Influence of ACP Probe Radiation in S11 Measurement

Mirmehdi Seyyedesfahlan, Ibrahim Tekin
Electronics Engineering, Sabanci University, Istanbul, Turkey, {msesfahlan, tekin}@sabanciuniv.edu

***Abstract*—The on-chip strip dipole antenna is measured for reflection coefficient with different GSG probes at W band. The manufactured antenna simulation is compared with three different measurement results which are realized using infinity and ACP probes. Although the simulation and measurement results obtained from infinity probes are in good agreement, however, the result of ACP probe shows discrepancy with the other measurements. Therefore, the model of ACP probe tip is employed in simulation to feed the antenna and show the radiation effect of the ACP probe tip. The ACP probe circuit is then de-embedded from the simulated S11 using the software calibration of the probe. Finally, the measured S11 via ACP probe is compared with the simulated/de-embedded result.**

***Index Terms*—antenna S11 measurement, ACP probe, probe radiation.**

I. Introduction

It is thought that a prefect RF circuit may be obtained when a desired design along with accurate fabrication are realized. However, some times the measurement part and measuring instruments and condition is forgotten. Neglecting in measurement can cause uncertainty in practical result and compel the designer to re-design or mislead his/her attention to other parts such as software fault or fabrication tolerance. As the frequency is increased to mm-waves the sensitivity of fabrication and measurement are also getting to be considerable since the miniaturization and delicacy of the structure, feeding probe and measurement surrounding. Ground-signal-ground (GSG) probe which feeds the device under test (DUT) is one of the important measurement instruments that has various types as infinity and ACP. The infinity type is isolated/shielded until its tips while some portion near the tip of ACP probe is open and can electromagnetically interface with its surround. Therefore, the ACP probe is radiating from that open part below the probe tip and can affect on both measured reflection coefficient and radiation pattern of the antenna under test (AUT). Although this effect can be reduced/de-embedded by preparing calibration on the same board of measurement, however, realizing same condition can be impossible in some cases. When a DUT is on a chip, implementing the calibration on the chip can sometimes be hard/impossible. Moreover, the GSG pads of the DUT are very close to the edge of the chip and thus below the ACP probe is vacant; while the calibration standards are usually placed in different places and material which cause to discrepancies in the calibration and measurement condition. Consequently, calibration/de-embedding which is performed by the network analyzer in all measurements is same whereas radiation/interface effect of the ACP probe tip changes calibration. Hence, the measured S11 using ACP probe can result in inaccurate value which is affected by the condition that is placed on that.

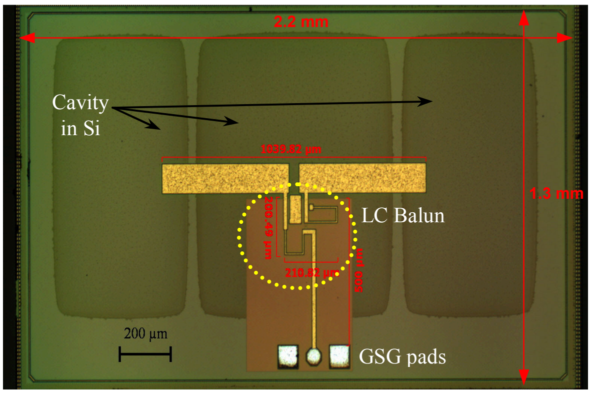

Fig. 1. Micrographic picture of the manufactured on-chip dipole antenna.

In this paper, the on-chip microstrip dipole antenna simulation and measurements with infinity and ACP probes are shown. The ACP probe model for feeding the dipole antenna is used in simulation. The software calibration is done on the simulated S11 to de-embed the probe circuit. The de-embedded S11, which is equivalent with the measured one using ACP probe is compared.

