# Characterization of FOWLP Antenna in Packages

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**Abstract**

The Antenna in Package (AiP) based on Fan-Out Wafer-Level-Packaging (FOWLP) enables compact beam steering solutions for Satcom On the Move (SOTM) and 5G applications. This paper presents the characterization of such AiPs in terms of S parameters, Gain and patterns as well as its building circuits of microstrip line and power dividers at the 27-31GHz SOTM band. The 6mm×6mm×0.384mm AiP element shows a measured Return Loss (RL) of >11.5dB, Isolation >19.8dB, Gain of 5.1-6.8dBi over 27-31GHz as well as pure V and H dual polarizations; The 12mm×12mm×0.384mm AiP 2×2 array achieves pure V polarizations with a measured RL of >9dB and Gain of 8.1-10.8dBi over 27-31GHz.

## Introduction

The beam steering phase array is the key technology to realize SOTM and 5G communications [1]. A compact Antenna in Package (AiP) based on double-molding FOWLP enables compact low RF loss phase array modules by molding the beamformer die directly within the package while with the antenna on its top as shown in Fig.1 [2-6]. We designed a dual-polarized AiP element and a 2×2 Array with a thickness of 0.384mm and fabricated in 12-inch wafers [4]. In this paper, we report on the characterization performance of such AiPs at 27-31GHz.

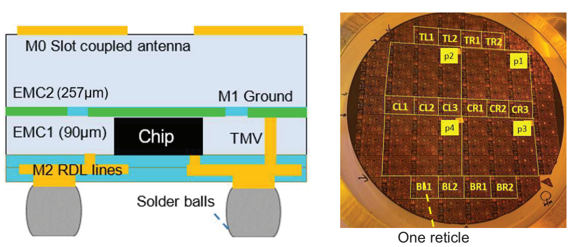



Fig. 1. AiP in FOWLP technology with fabricated wafers.

## Methodology

The reticles and AiP samples are diced out as shown in Fig. 2 for characterization. Fig. 3 shows the AiP and circuit characterization setup at the Institute of Microelectronics (IME) lab [6]. The Keysight N5290A vector network analyzer and Formfactor 12-inch probe station are used for the S-parameter test. The in-house Gain and pattern tester is equipped with rotation arms, laser alignment features as well as software for test control, data reading, and pattern plot, where the signals are tested with a frequency tunable Oscillator, horn, and R&S FU67 Spectrum Analyzer. The AiP samples have GSG ports with a fine pitch of 100μm, which are taped onto a support foam and touched by an ACP GSG probe for testing as helped by the fine-tuning positioner and microscope.

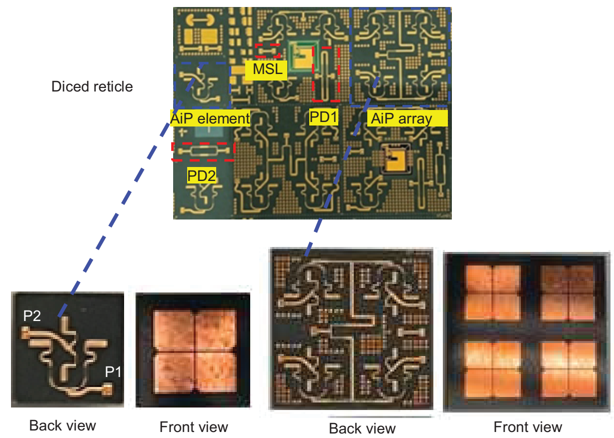



Fig. 2. The diced reticle and AiP samples.

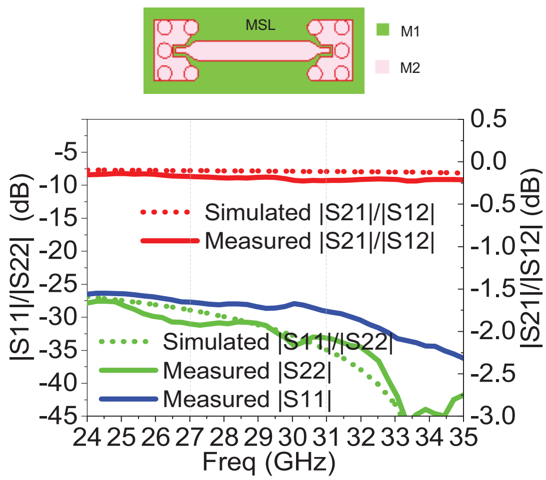

Fig. 3. AiP and circuit test setup.

