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Low-Cost Planar Omnidirectional Antenna for mm-Wave Applications

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***Abstract*—This letter presents a planar omnidirectional antenna structure with wide beam for applications in the 60-GHz band. The antenna was designed using only one metal layer on top of a quartz substrate, which is very cost efficient. The optimal structure, of size 4.5 × 4.3 mm^2, exhibits a gain of 1.4 dBi ± 0.5 dBi in the omnidirectional plane and a half power beamwidth of about 75 deg in the perpendicular plane. The bandwidth with return loss at least 10 dB covers the 57–64-GHz license-free band, which is commonly considered for very high data rate communications. The consistency of the simulated results was successfully checked with measurements.**

***Index Terms*—Millimeter wave (mm-wave) antennas, omnidirectional antennas.**

I. Introduction

OMNIDIRECTIONAL antennas are required in applications such as wireless communications (e.g., WLAN) or for more specific purposes like radio channel sounding. In wireless communications antennas also have to be as compact as possible and fabricated with low cost, i.e., with a simple manufacturing process. This is particularly important at millimeter wave (mm-wave) range where manufacturing antennas is much more difficult and expensive than at microwave frequencies. An advantage of wireless communications in the 60-GHz band is that the antennas do not need to be ultrawideband (at least 25% bandwidth) to cover the 7-GHz bandwidth allocated for short range communications. In addition, the antenna should have wide beam in the planes where the pattern is not omnidirectional since receivers and transmitters are not necessary located at the same height in mobile wireless communications. Many omnidirectional antennas have already been designed and presented, but most of them are not planar [1]–[3]. Therefore, these antennas will be complicated to fabricate and expensive at mm-wave frequency. Planar omnidirectional antennas already reported are also using sophisticated manufacturing processes as in [4] where specific shapes for the ground plane are needed. In this letter, an antenna is presented which uses shaped metal layer only on one side of the substrate, which decreases the complexity of the manufacturing process and therefore significantly decreases the cost.

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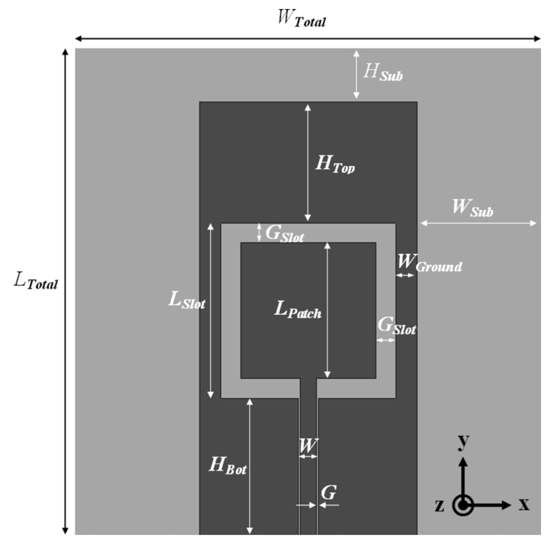

Fig. 1. Layout of the antenna.

II. Antenna Design and Fabrication

As is well known, in printed antennas with single metal layer the radiated power is directed toward the substrate, and the thicker the substrate is, the more significant this effect becomes. Ideally, to get a perfect omnidirectional pattern, an antenna should be suspended in air or any homogeneous medium. For this reason, the antenna was first designed on very thin substrate: 150-μm-thick quartz substrate. The proposed structure is a coplanar patch antenna (CPA) on finite ground plane and substrate with single metal layer as shown in Fig. 1.

This type of antenna is based on the concept of open-ended coplanar waveguide resonator [5]. The structure was designed and simulated with the finite element method software HFSS from Ansoft Corporation. The metal part is drawn in dark gray and the substrate in light gray. The length of the slot $L_{\rm Slot}$ was designed to be half guided wavelength in the slot. The shape of the patch in the centre of the slot is a square. The width and length of the substrate as well as the width and length of the ground plane affect significantly the radiation pattern. $W_{\rm ground}$ and $W_{\rm Sub}$ mainly define the x-z plane radiation pattern—where the antenna is desired to be omnidirectional. The dimensions of $W_{\rm ground}$ and $W_{\rm Sub}$ were optimized for 4.3-mm-wide substrate.

TABLE I
ANTENNA PARAMETERS

Parameters	Value (in mm)
L_{Total}	4.5
W_{Total}	4.3
H_{Sub}	0.5
W_{Sub}	1.15
H_{Top}	1.12
H_{Bot}	1.27
W_{Ground}	0.195
L_{Slot}	1.61
G_{Slot}	0.18
L_{Patch}	1.25
W	0.15
G	0.018

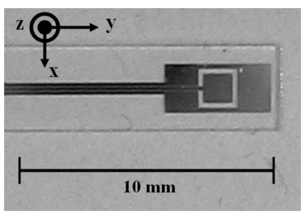

Fig. 2. Picture of the measured antenna with part of the feed line.

