Wideband Circularly Polarized FOWLP Antenna in Package for Satellite Communications

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***Abstract* — This paper presents a wideband circularly-polarized Antenna-in-Package (AiP) element implemented in Fan-Out Wafer-Level-Packaging (FOWLP) technology for satellite communication. The AiP element features a meta-surface radiator with a single-ended aperture coupled feeding structure to achieve a wideband and circular polarization performance. By stacking a top mold of 500µm, a middle mold of 90µm and a 42µm RDL layer at the bottom, with a size of 10 mm×10 mm×0.652 mm, the AiP element achieves a Return Loss >17.95 dB, an Axial Ratio < 2.67 dB, and a Gain of 7.19-7.88 dBi over 27-31 GHz. The antenna design concept is further confirmed using printed circuit board (PCB) technology for fast prototyping and evaluation.**

Keywords—circularly polarized antenna, wideband antenna, FOWLP, Wafer Level Packaging, SOTM, Antenna-in-Package, Meta-surface

I. Introduction

Satellite communication (SATCOM) systems are a key stepping stone in achieving a globally integrated communication network that provides network coverage spanning land, sea, and sky [1]. It allows users to connect to the network, whether on land, sky, or sea, ensuring uninterrupted internet connectivity. The antenna is crucial in establishing a reliable telecommunication link between the user equipment and a satellite-on-the-move (SOTM) communication system. A Circular Polarized (CP) antenna can reduce polarization mismatch loss between a transmitter and receiver making it desirable for a satellite communication system.

This paper targets using Fan-Out Wafer-Level-Packaging (FOWLP) technology to realize a compact wideband single-end CP antenna for Satellite communications at 27-31GHz. As shown in Fig. 1 the Mold-on-Mold (EMC1 and EMC2) FOWLP is used. It directly molds the bare die inside the package with the antenna fabricating on top of the package leading to a compact Antenna in Package (AiP) solution. As a follow-up of previously reported AiPs for SOTM [2, 3], 5G [4], and 77GHz car radar [5,6] applications, this study enriches the FOWLP AiP design knowledge for Satellite communications by differentiating with a single-port wide band CP design. The Axial Ratio bandwidth is optimized to cover 27-31GHz. The patterns are also plotted with Right Hand CP demonstrated. In addition, the antenna design concept is further confirmed using PCB technology for fast prototyping and evaluation.

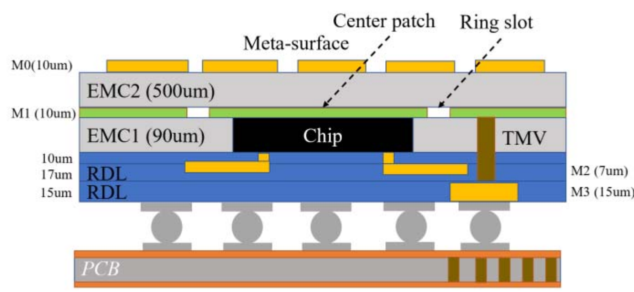


Fig. 1. FOWLP AiP cross-section.

II. FOWLP AiP Design

A. FOWLP AiP element design

As shown in Fig. 2 (a), the AiP element uses a meta-surface radiator on M0, providing a wide bandwidth and stable radiation pattern. As shown in Fig. 2 (b), the element uses a single-end feeding topology on M2 with a T-shape structure to act as both an impedance transformer and circular polarizer. This feeding structure couples its energy to the meta-surface radiator (M0) through a ground-etched ring slot (M1) with two rotated perturbation notches slanting at 45 degrees and 135 degrees away from the asymmetric feeding structure. As a result, the off-center feed T-shape impedance transformer and the ground etched ring slot produce a wideband circularly polarized excitation. It is also noted that the AiP features wideband performance without using an air gap or cavity, making it suitable for mass production.