## Results

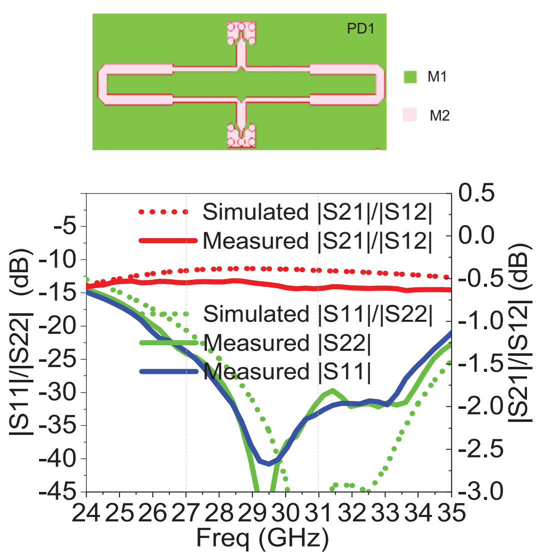
The characterization of Microstrip Lines (MSL) and Power Dividers (PD) are important as building circuits for AiP array. As shown in Fig. 4 (a), for the 1-mm long MSL with testing pads, the measurement agrees well with modeling and shows Return Loss (RL) > 25dB and Insertion Loss (IL) <0.3dB over 27-31GHz. The back-to-back testing circuit is designed for PD characterization. As shown in Fig. 4 (b) and (c), for the PDs the measurement agrees well with modeling and shows RL>15 dB and IL<0.7dB over 27-31GHz. The performance consistency of samples at different reticles P1, P2, and P3 (Fig. 1) measured remains reasonably well which shows the process fabrication stability.

Fig. 5 shows the layout and performance of the dual-polarized AiP element. The AiP element features a power divider format RDL feeding to the top meta-surface radiator through the ground apertures. With two sets of such feedings in an orthogonal configuration, the Horizontal and Vertical dual-polarized radiations are produced [4]. It is noted that the meta-surface design releases the 300µm fabrication limitation of the top mold thickness and effectively helps to achieve wide bandwidth. The 6mm×6mm×0.384mm AiP element shows a measured RL of >11.5dB that meets the target of >10dB, Isolation >19.8dB that is close to the target of >20dB over 27-31GHz, a measured Gain of 5.1-6.8dBi over 27-31GHz and 6dBi @ 30GHz, and pure V and H dual polarizations with very small cross-polarization components.

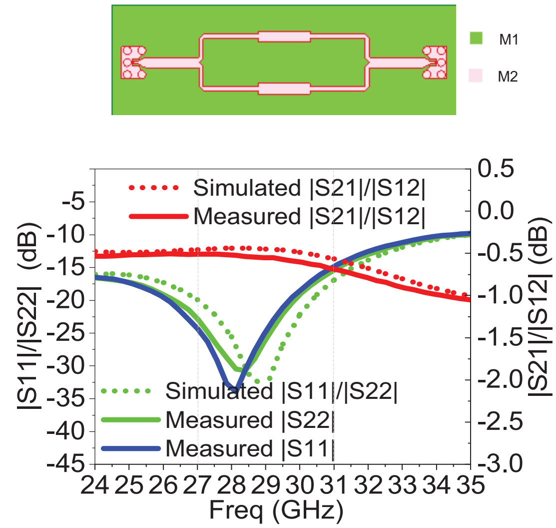
Fig. 6 shows the layout and performance of the AiP array. Here, power dividers as shown in Fig. 4 are used to excite four V-polarized elements thus forming a 2×2 AiP array with V polarizations. The 12mm×12mm×0.384mm AiP 2×2 array achieves a measured RL of >9dB, a measure Gain of 8.1-10.8dBi over 27-31GHz and 10.2dBi @ 30GHz, and pure V polarizations with very small cross-polarization components.