II. On-Chip Antenna

An on-chip microstrip dipole antenna is designed and manufactured (with dimensions 2.2 mm × 1.3 mm), as shown in Fig. 1, to be operated at 77 GHz. The antenna is manufactured on thick (670 µm) Si substrate and thin (11.4 µm) film of SiO_2. The Si substrate has ε_r = 11.9 and σ = 2 S/m, while for SiO_2, ε_r = 4.1. As shown in Fig. 2, Metal 2 layer is used for implementing the antenna and balun circuit, while Metal 1 is handled as the ground plane of the RF signal that feeds the antenna arms. To increase the antenna directivity, the antenna is designed on ground plane as a reflector, and Si substrate below the antenna is etched. Due to PEC ground plane and chip height (that is around λ/4) the reflected EM waves can impose an additive effect on increasing the antenna

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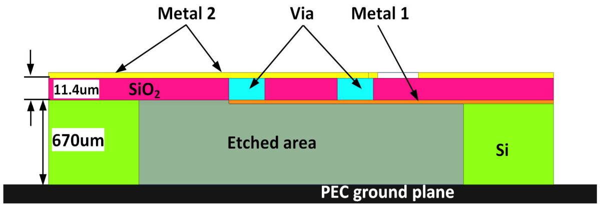


Fig. 3. Lateral view of the chip with different layers on the ground plane.

gain at its top. As shown in Fig. 1, two walls of Si are left beneath the antenna to prevent the SiO_2 from breakage. The antenna length is designed to be $\lambda_e/2$ = 1040 µm at the effective wavelength [1].

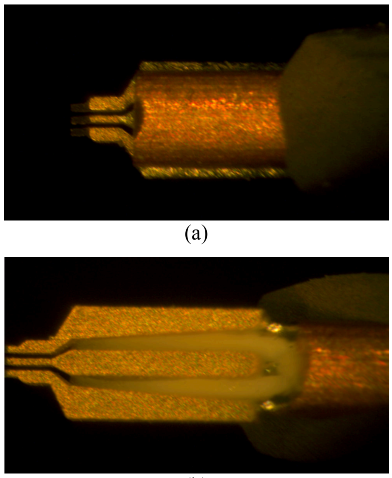
Distributed components LC balun circuit [2] is used to divide the microstrip mode to differential mode with 180° phase difference. Inductors are implemented using the microstrip transmission lines. IHP metal-to-metal process is also used to execute the capacitors. The balun inductor and capacitor are grounded using the vias which pass through the SiO_2 layer and connect Matal 1 and 2 to each other. The manufactured balun dimensions are 210 µm × 200 µm.

III. ACP Probe Model

There are different types of GSG probe such as infinity and ACP probes which are used for coplanar measurements. Input of both probes is terminated by coaxial port while their output (tip) is designed to feed coplanar waveguide (CPW) type transmission lines. Thus, the transition from coaxial to CPW is performed near the probe tips.

In infinity probe the transition is performed using a microstrip line. In this probe the microstrip line and ground are connected to coax inner cylinder and outer body, respectively. Moreover, the ground tips are connected to microstrip ground using vias to have signal and ground tips at the same plane. Since the microstrip ground and coax body are perfectly connected to each other, hence no EM field is radiated out of the infinity probe around the transition portion.

In ACP probes, the air coplanar waveguide is connected to the coax to transit the signal to the probe tips. Top and bottom view of the ACP probe are shown in Fig. 3. As shown in Fig. 3 (b), the opening in transition portion cause to EM field radiation and coupling with the devices nearby the probe tip. The radiated EM field can also be reflected back to the probe from the materials and especially metals below the probe tip. Therefore, the EM field distribution inside the ACP probe can be affected not only by terminating the probe tip with an impedance, but also the reflected EM waves from the probe surrounding. Moreover, the material (and different surrounding) around the GSG pads, that the ACP probe lands on, (especially bellow the probe tip) can differ in each DUT, and hence no unique calibration can be meaningful for all measurements. The effect of ACP probe radiation on scattering parameters measurement can be alleviated if same measurement and calibration conditions are created below the probe tip. These conditions which can reduce the effect of reflected EM waves can include the use of same board for both measurement and calibration, removing extra metals below the probe tip, increasing the spacing between two DUT on the same board or dicing. In addition, exploiting the ACP probes in the situations on which the ground plane is not used can increasingly cause the improvement of the scattering parameters measurement.



(a)

(b)

Fig. 2. (a) top and (b) bottom micrographic pictures of the ACP110-A-GSG-100 probe.

