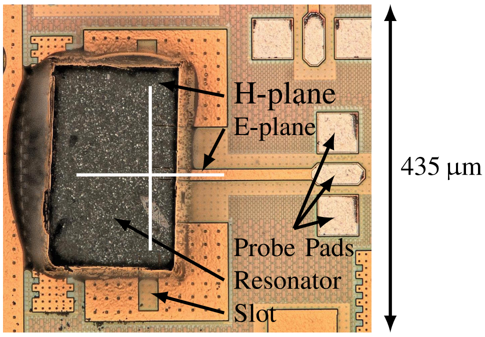


Fig. 5. Picture of the integrated antenna at 280 GHz.

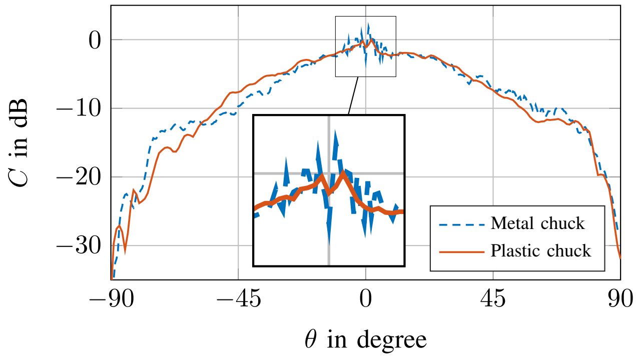


Fig. 6. Measurement of the integrated antenna in the H-plane.

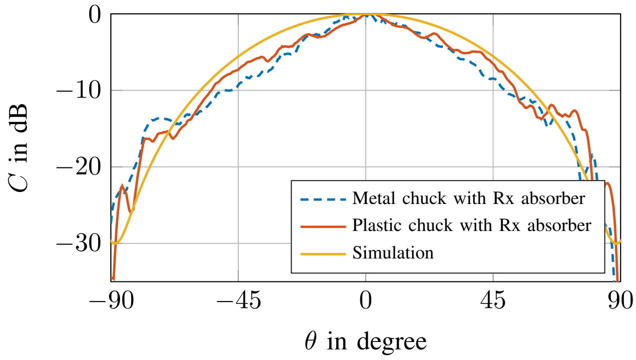


Fig. 7. Measurement of the integrated antenna in the H-plane with absorber at Rx module.

measured pattern with the plastic chuck is more symmetric than the pattern measured with the metal chuck. This shows that the intensity of the reflected signals was significantly reduced, however, ripples still occur in the direction of the main beam. In order to reduce these ripples the mounting structure of the Rx antenna was covered with absorbers to minimize reflections.

The effect of the Rx mounting structure reflections is displayed in Figure 7. The blue line shows a measurements for a metallic chuck and the red line for a plastic chuck, both with absorbers at the Rx mounting structure. Again, the ripples that occurred with the metal chuck and without absorbers (see Figure 6) are decreased. Both the plastic chuck and the absorbers at the Rx reduce the ripples significantly, which indicates that most of the interference is caused by reflections that bounce back and forth between Rx and chuck. If the reflectance of either one of the surfaces is reduced, interference decreases.

When both approaches are combined (see Figure 7, red), the pattern does not change as much in direction of the main beam, but the symmetry of the pattern increases and the deviations to the simulated pattern decrease. This improvement can be attributed to less reflections from type 1 (see Figure 2a).

B. Measurements in the E-plane

Figure 5 shows the probe pads for the wafer probe. The probe is placed from the right hand side and therefore, the H-plane is perpendicular to the probe orientation and the E-plane in the direction of the probe. As previously mentioned the probe is made of metal and disturbs the field severely when measuring in the E-plane of the antenna.

Figure 8 shows a comparison of two E-plane measurements with metal and plastic chuck. As for the H-plane the ripples around the z-axis are reduced, however, the measurement result is dominated by the reflections on the wafer probe. In order to make meaningful measurements in the direction of the probe further measures to reduce the probe influence have to be taken.