It has to be noticed that if one wants to use this antenna as an elementary radiating element in an array, which means that the antenna is on a much wider substrate, the width of the ground plane $W_{\rm ground}$ has to be reoptimized. $H_{\rm Top}$, $H_{\rm Bot}$ and $H_{\rm Sub}$ which control the y-z pattern have been designed such that the antenna will have wide beam in this plane. The length of the patch $L_{\rm Patch}$ together with the width of the slot $G_{\rm Slot}$ mainly determinate the return loss. The coplanar waveguide (CPW) transmission line was designed to be 50 ohm with the smallest gap G that can be acceptable for manufacturing, in order to minimize the effects of the line, and also in order it can be measured with a standard 150 μm pitch ground-signal-ground (GSG) probe. The value of each parameter is given in Table I.

Because of practical limitations in our manufacturing process, the antenna had to be fabricated on 300-μm-thick quartz substrate, although in several manufacturing places the use of 150-μm substrate is possible. For this reason, the structure has been reoptimized for 300-μm-thick substrate. Nevertheless, this altered slightly the omnidirectionality as can be seen in the simulation results presented in the next section. It was noticed that the effect of the change of the width of the substrate on the radiation pattern is more significant for 300-μm than for 150-μm-thick substrate.

In order to allow measuring the performances of the antenna (return loss and radiation pattern), an additional transmission line has to be added to the structure – otherwise the feeding probe would be too close to the radiating element and interfere with it. Since the ground plane around the patch acts as a part of the radiator, an 8-mm-long finite width coplanar waveguide (FCPW) was inserted between the radiating element and the antenna port, see Fig. 2.

The antenna was manufactured using standard photolithography process, sputtering 1-μm aluminium layer on 300-μm quartz wafer. This technique is very cost efficient, especially

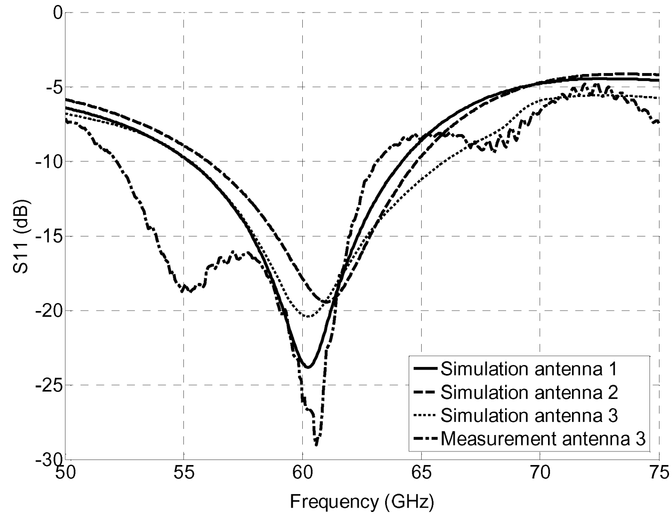

Fig. 3. Simulated and measured return loss.

in mass production when only one mask is needed and tens of antennas can be made on a 10-cm wafer. In the following, the original structure on 150-μm-thick substrate, the same structure on 300-μm-thick substrate and the fabricated antenna with additional transmission line of 8 mm on 300-μm-thick substrate are referred to as *antennas 1*, *2*, and *3*, respectively.

III. RESULTS AND DISCUSSIONS

Fig. 3 shows the simulated return loss of the three antennas and the measured return loss of *antenna 3*.

The return loss was measured on a probe station using a traditional GSG probe. It is shown that the difference of substrate thickness as well as the addition of transmission line does not significantly affect the return loss. One can also notice that the antennas fully cover the 57–64-GHz band. Although some additional resonances are visible in the measured S11, there is a quite good agreement between the simulated and measured S11 for the main resonance. The additional resonances are most likely due to the presence of metallic surfaces nearby the antenna during the measurement of the return loss.

The antenna radiation pattern was measured at 60.5 GHz using an advanced on-wafer measurement system which allows measuring both above and under the antenna. The antenna was fed by the GSG probe. The reference angle $\rm theta = 0$ is pointing upward, in the z direction. Fig. 4 shows that the gain of *antenna 1* in the x-z plane is $1.4\ \rm dBi \pm 0.5\ dBi$, which is more omnidirectional than the measured patterns reported in [1], [3], and [4] and the simulated pattern reported in [2].

From Table II it can be seen that, over the 57–64-GHz band, the gain of *antenna 1* is nearly constant and the omnidirectional property is kept. This is due to the fact that only one mode is excited over the frequency band, and that 7 GHz is only about 12% of the resonance frequency.

