

Antenna-in-Package Using PCB and IPD Technologies for 60 GHz Applications

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Abstract— In this paper, we present several antennas for 60 GHz low-cost packaged modules. These antennas are fabricated using a PCB substrate and the IPD™ technology. In the first part, an antenna is etched on the Taclamplus substrate from Taconic and shows very promising performances. In the second part, a microstrip line on this substrate is directly coupled to an upper patch antenna fabricated in the IPD™ technology from ST Microelectronics. The purpose is to increase the matching bandwidth and still address a low-cost antenna-in-package solution.

Keywords— 60 GHz antenna; PCB substrate; IPD technology; patch antenna.

I. INTRODUCTION

The 60 GHz unlicensed frequency band offers a large available spectrum (8 GHz) which is of strong interest for Wireless Personal Area Network (WPAN) applications [1]. Consequently, several RF modules have been designed and are now already sold on the market. However, to become a key player in this field, one of the big issues consists in addressing a low-cost packaging solution for such modules. Therefore, several possible antenna-solutions have been investigated. First, antennas on bulk silicon substrate as the most natural candidate for direct integration with the radio chip already showed very poor gain and are consequently inefficient solutions [2]. To overcome this drawback, antennas etched over micro-machined [3] or High-Resistivity (HR) silicon [4] have led to an improvement of the gain but are still too expensive because too many steps are necessary to the fabrication process. The Antenna-in-Package solution is addressed using LTCC in [5] which is a robust and reliable approach but still quite expensive [6]. Consequently, a more affordable solution has to be found. One of them consists in using a low-cost PCB substrate in conjunction with its proper integration with the radio front-end module.

In this paper, we present several antennas for 60 GHz low-cost packaged modules. In the first part, an antenna is realized on the Taclamplus substrate from Taconic [7-8]. In the second part, a microstrip line is directly coupled to a patch antenna fabricated in the IPD™ technology from ST Microelectronics

[9]. The glass substrate is mounted on the PCB using flip-chip technology. The purpose is to increase the matching bandwidth and still enable a low-cost antenna-in-package solution. This approach has already been investigated using a coplanar feed on a BiCMOS substrate but we propose here to further use a low-loss and low-cost PCB substrate [9].

II. ANTENNA-IN-PACKAGE ISSUES

The proposed solution for low-cost package is shown in Fig. 1. In Fig.1.a, the antenna is directly integrated in the PCB package. This is the more convenient way to achieve a low-cost package. But, as will be presented in III, it is difficult to achieve wideband antennas with this kind of architecture. To overcome this problem, another solution is presented in Fig.1.b. The IPD process from ST Microelectronics, Tours is used as a superstrate for the antenna. In that case, there is a higher height between the ground plane and the patch and wideband capability is achievable while still addressing low-cost packaging.

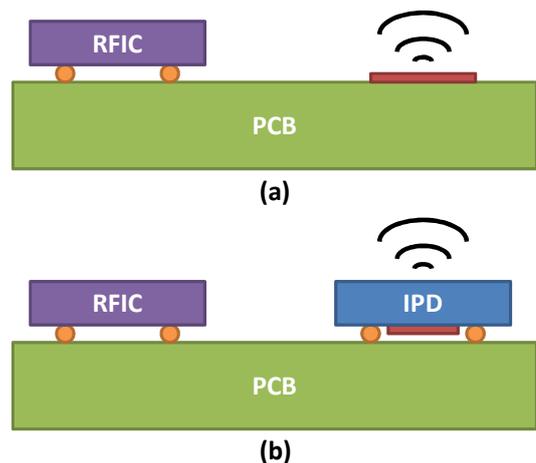


Figure 1. Example of packages. (a) Direct integration of the antenna into the PCB. (b) Integration of the antenna using the IPD process.

III. PATCH ANTENNA ON THE PCB SUBSTRATE

A. Design

We first realized a patch antenna using the Taclamplus substrate from Taconic. The Taclamplus substrate is 0.1 mm thick with 17 μm of copper on one side and 1mm thick copper on the other side (Fig. 2). This substrate has a permittivity of 2.1 and a loss tangent of only 0.0008 [7-8]. Hence, at 60 GHz, the guided wavelength λ_g is reduced to 3.4 mm.

