# A superstrate patch antenna for 60-GHz applications

# A Superstrate Patch Antenna for 60-GHz Applications

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*Abstract*— **This paper presents a balanced-fed aperture-coupled patch antenna suitable for broadband millimeter-wave communications. The antenna is realized in a low-cost PCB technology and can be integrated with RFIC chips. To improve antenna bandwidth and radiation efficiency, an air cavity has been embedded in the PCB stack. The measured antenna performances agree very well with the simulated results. The antenna has about 7 dBi gain, with at least 12 GHz impedance bandwidth.**

## I. Introduction

There is an increasing demand for low-cost wireless communication systems that operate in the 60-GHz frequency band and that support gigabit-per-second (Gbps) data rates. Typical applications demanding Gbps data rates include wireless gigabit Ethernet and wireless uncompressed high-definition video. The success of these types of applications very much depends on the cost of a single transceiver. Recent advances in the integration level of silicon millimeter-wave (mmWave) circuits [1] allow the integration of most of the passive devices on the silicon integrated circuit, which reduces the cost and size of the mmWave modules. However, an efficient antenna cannot be realized on-chip and should therefore be embedded in the transceiver package. The realization of a robust, efficient and broadband mmWave antenna within a plastic or multilayer organic (MLO) package is challenging due to assembly difficulties and material parameter tolerances. In [2] we indicated that our cavity-backed folded dipole superstrate antenna has potential for integration with our 60-GHz SiGe chipset [1] in a plastic land-grid array (LGA) package [3]. This package concept includes a fused-silica substrate with antenna structures, a metal frame forming the cavity and providing the support for the fused-silica substrate, a package carrier to carry the radio frequency (RF) chip and antenna assembly, and glob-top to protect the chip and the antenna. Although this package shows excellent performance, the assembly is still complicated and expensive. To further reduce the package costs the number of package components needs to be reduced and the assembly process needs to be simplified. Therefore, a new planar antenna topology is proposed here.

The main challenge of planar antenna design is the trade-off between radiation efficiency and bandwidth. There are two ways to achieve wide bandwidth, namely a very low dielectric constant, preferably close to 1, or a relatively thick dielectric layer [4]. Since a thicker dielectric layer introduces more losses due to surface-wave excitation in the dielectric, most attention is directed towards the realization of an (effective) low dielectric constant. In [2] a cavity-backed antenna topology has been proposed that has more than 90% radiation efficiency. In this topology, the antenna has an air cavity underneath the radiating dipole element which enhances the radiation efficiency. Alternatively, a balanced patch antenna design has been proposed in [5] that employs Teflon-based substrate materials ($\varepsilon_r$ = 2.2). In this design, the antenna element itself cancels part of the surface-wave excitation. Therefore, a radiation efficiency of more than 80% is obtained throughout the band of operation. On top of that, a bandwidth of more than 10% is realized by using two resonant elements.

Although the aforementioned designs are promising, they are not directly amenable in practical applications since in these applications the use of mainstream printed circuit-board (PCB) substrate materials is required as well as a bandwidth of more than 15%. Therefore, we propose to combine the benefits of both the air cavity in [2] and the antenna design in [5]. For this purpose, a novel PCB stack is proposed. We will show that this results in a superstrate antenna topology [6] that has a bandwidth of more than 15% and a radiation efficiency of more than 90%.