V. Gain Measurements

The gain measurement was done with the gain comparison method, where the received signal of the AUT is compared to the received signal of a reference antenna with known gain G_{ref}. The gain of the AUT can then be calculated with

$$G_{\text{AUT}} = G_{\text{ref}} \cdot \frac{S_{21,\text{AUT}}}{S_{21,\text{ref}}} \cdot \frac{1}{S_{21,\text{con}}}, \qquad (2)$$

where $S_{21,\text{con}}$ contains the combined gain of all connectors that are not used during both measurements. In this case these

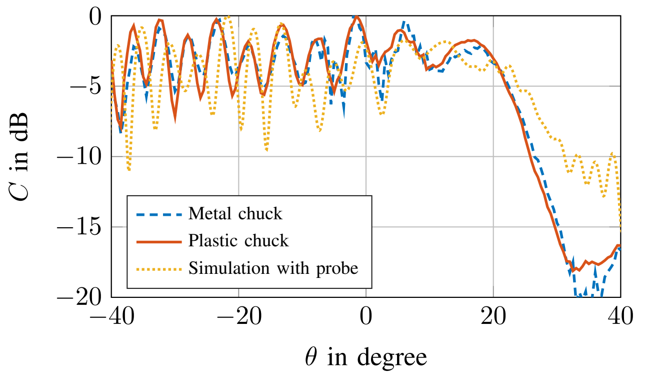


Fig. 8. Antenna pattern measurement in the E-plane with absorber at the Rx module.

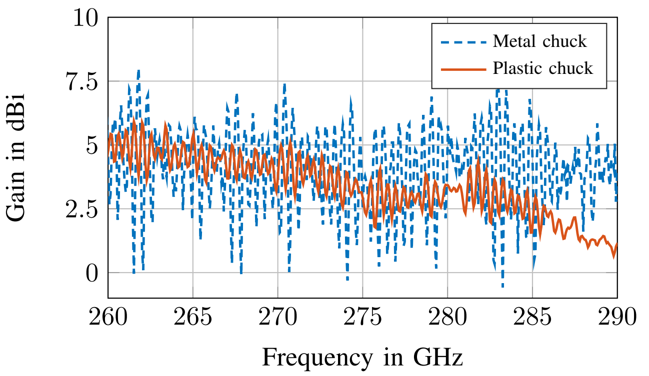


Fig. 9. Gain measurement of the integrated antenna without absorber at the Rx module.

connectors are a wafer probe and a microstrip line to connect the AUT and a waveguide bend to connect the reference horn antenna.

Figure 9 shows the measured gain of the integrated antenna when measured with the metal chuck (blue) and with the plastic chuck (red). The measurement with the metal chuck is highly distorted and has ripples of more than 5 dB. When using the plastic chuck, the measurement is still distorted, but the ripples decrease to less than 2 dB.

The measurement result can be further improved by covering the receiver module with absorbers. This decreases the distortions to less than 1 dB, ensuring reliable measurement data. Figure 10 shows the gain measurement with the plastic chuck and absorbers as well as the simulation results. Over the entire measured frequency range of 260 GHz to 290 GHz, the measured and simulated gain are within 2 dB of one another. Deviations can be caused during measurement for example by the wafer probe, or by false material parameters in the simulation.

VI. Conclusion

In order to reduce measurement errors caused by metallic objects in the measurement setup a plastic chuck, which has a

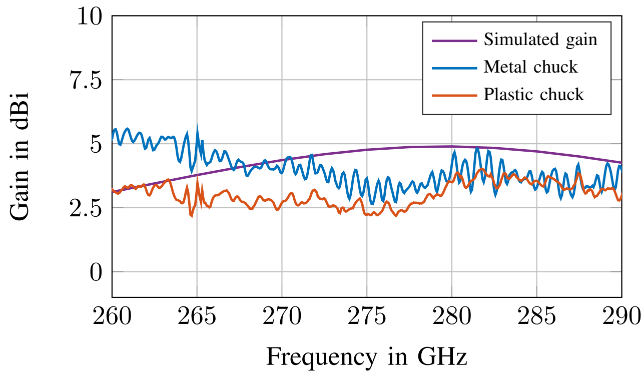


Fig. 10. Gain measurement of the integrated antenna with absorber at the Rx module.

much lower reflectivity than the usually used metal chucks was produced. The reflection from metal chucks cause distortion and errors in antenna measurements. Ripples that occur when measuring with a metallic chuck were reduced significantly by using a non-metal chuck. The symmetry of measurements taken in the plane orthogonal to the direction of the wafer probe is also increased. When measuring in probe direction, the majority of the interference is caused by the probe and further methods to decrease the effect of the probe have to be investigated.

In gain measurements the same effect of chuck reflections can be seen. Ripples that occur over frequency were reduced from more than 5 dB to less than 1 dB by using a plastic chuck and proper shielding of the receiver fixture.

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