The antenna design was carried out using ANSYS HFSS full-wave simulation software. The molding compounds (EMC1 and EMC2) as in Fig. 1 have a dielectric constant of 3.4 and a loss tangent of 0.005. The redistribution layer (RDL) has a dielectric constant of 2.7 and a loss tangent of 0.0075. Copper is used for all metal layers (M1, M2, and M3).

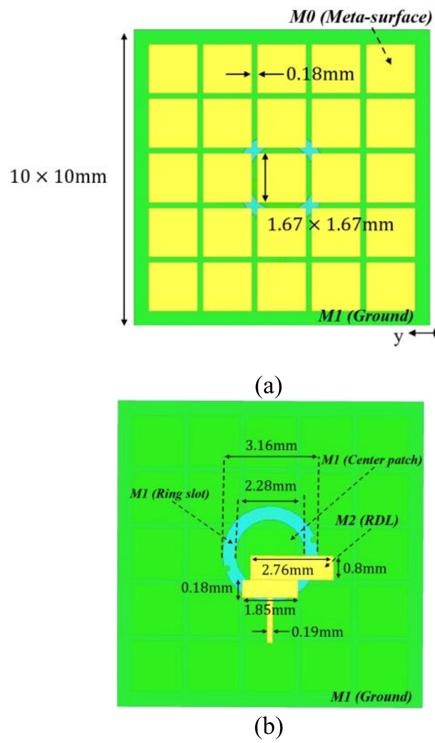


Fig. 2. FOWLP AiP element: (a) front view and (b) bottom view.

B. FOWLP AiP surface current analysis

To reveal the CP working mechanism, Fig. 3 shows the simulated surface current distributions observed in the +*z*-direction of the proposed CP AiP element at different times *t*=0, *T/4*, *T/2*, and *3T/4*, where *T* denotes the period of oscillation at 29 GHz. Note that *Jo* represents the vector sum of all major current contributions. As seen from the figure, the vector sum *Jo* rotates anticlockwise as the time *t* increases; thus, the RHCP is generated in the +*z*-direction.

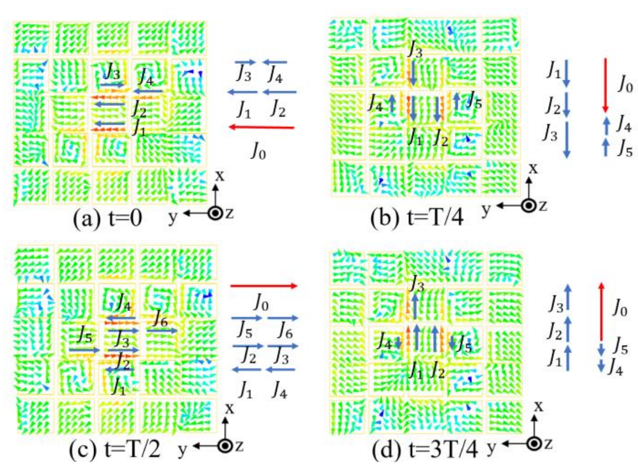


Fig. 3. Simulated surface current distributions with period *T* at 29 GHz: (a) *t=0*, (b) *t=T/4*, (c) *t=T/2*, and (d) *t=3T/4.*

C. FOWLP AiP element performance

The simulation results in Fig. 4. show that the antenna has a minimum Return Loss of 17.95 dB and a maximum Axial Ratio of 2.67 dB from 27 to 31 GHz. In addition, it has a realized Gain of 7.19 to 7.88 dBi from 27 to 31 GHz. The radiation pattern plots show the right-hand circular polarizations in Fig. 5 with small left-hand polarization components. The single-fed wide band CP FOWLP AiP is thus demonstrated to cover 27-31GHz with desirable patterns.