It can be noticed from Fig. 4 that the omnidirectionality of the antenna deteriorates when using 300-μm instead of 150-μm -thick substrate. One can also see that the additional transmission line does not decrease significantly the performances of the antenna. The simulated gain of *antenna 3* in the x-z plane is $1.4\ \rm dBi \pm 1.4\ dBi$ and the measured one is $1.5\ \rm dBi \pm 1.4\ dBi$,

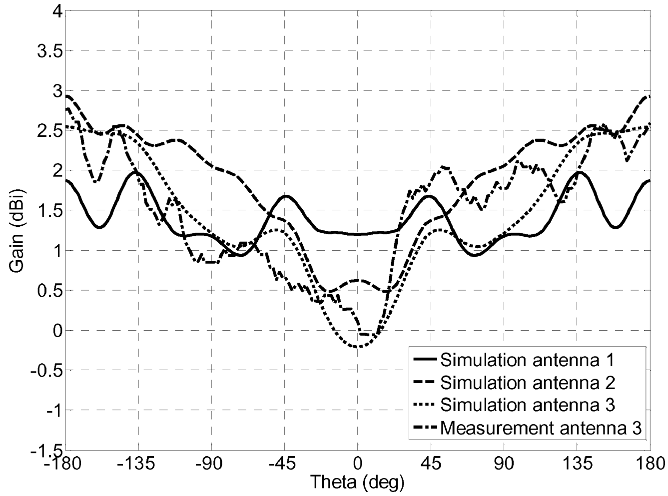

Fig. 4. Simulated and measured gain in the x-z plane at 60.5 GHz.

TABLE II
SIMULATED GAIN OF *ANTENNA* 1 IN THE x-z PLANE AS A FUNCTION OF THE FREQUENCY

Frequency (GHz)	57	58	59	60	61	62	63	64
Mean gain (dB)	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.2
Variation (dB)	±0.6	±0.6	±0.5	±0.5	±0.5	±0.5	±0.5	±0.5

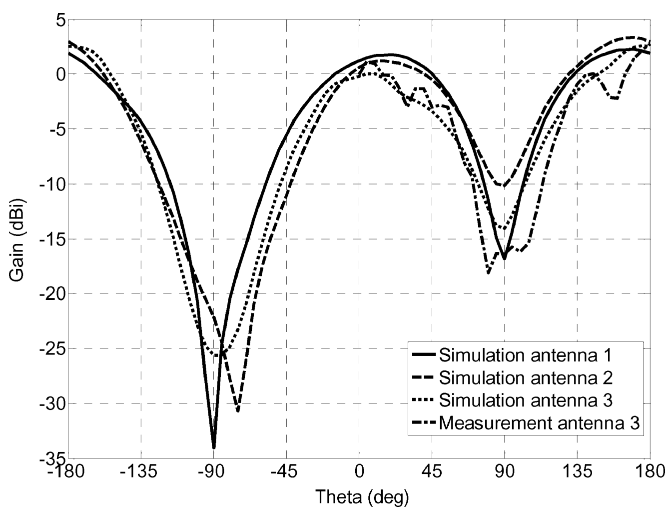

Fig. 5. Simulated and measured gain in the y-z plane at 60.5 GHz.

which shows good agreement between the two results. The gain of the antennas in the y-z plane is shown in Fig. 5.

The simulated half-power beam width (HPBW) of *antennas 1*, *2*, and *3* is about 75 deg, 70 deg, and 65 deg, respectively. Due to practical limitations, the gain of *antenna 3* in the y-z plane was measured only in one half plane. Good agreement between simulated and measured gain of *antenna 3* can still be observed. Finally, one can notice that the additional transmission line affects the radiation pattern mainly in the y-z plane whereas the thicker substrate affects the pattern in both x-z and y-z planes. The simulated total efficiencies of *antenna 1*, *2* and *3* are 99%, 99%, and 83%, respectively. This reveals that the additional transmission line introduces some losses.

IV. CONCLUSION

A planar omnidirectional antenna structure with a wide beam for applications in the 60-GHz band was presented. The antenna was designed such that only one metal layer is needed, and therefore it can be manufactured at low cost. The optimal structure (using 150-μm-thick substrate) has been simulated and shows very good characteristics: the 10-dB bandwidth covers the 57–64-GHz band. The simulated pattern is more omnidirectional (x-z plane) than the measured patterns reported in [1], [3], and [4] and the simulated pattern reported in [2], and it exhibits a wide beam in the y-z plane (HPBW of 75 deg). The good omnidirectional property is observed over the full frequency band. Due to manufacturing limitations, the antenna was fabricated on 300–μm–thick substrate, which decreases, reasonably, the performance of the structure. The measurement results of this antenna are presented and good agreement was found with the simulation results, which shows the reliability of the simulation results. Therefore, it is reasonable to expect that the performance of the optimal antenna is close to that extracted from the simulations. The influence of an additional transmission line has been studied and it can be concluded that it does not affect significantly the radiation pattern.

This antenna is very suitable for 60-GHz MIMO communications since it is compact, low profile, inexpensive to fabricate and has good omnidirectional property over the full 57–64-GHz band which is allocated for short-range high data-rate wireless communications. It is also very suitable as a single antenna for wide band MIMO channel sounding with virtual (or synthetic) arrays in the 60-GHz band.

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