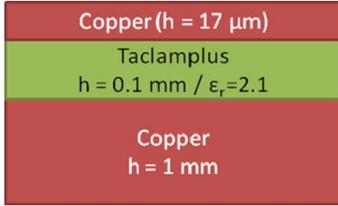


Figure 2. Side view of the Taclamplus substrate from Taconic.

The patch antenna is a simple radiating structure which consists of a rectangular element on top of a substrate, being backed by a ground plane. Typical dimension of the square sides is $\lambda_g/2$. The height between the rectangular patch and the ground plane should be $\lambda_g/4$ for in-phase recombination of the direct and reflected waves in the far-field region. However, as the thickness of the Taclamplus substrate is far lower from being equal to $\lambda_g/4$, the resulting antenna will be inherently narrowband but will lead to high gain and high efficiency. The HFSS model of the optimized patch is presented in Fig. 3.a along with its feeding structure and the coordinate system we used. The length of each side is 1.6 mm. A 400- μm GSG pad is used to feed the antenna through a microstrip line. A double-tuning stub is necessary to match the antenna to 50 Ω as the patch is galvanically fed to its edge. The capacitances introduced by the GSG pads are also taken into account to optimize the input impedance of the structure and therefore, no de-embedding technique will be needed. It should be noted that the ground pads are optimized with a proper length to convert the coplanar mode to the microstrip mode (no via in the taclamplus substrate).

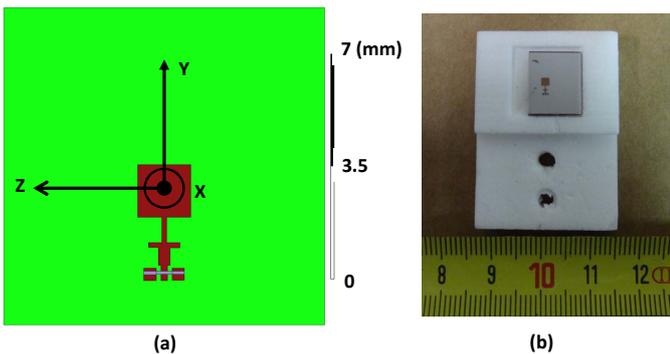


Figure 3. (a) HFSS design of the patch antenna. (b) Realized patch antenna in its foam holder.

B. Experimental Results

The fabricated antenna is shown in Fig.3.b. It is presented in its foam holder, important piece for the radiation pattern measurement as its permittivity is close to one. The simulated reflection coefficient (Fig. 4) was found to be narrowband with a -10dB bandwidth only ranging from 59 to 60 GHz.

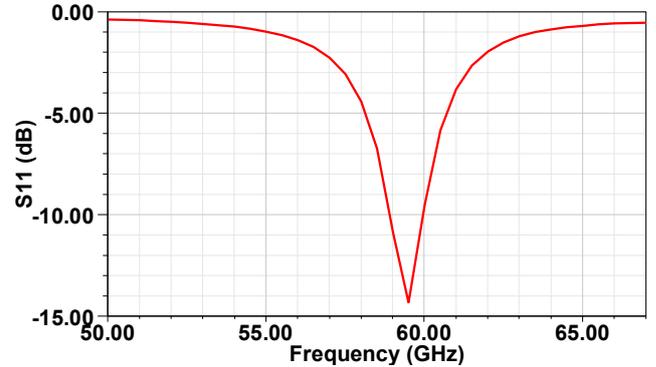


Figure 4. Simulated reflection coefficient of the patch antenna.

The antenna has been measured using the CIM-PACA 3D radiation setup available at the CREMANT of University Nice-Sophia Antipolis [10-11]. The realized gain has been measured from 50 to 67 GHz (Fig. 5) in the broadside direction ($\Phi=0^\circ$ and $\Theta=90^\circ$). Although we can see some ripples in the measurement, the values of the measured and simulated gain are quite close with a maximum measured realized gain of 6.85 dBi at 62 GHz.

The simulated and measured radiation patterns are plotted in the two main planes (E and H) at 62 GHz (Fig. 6). The measured ripples are attributed to the radiation of the big body of the GSG probe. We obtain a maximum realized gain of 7.27 dBi at $\Phi=30^\circ$ and $\Theta=90^\circ$ in the E-plane which validate the benefit of using the Taclamplus substrate at 60 GHz. However, the next step of this preliminary work is definitely to enlarge the operating bandwidth of the antenna.