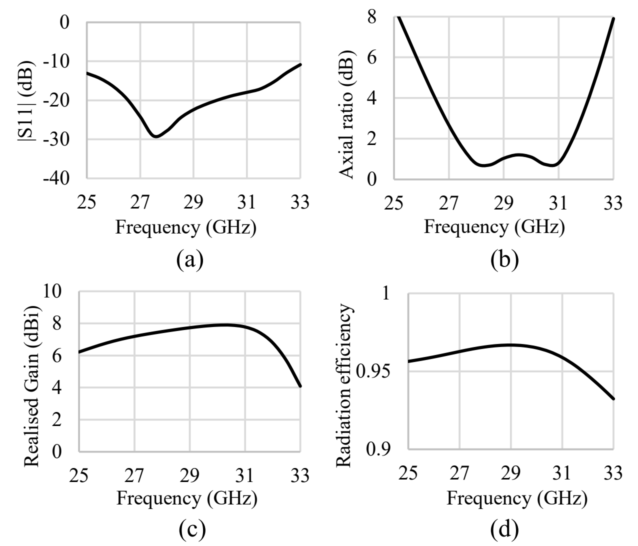
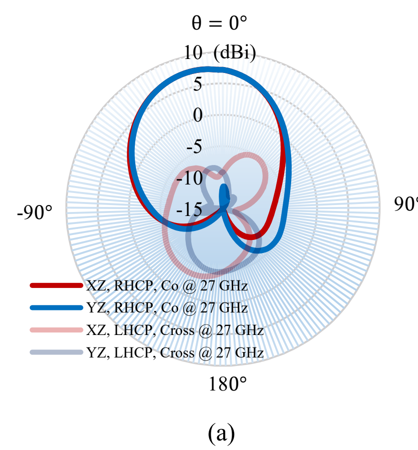
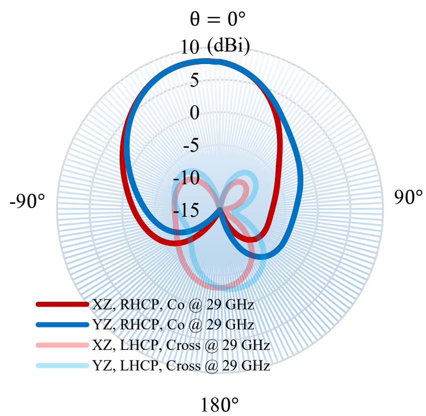


Fig. 4. Simulated performance of the FOWLP AiP element: (a) |S11|, (b) Axial ratio, (c) Gain, and (d) Radiation efficiency.





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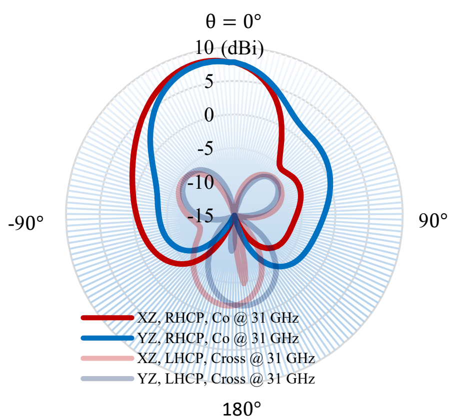

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Fig. 5. Radiation patterns of the FOWLP AiP at 27 GHz, 29 GHz, and 31 GHz, respectively.

III. PROOF-OF-CONCEPT PCB PROTOTYPE DESIGN

To prove the wideband CP antenna concept used for FOWLP AiP, PCB prototypes are designed for fast fabrication and quick evaluation. Fig. 6 shows the PCB prototype cross-section. RO4003 and RO4450 are used to replace EMC2, EMC1, and RDL layers in the stack-up, where RO4450 with a dielectric constant of 3.52 and a loss tangent of 0.004 is used as an adhesive layer to bond RO4003 and M1 copper.