As mentioned, manufacturing the calibration kit on the material/board that is used for DUT can be considered as a remedy to increase the accuracy of the measured S-parameters that are performed by ACP probes. However, it can be hard or impossible for some cases such as on-chip design. Implementing the 50-ohm load and short on the chip is hard and cause to parasitic inductance. In addition, most of the chips are diced near the GSG pads and thus no area of the chip is placed below the probe; consequently, this condition is required to be considered in all standards of calibration on the kit. Also, due to the costly chip area, designers do not prefer to have the calibration kit on the chip. All the aforementioned problems can cause to exploit impedance standard substrate (ISS) calibration kit for chip measurement. Consequently, the discrepancy between simulation and measurement can arise in the case of employing the ACP probe in measurement of S-parameter.

The radiation of ACP probe and reflections from its surround are various in different DUTs and measurement, and hence, this effect cannot be de-embedded from measurements to specify the real performance of DUT. As shown in Fig. 4, we propose to model the ACP probe tip (transition part) along with the DUT in the simulation. In this method, the ACP probe

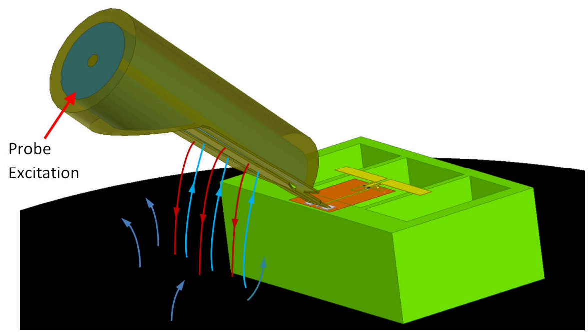


Fig. 4. Probe-fed simulation model of the on-chip dipole antenna.

which feeds the DUT is simulated by putting a lumped port at coax edge in HFSS (see Fig. 4). The obtained input impedance from lumped port in simulation is called Z_{in}. Then, the DUT is replaced by a 50-ohm load, short and open standards (in three simulations) by modeling the ISS calibration board which is used during the calibration in practice. The impedances, Z_{load}, Z_{short} and Z_{open}, at the coax edge of probe model are approached at the end of simulations.

In measurement of antenna S11, the vector network analyzer (VNA) is calibrated for single port. Then, the measured S11 for antenna is the value that is calculated at the tips of ACP probe by de-embedding the performed single port calibration in VNA. The same work is performed in software and the ACP probe circuit is de-embedded to achieve antenna impedance, Z_{ant}, at the edge of GSG pads on the chip. Therefore, the Z_{ant} can be concluded as (1) by calculating the unknowns of ACP probe ABCD matrix using the obtained Z_{in}, Z_{load}, Z_{short} and Z_{open} from simulations.

$$Z_{ant} = 50\frac{Z_{load} - Z_{open}}{Z_{load} - Z_{short}}\frac{Z_{in} - Z_{short}}{Z_{in} - Z_{open}} \quad (1)$$

In this technique, the effect of ACP probe is inserted in simulation and its circuit is de-embedded using (1). Note that, we follow the same operation that is performed practically. If the probe circuit be same at the time of calibration and measurement, the obtained de-embedding relation will lose its concept. However, the probe radiation causes to do not have unique circuit for ACP probe; and the circuit that is de-embedded in both measurement and software, belongs to ACP probe circuit at the time of calibration. Furthermore, the reason of discrepancies between the probe-fed and non-probe simulations is the change of ACP probe circuit in different situations.

To compare the probe-fed simulation and measurement with ACP probe, the antenna reflection coefficient can be calculated as:

$$|S_{11}|(\mathrm{dB}) = 20\log\left|\frac{Z_{ant} - 50}{Z_{ant} + 50}\right| \quad (2)$$

Although, the ACP probe radiation can affect on antenna radiation pattern as well, however, it is not investigated in this paper. Another important part of all types of probes that can have significant effect on the radiation pattern of antennas is the head of probes. Usually, the antenna radiation pattern can be seriously affected on the plane which is perpendicular to the measuring surface and parallel to the probe needle. Moreover, the radiation pattern distortion can increase when the angle of view is increased with respect to the antenna top, as the angle reference. Influence of the probe head on radiation pattern distortion is investigated in [3]-[4].