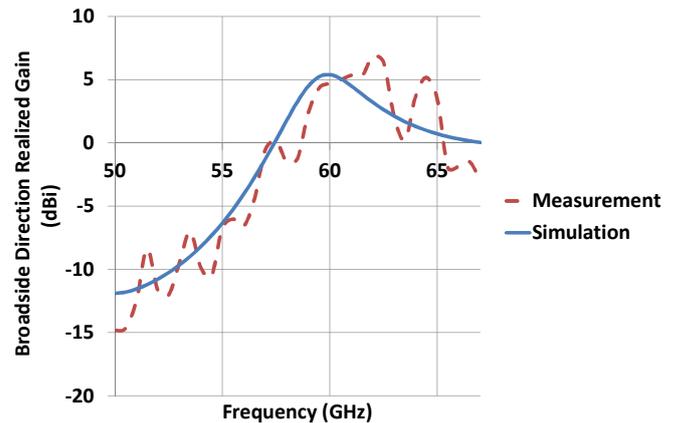


Figure 5. Simulated and measured realized gain versus frequency of the PCB antenna.

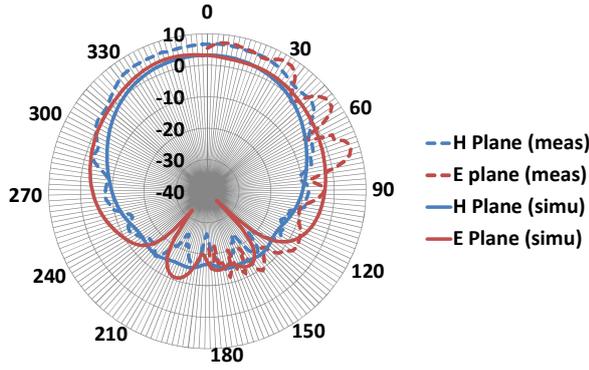


Figure 6. Simulated and Measured E- and H-planes of the patch antenna on PCB substrate at 62 GHz.

IV. COUPLED PATCH IN IPD PROCESS

A. IPD Process

The IPD™ process developed by ST Microelectronics Tours has been especially created for lossless and miniature passive devices like resistors, capacitors or inductors. A simplified side view of the most significant layers of this process is presented in Fig. 7. On top of the glass substrate ($\epsilon_r=4.6$), we choose to use the third level of metallization (Meta3, $h=3 \mu\text{m}$) which is covered by a BCB material ($\epsilon_r=2.7$) to etch the patch antenna.



Figure 7. IPD process build-up.

B. Design

A direct coupling from a microstrip line etched on the Taclamplus substrate is used to feed the patch fabricated on the IPD™ substrate. As before, the microstrip is fed using GSG pads and incorporates a double-tuning stub. This part is still etched on the Taclamplus material. Then, above the line, we electromagnetically couple the IPD™ patch. The IPD™ substrate is flip-chipped and soldered onto the Taclamplus using $140 \mu\text{m}$ bumps (called micro-bumps). After assembly, the air height between the IPD™ and the Taclamplus is given to be around $90 \mu\text{m}$ with a $\pm 10 \mu\text{m}$ tolerance for a good. The HFSS model and its coordinate system are presented in Fig. 8.a.

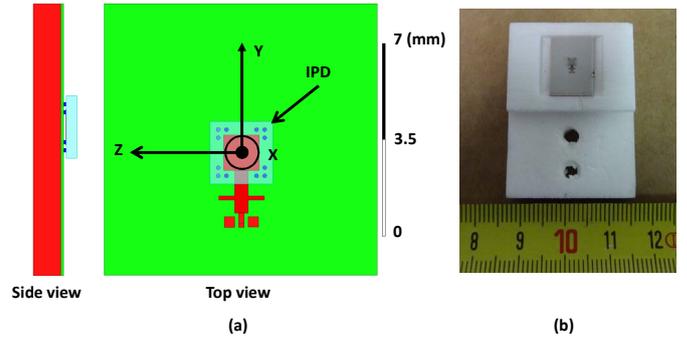


Figure 8. (a) HFSS model of the coupled IPD patch antenna. (b) Realized coupled IPD patch antenna in its foam holder.