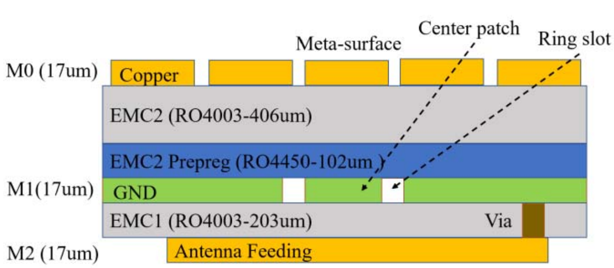
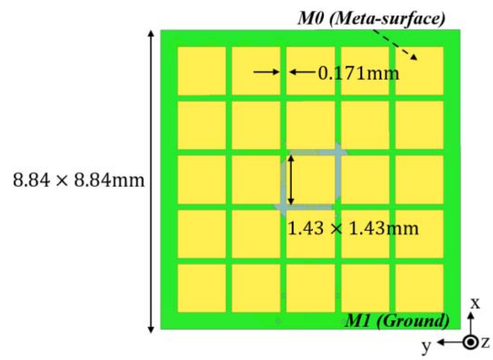


Fig. 6. PCB prototype cross-section.

A. Prototype Design A: for GSG probe test

Fig. 7 shows the front and back views of prototype Design A. The port transition enables the prototype to be tested using a Ground-Signal-Ground (GSG) probe with a 250µm pitch.

The simulation results in Fig. 8. show that the antenna has a minimum Return Loss of 16.15 dB and a maximum Axial Ratio of 2.54 dB from 27 to 31 GHz. In addition, it has a realized Gain of 7.07 to 7.34 dBi from 27 to 31 GHz. Fig. 9 shows the right-hand circular polarization patterns over a wide frequency. The single-ended wideband CP PCB prototype is thus demonstrated to cover 27-31GHz with desirable patterns.



(a)

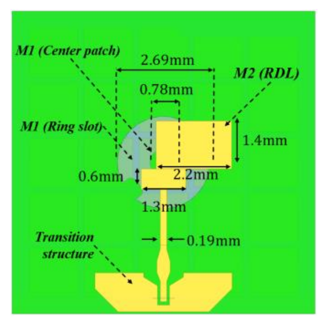


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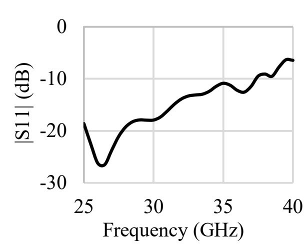
Fig. 7. PCB prototype design A: (a) front view and (b) bottom view.



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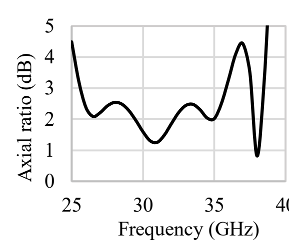

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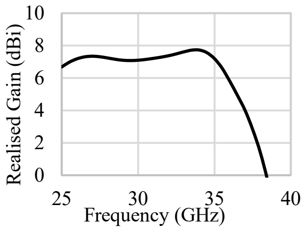

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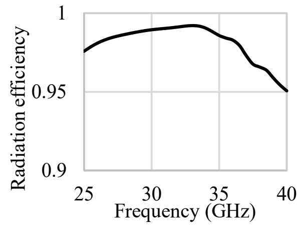

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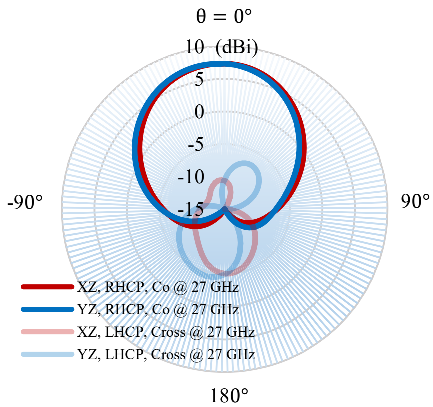
Fig. 8. Simulated performance of PCB prototype design A: (a) |S11|, (b) Axial ratio, (c) Gain, and (d) Radiation efficiency.



