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One-Antenna Gain Measurement in a Probe Station

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Abstract—This paper presents gain measurement results of a printed patch antenna in a probe station environment at millimeter wavelengths. The one-antenna gain measurement method relying on the use of a reflective plate and measurement of the reflection coefficient is applied. The accuracy of the measurement is improved by moving the reflective plate and thus changing its distance from the antenna. In addition, the time-gating is used in order to avoid the effect of the multiple reflections and other stray signals from near-by reflecting objects. The size requirement for the reflective plate is experimentally studied by using three different plate sizes. Also, different reflective plate distance ranges for the gain retrieval are investigated. The obtained results suggest that the distance range of 20–30 mm and reflective plate width of 30 mm are sufficient to provide accurate gain results for a patch antenna at W-band.

Index Terms—antenna measurements, probe station, on-wafer antennas, millimeter-waves

I. INTRODUCTION

There is a need of small, integrated antennas, and furthermore antennas in package solutions in the future telecommunications. In the development of the small on-chip or on-wafer antennas, reliable measurement techniques for antenna characterization are needed. The reliable feeding of the antenna through, e.g., GSG-probe, requires use of a microscope and stable base to maintain an appropriate contact throughout the measurements. A probe station fulfils these requirements but the environment with reflective structures is challenging from the antenna measurement point of view.

Several antenna measurement set-ups dedicated for on-wafer antenna characterization have been reported since 1990's, either using a probe station or a custom sample holder, or either based on far-field or near-field techniques [1] – [6]. However, they typically require complex and highly accurate, and thus expensive equipment.

We propose the use of one-antenna method because of its easy implementation requiring only a flat reflective plate and a linear translation stage. For the full antenna radiation pattern measurement, a sophisticated measurement system may be required but the proposed method provides an efficient way to characterize the most important performance indicator, the gain of the antenna.

Purcell presented the one-antenna gain measurement method using a reflective plate and measuring the reflection coefficient [7]. The method was further revised by Pippard

et al. and Lee and Baddour [8], [9], and by varying the distance of the plate the accuracy was improved. We have studied the method in the probe station environment where there are reflective objects near-by the antenna under test [10], [11]. In the following, these studies are extended by investigating experimentally in more details the use of time-gating to mitigate the effects of multiple reflections and the effect of the reflective plate size.

II. REFLECTIVE PLATE DIMENSION

In the one-antenna gain method, a reflective plate is placed in front of the antenna. The plate should be in the far-field of the AUT to obtain reliable results. For small, e.g., for patch antennas this requirement is not stringent at millimeter wavelengths. On the other hand, the size of the reflective plate should be large enough. For example, Purcell proposes the reflective plate should be large enough to cover the 3-dB beam width of the AUT [7]. Small antennas have wide beam, thus the requirement for the plate size may limit the practical use of the method. Assuming a beam width of λ/d , where d is the antenna dimension and λ is the wavelength, and approximating the angle subtended by the plate roughly as L/D , where L is the plate dimension and D is the distance, the requirement for the plate dimension is

$$L \geq \frac{D \times \lambda}{d}. \quad (1)$$

As an example, Fig. 1 shows the minimum reflective plate dimension for a 2.5-mm antenna calculated with (1). Effective aperture of 2.5 mm $\times$ 2.5 mm gives gain of 7 dBi at 75 GHz, resembling the directivity of the test antenna used in this study. For example, the required plate dimension is 80 mm for the distance of 50 mm at 75 GHz. For higher frequencies the directivity increases for the fixed effective aperture and a smaller plate dimension is sufficient. In the following section, experimental results for different plate widths are presented.

III. EXPERIMENTAL RESULTS

The antenna-under-test is a patch antenna having a resonance frequency of 81 GHz [12]. It is fabricated with reverse offset printing method using conductive silver ink. The substrate is 125- μ m thick PEN plastic ($\epsilon_r = 2.95$, $\tan \delta = 0.004$). After sintering of the antenna, the square resistance of the metal layer is estimated to be 1–2 $\Omega/\square$ [13].