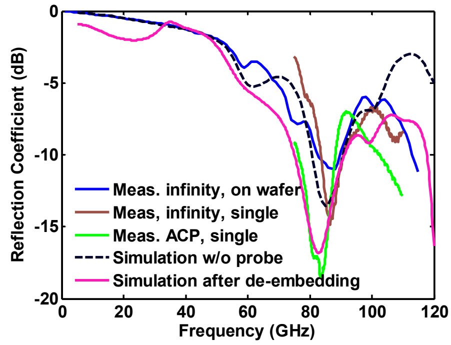


Fig. 5. Antenna reflection coefficient for different on-wafer and single measurements using infinity and ACP probes and simulations without probe and with ACP probe effect.

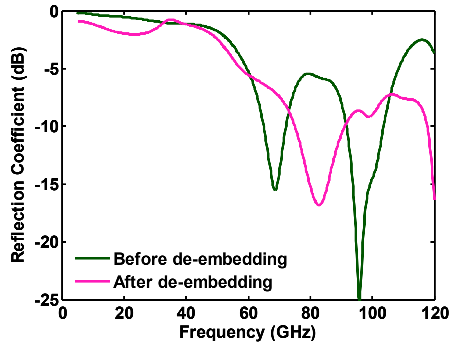


Fig. 6. Antenna reflection coefficient results for probe-fed simulation (before and after ACP probe circuit de-embedding).

IV. SIMULATION AND MEASUREMENT RESULTS

To show the effect of infinity and ACP probes on the antenna reflection coefficient and compare with the simulated results, corresponding curves are displayed in Fig. 5. As shown in Fig. 5, the antenna was measured for S11 when it was on wafer and after dicing, by exploiting the infinity probe. When these curves with colors blue and brown are compared with the simulated antenna S11 (the dashed black curve without probe model), show the antenna resonance at frequencies which are very close to each other (around 84 GHz). Also, these curves are in good agreement for frequencies below 100 GHz. On-wafer measurement has acceptable performance since has done with infinity probe. However, it is expected that in on-wafer measurement the measuring antenna and other devices around it, interfere in antenna near field, and consequently change the measured S11.

The third measurement is performed using ACP probe, shown with green curve, which is different than others measurements and antenna simulation (dashed black curve). Although the measurement is realized on single antenna (after dicing), however, the radiation of ACP probe and its coupling with its surround cause to uncertainty on the measured S11. To show the ACP probe effect, its model is used in the simulation, as shown in Fig. 4, and obtained Z_{in} is inserted into (1) to de-embed the probe circuit and calculate the input impedance of the antenna as, Z_{ant}. The calculated S11 magnitude using (2), is shown with purple curve in Fig. 5. This curve and the ACP measured one present very similar performance, and demonstrate the ACP probe effect.

The reflection coefficient of the probe-fed model simulation before (can be calculated by replacing Z_{in} by Z_{ant} in (2)) and after probe circuit de-embedding are shown in Fig. 6. This figure shows that de-embedding can completely change the shape of the simulated S11 which is seen from the coax edge.

Although the antenna was designed to be operated at 77 GHz (as mentioned in the paper text), however, simulation and measurements show resonance around 84 GHz. This frequency shift is attributed to the GSG pads [1]. Since the antenna will be used at the front end of automotive radar and is connected directly to other component, the GSG pads model was not considered in the design process. However, the pads are inserted to feed and measure the antenna. To compare the simulation and measurement results, the simulation result of the manufactured model (added GSG pads) is utilized.

V. CONCLUSIONS

Probe-fed measurements and simulations were investigated using infinity and ACP probe types on the single and on-wafer dipole antenna. The results of antenna alone simulation and measurement with infinity probe agree well, while do not coincide with the measured result performed by ACP probe since its radiation.

The probe-fed measurement and simulation confirm the effect of ACP probe on S11 measurement. Although some frequency shift was occurred due to the ACP probe effect, however, when disturbing metal particles surround the probe tips and especially below transition part, the S11 can be easily distorted. Furthermore, more resonances which are occurred by the ACP probe effect can also be seen in other measurements on which there are disturbing metals or devices around GSG pads.

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