C. Results

The fabricated antenna is shown in Fig.8.b. The antenna has now a -10 dB simulated matching bandwidth ranging from 57 to 65 GHz (Fig. 9).

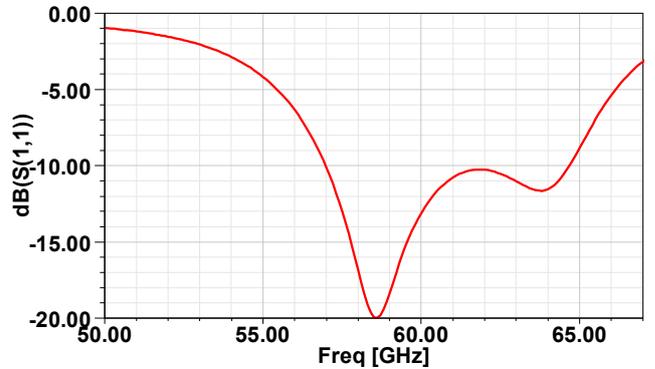


Figure 9. Simulated reflection coefficient of the coupled IPD patch antenna.

The antenna has been measured in the same conditions the one given previously for the patch antenna on PCB substrate. The realized gain has been measured from 50 to 67 GHz (Fig. 10) in the broadside direction ($\Phi=0^\circ$ and $\Theta=90^\circ$). We observe very close values between simulation and measurement despite some ripples. The measured realized gain in the broadside direction is above 6 dBi from 56 to 67 GHz.

The simulated and measured radiation patterns are plotted in the two main planes (E and H) at 60 GHz (Fig. 11). We obtain a maximum realized gain of 8.71 dBi at $\Phi=12^\circ$ and $\Theta=90^\circ$ in the E-plane. Simulated radiation efficiency is expected to be 95 % at 60 GHz. Future work will focus on the extraction of the radiation efficiency from a 3D measure of the realized gain of any AUT.

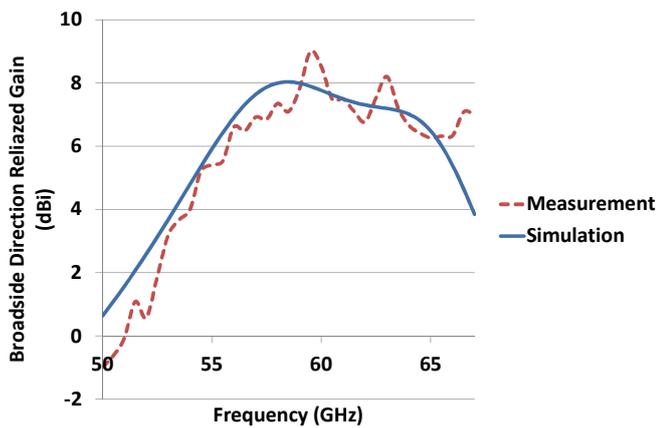


Figure 10. Simulated and measured realized gain versus frequency of the coupled IPD patch antenna.

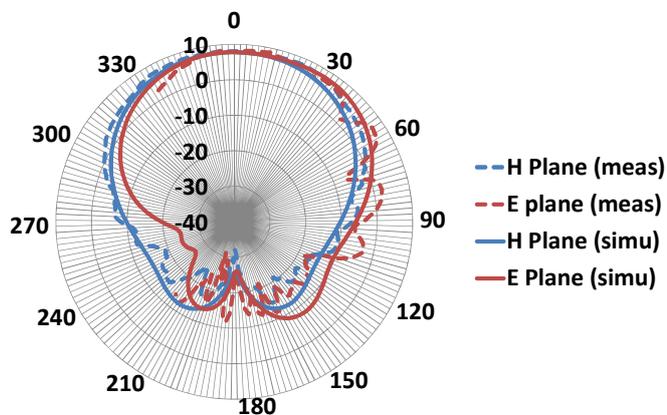


Figure 11. Simulated and Measured E- and H-planes of the coupled IPD patch antenna at 60 GHz.

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