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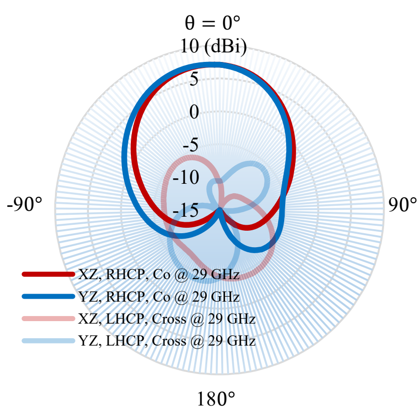

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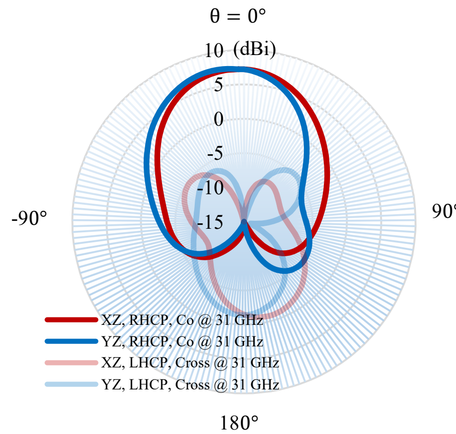
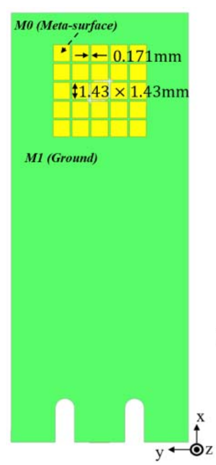


(c)

Fig. 9. Radiation patterns of PCB prototype design A at 27 GHz, 29 GHz, and 31 GHz, respectively.

B. *Prototype Design B: for RF end-launch connector test*

Fig. 10 shows the front and back views of prototype Design B. The port transition enables the antenna to be tested using an RF end-launch connector. The simulation results in Fig. 11. show that the antenna has a minimum Return Loss of 11.96 dB and a maximum Axial Ratio of 2.55 dB from 27 to 37 GHz. In addition, it has a realized Gain of 5.79 to 6.19 dBi from 27 to 37 GHz. Fig. 12 shows the right-hand circular polarization patterns. The wideband CP performance is thus confirmed.



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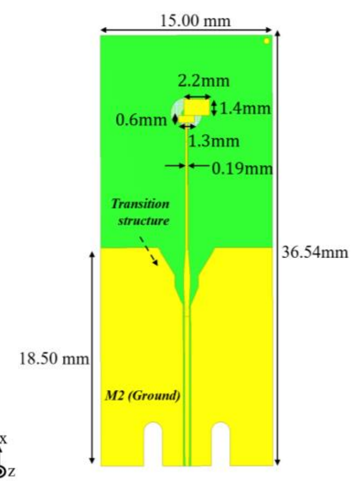

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Fig. 10. PCB prototype design B: (a) front view and (b) bottom view.