(a)

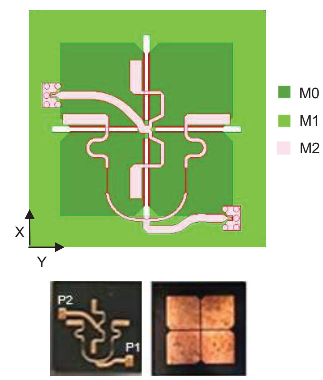



(b)

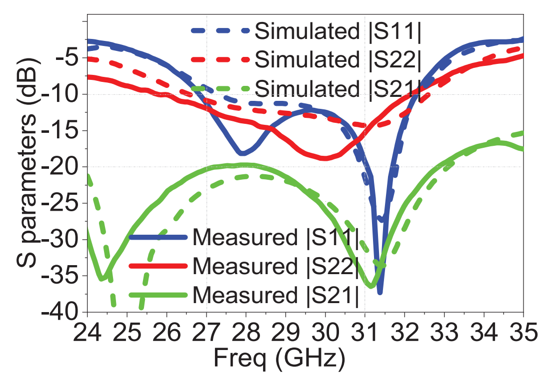



(c)

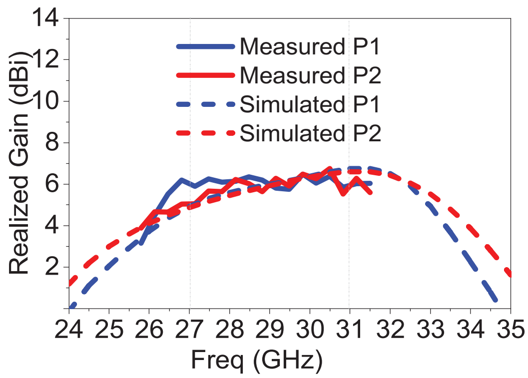
Fig. 4. Performance of microstrip line and power dividers as used in the AiP array.



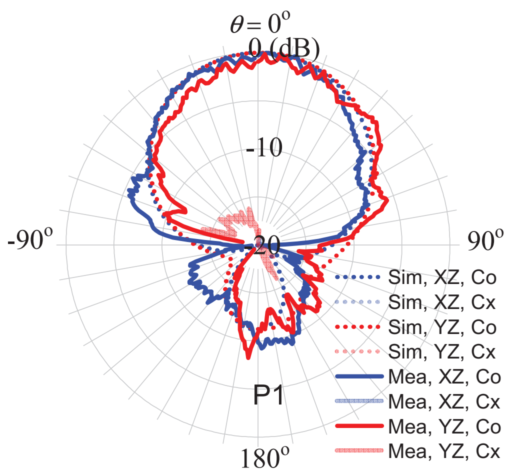

(a)



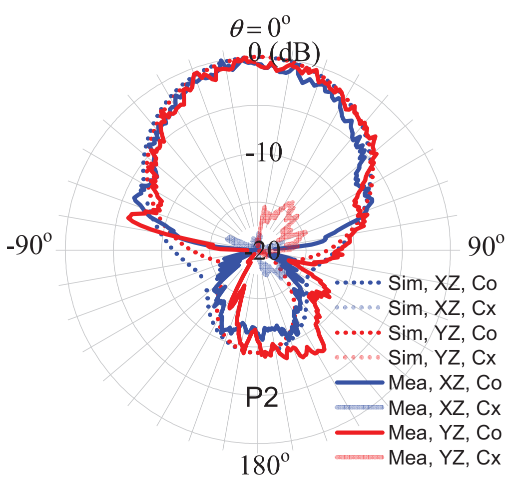

(b)




(c)