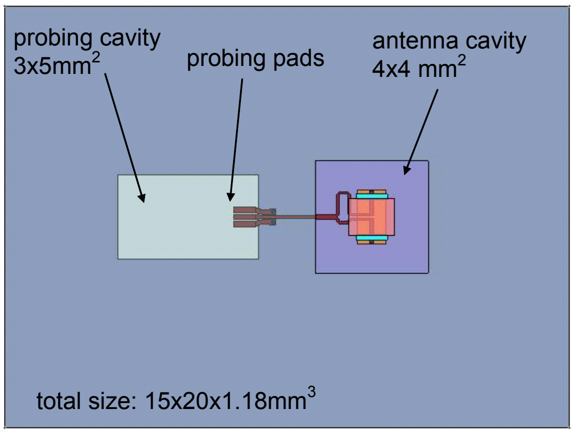


Fig. 1: A top view of the antenna structure

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## II. Antenna Design

As mentioned, the proposed antenna design is based on the balanced-fed aperture coupled patch antenna [5] with a stack-up from the reference [7]. This is essentially an aperture-coupled patch antenna with two apertures (slots) and a balanced feed. The two slots play an important role in the antenna design. First, they are used to reduce the surface-wave excitation in the substrate. The two slots are positioned such that the surface waves generated by the slots and the patch interfere destructively and therefore the radiation efficiency of the antenna is improved. Second, the resonant slots are also used to improve the antenna bandwidth. As a result, the bandwidth is increased significantly since the antenna now has two resonant elements, i.e., the patch and the slots, with slightly different resonance frequencies. As a consequence, the slots also cause back radiation. To reduce this back radiation, a reflector element is placed behind the ground plane [8]. The antenna bandwidth can be increased further by implementing an air cavity between the ground plane and the patch. A proper selection of cavity depth, superstrate thickness and superstrate dielectric constant optimizes the radiation efficiency to more than 90% (see also [6]).

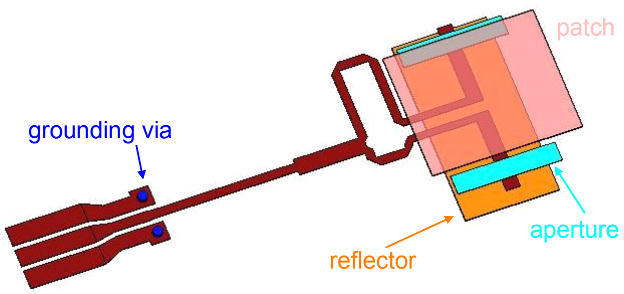


Fig. 2: A close-up view of the antenna metal structure

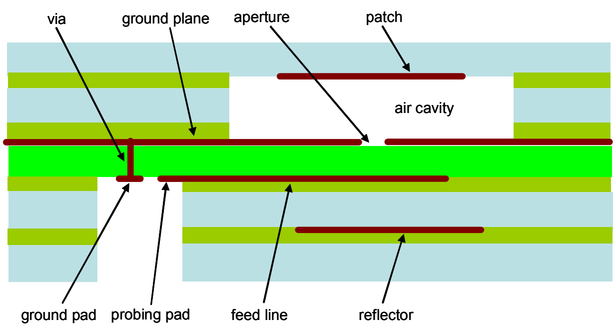


Fig. 3: Cross sectional view showing substrate layer stack-up

Figs. 1 to 3 show the antenna structure. In Fig. 1 a top view of the antenna is shown with accompanying dimensions. Since the antenna feed line is buried in the substrates, a cavity is used to probe the feed line for measurements. As shown in Fig. 2, the antenna is fed with a dipole structure; this naturally results in a balanced-fed antenna. The antenna is designed for 100 Ohm differential impedance. To enable proper measurement of the antenna in the 60-GHz frequency band, a balun is used to convert the 100 Ohm differential feed to a 50 Ohm microstrip line. Moreover, a conversion from microstrip line to coplanar waveguide is implemented to enable measurement with a ground-signal-ground RF probe. Fig. 3 shows the PCB stack of the antenna construction. Note the air cavity that is embedded in this stack. The thickness of the feed line structures and the ground plane is 9 $\mu$m while all other metal structures are 18 $\mu$m thick.