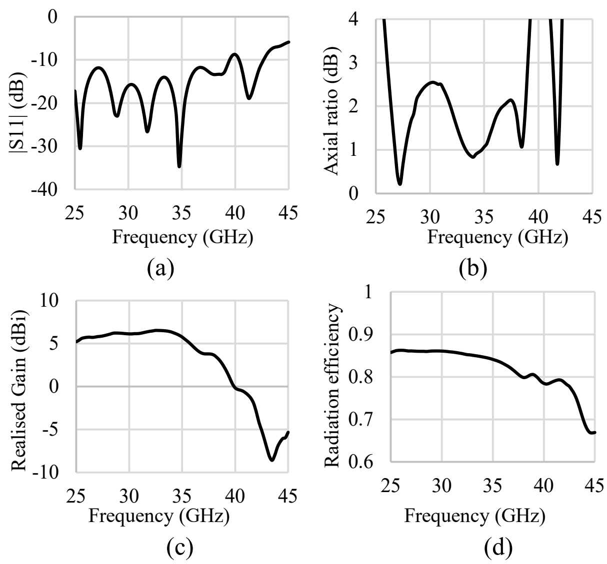
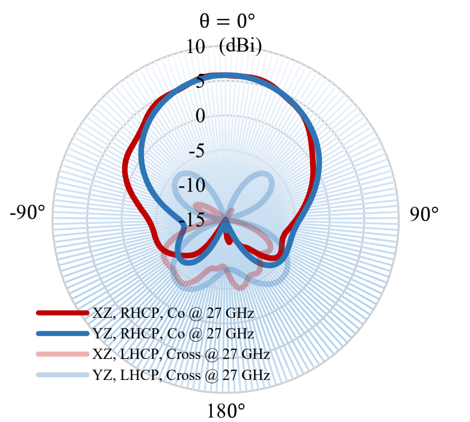


Fig. 11. Simulated performance of PCB prototype design B: (a) |S11|, (b) Axial ratio, (c) Gain, and (d) Radiation efficiency.



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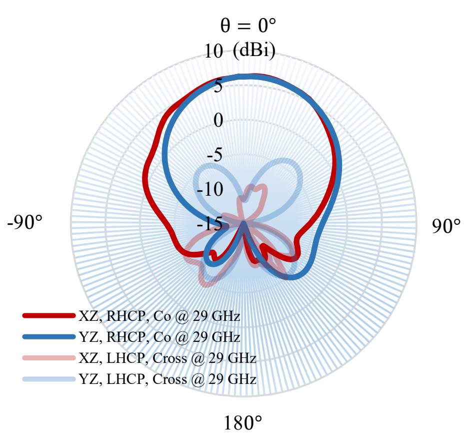

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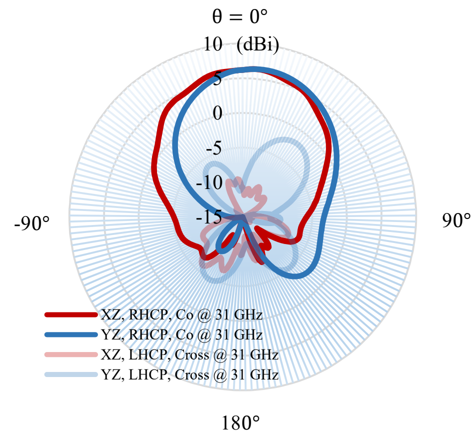

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Fig. 12. Radiation patterns of PCB prototype design B at 27 GHz, 29 GHz, and 31 GHz, respectively.

IV. Conclusion

This paper presented a wideband circular polarized FOWLP AiP based on double mold FOWLP topology. It features a meta-surface radiator with a compact aperture coupled feeding structure. The FOWLP AiP element achieves a Return Loss > 17.95 dB, an Axial Ratio < 2.67 dB, and a Gain of 7.19-7.88 dBi over 27-31 GHz. The proof-of-concept PCB prototypes were also designed and the wide impedance and axial ratio bandwidth as well as desirable CP patterns were confirmed.

TABLE I lists a comparison of the minimum feature size between the PCB and FOWLP AiP design. It is to note that PCB fabrication has more feature size and tolerance limitations as well as a lamination layer subjected to 10% thickness compression due to the fabrication process. In our design, the prototypes have met all dimension and feature size requirements while taking compression effect.

TABLE I. AiP Design and Feature Size Comparison

Dimension	Antenna-in-Package Designs	
	PCB	***FOWLP***
Meta-surface gap width	0.18mm	0.18mm
Aperture slot width	1.34mm	0.44mm
Notch width	0.9mm	0.176mm

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