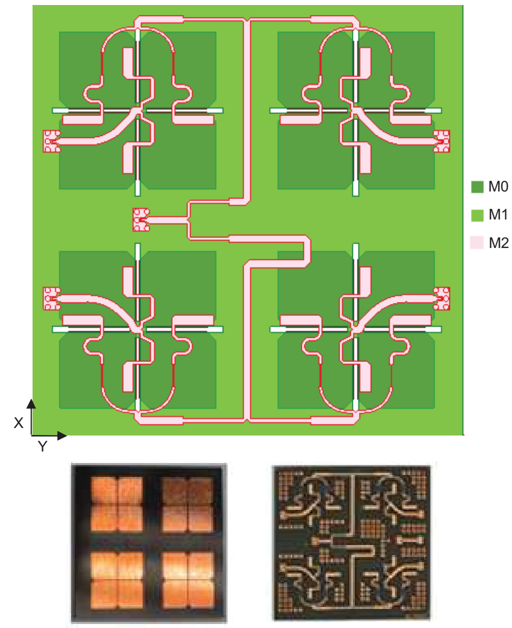



(d)

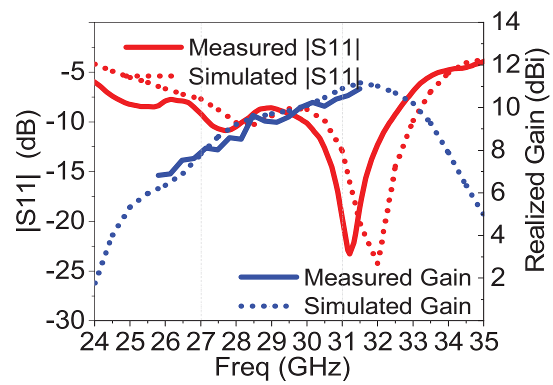



(e)

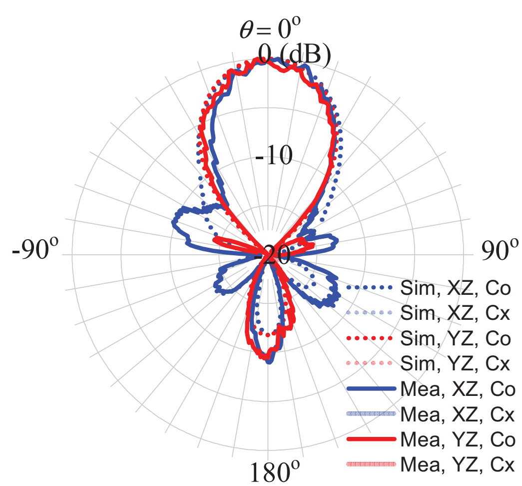
Fig. 5. AiP element layout (a) and performance in terms of: (b) S-parameters, (c) Gain, (d) and (e) patterns.




(a)




(b)




(c)

Fig. 6. AiP array layout (a) and performance in terms of: (b) |S11| & Gain, and (c) patterns.

Table 1 lists measured cross-sectional thickness dimensions. Fig. 7 shows captured dimensions of one fabricated AiP sample. It is also found from the poststimulation that layer thickness variations as measured has insignificant effects on the AiP performance.

Table 1. Cross-sectional Thickness (in µm)

| | Design | Test1 | Test2 |
|---|---|---|---|
| EMC2 | 257 | 257.38 | 255.71 |
| EMC1 | 90 | 94.07 | 89.38 |
| M2 | 15 | 14.53 | 14 |
| M1 | 10 | 8.35 | 7.36 |
| M0 | 10 | 5.37 | 7.01 |

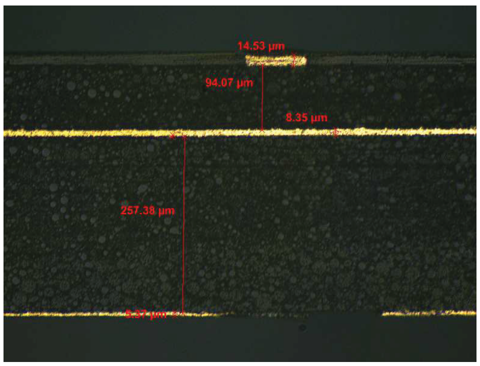


Fig. 7. Measured cross-sectional dimensions.

## Conclusions

This paper presents the characterization of FOWLP AiPs in terms of S parameters, Gain, and patterns as well as its building circuits of microstrip line and power dividers at 27-31GHz. The characterization as compared with the simulation presented in this paper is an important study to realize a compact FOWLP AiP solution thus enabling the highly integrated Ka-band phased array module, which will find wide applications for SOTM or 5G beam steering applications.

## Acknowledgments

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