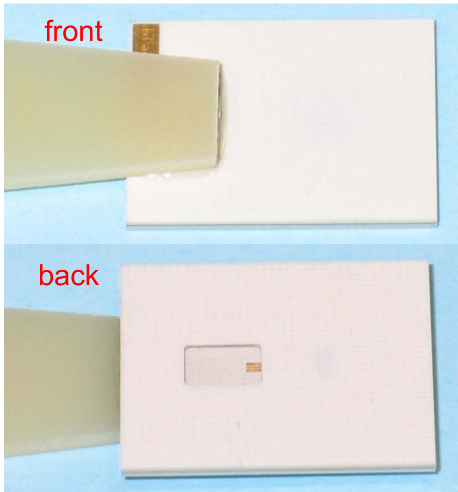


Fig. 4: Photos of the manufactured antenna

## III. Results

The antenna has been designed for operation in the 60 GHz frequency band that ranges from 57 to 66 GHz. Fig. 4 shows the manufactured antenna with FR4 test fixture (partially shown). The antenna was measured in an anechoic chamber using a probe-based measurement setup that has a frequency limit of 65 GHz [9]. The measured and simulated (HFSS) reflection coefficient $S_{11}$ is shown in Fig. 5. From this figure, it is clear the antenna is well matched to 50 Ohms in a bandwidth that is adequate for 60-GHz applications. The simulated 10 dB return loss bandwidth is about 13.5 GHz. The measured bandwidth is at least 10 GHz but the measured frequency range is limited to 65 GHz. Fig. 6 shows the measured and simulated antenna gain which are in good agreement in the 60-GHz band. The gain is also flat over this frequency band. The measured and simulated peak gains are 7.8 dBi and 7.9 dBi respectively. Figs. 7 and 8 show the measured and simulated antenna radiation patterns in the H and E planes respectively. Due to the measurement setup, the radiation patterns can only be measured for a 180 degree span in elevation.

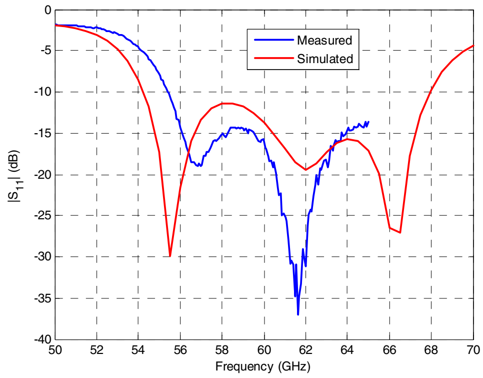


Fig. 5: Measured antenna S11

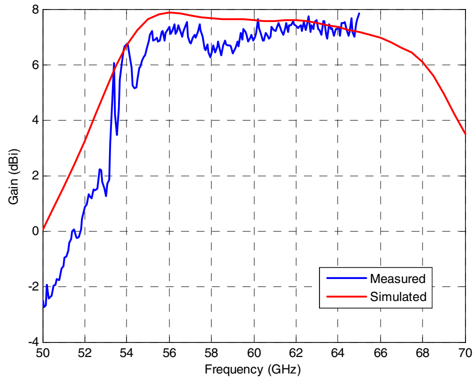


Fig. 6: Measured antenna gain

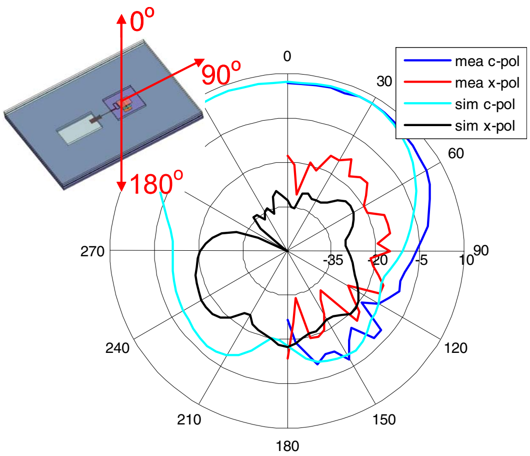


Fig. 7: Measured radiation pattern from the front side (H-plane)

## IV. Conclusions

We have presented a balanced-fed aperture-coupled patch antenna suitable for broadband mmWave communications. The antenna is realized in a low-cost PCB technology and can be integrated with RFIC chips. To improve antenna bandwidth and radiation efficiency, an air cavity has been embedded in the PCB stack. The measured antenna performances agree very well with the simulated results. The antenna has about 7 dBi gain, with at least 12 GHz impedance bandwidth.

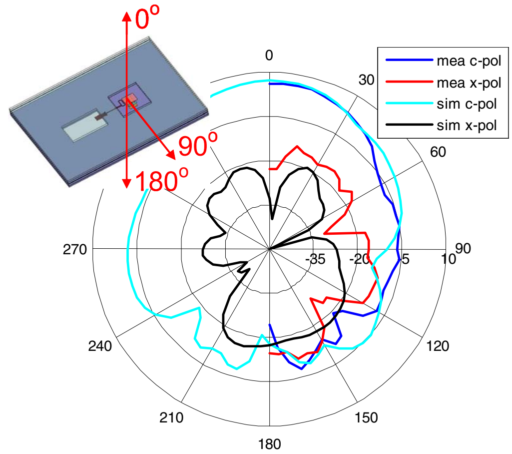


Fig. 8: Measured radiation pattern from the side (E-plane)

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