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Fig. 1: Minimum plate dimension for 2.5-mm antenna as a function of the plate distance for different frequencies. Half-power beam width coverage is required.

In the measurements, the antenna under test is placed on the metal chuck of the probe station and it is fed with a 100- μm pitch GSG-probe. The large metal chuck forms a large reflective area, thus, the multiple reflections between the AUT, the reflective plate, and antenna surroundings are inevitable. In order to avoid multiple reflection distortions in the results, the time-gating is applied. The time gating requires large enough bandwidth in the reflection coefficient measurements in order to allow accurate filtering of the correct terms in the time domain. In the experiment, the full frequency bandwidth of 43 GHz (67 – 110 GHz) allowed by the frequency extension unit of the PNA is used. This bandwidth allows nominally 3.5 mm resolution. The frequency response is transformed in to the time domain via Fourier transform.

Fig. 2 shows the time-domain response of the measured patch antenna reflection coefficient for three different plate widths, i.e. 30 mm, 60 mm, and 80 mm. The plate length is the same 100 mm for all the cases. The movement range of the plate is from 4 mm to 64 mm from the patch antenna. The time-domain response is very similar for all the strip widths. The multiple reflections can be clearly discerned by the different slopes with the increasing time. Note, that the original antenna reflection coefficient or the free-space response is removed, i.e there should not be any response at the time instant $t = 0$. Some remaining response can be seen especially with the 80-mm strip, which may be caused by the further time passed from the calibration and the free space response measurement.

For the close strip distance, less than 15 mm, there are distortions or interferences between multiple reflections of different orders. Also, there are some measurement artefacts at some strip distances for 60-mm and 80-mm wide strips. According to these results, the selected strip distance ranges for the further gain retrieval are 20–30 mm and 50–60 mm. A filter of 0.13 ns is used to time-gate a suitable section of the time domain signal. Fig. 3 shows examples of the time-

Fig. 2: Time domain response calculated from the measured frequency domain reflection coefficient. The plate width is (a) 30 mm, (b) 60 mm, and (c) 80 mm. The plate length is 100 mm for all the cases.

gated signals to be used to calculate the antenna gain. The

(a)

(b)

Fig. 3: Gated time domain signal used for the antenna gain retrieval. The plate distance range is (a) 20–30 mm and (b) 50–60 mm.

time-gate is shifting with the distance in order to maintain the useful signal from the first reflection. The time-domain signal is transformed back to the frequency domain and the slope method is used to calculate the gain for each frequency [10].

Fig. 4 shows the gains retrieved with three different reflective plates and the simulated gain. In the simulations, the ink square resistance is $1.5 \Omega/\square$. The plate distance from the antenna varies from 20 mm to 30 mm. Fig. 5 shows the gains retrieved from the strip movement range of 50 mm to 60 mm. The measured values agree with each other better with the closer distance, the maximum gain being within 1 dB in all the measured cases. The signal level is about 10 dB lower at the further distance, thus deteriorating the accuracy of the gain retrieval and the peak gain variation is approximately 3 dB.

IV. CONCLUSION

The paper presents experimental data obtained with the one-antenna gain measurement method in the probe station. The time gating is necessary to mitigate the effect of multiple reflections, and a wide frequency band is required to obtain

Fig. 4: Antenna gains retrieved from the antenna reflection coefficients. Reflective plate is moved in the range of 20–30 mm.

Fig. 5: Antenna gains retrieved from the antenna reflection coefficients. Reflective plate is moved in the range of 50–60 mm.

sufficient resolution in the time domain to filter out the undesired signals. The results show that the reflective plate width of 30 mm and the plate movement range of 20–30 mm are sufficient to provide accurate gain results for a patch antenna at W-band.

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