Quasi-Isotropic Antenna-in-Package with a Shielded Core and Wide Circular Polarization Coverage

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***Abstract*—Given the dynamic nature of the Internet of Things (IoT) scenarios, peripheral devices' radiation patterns must cover large areas to avoid disconnection in case of change of orientation relative to the base station. This broad coverage should be for both the power radiated as well as for the polarization of the electromagnetic wave, increasing the probabilities of a sturdy link between peripheral devices and the base stations. Current devices implement simple omnidirectional antennas that are linearly polarized and can be easily detuned due to the proximity of the electronics. This paper proposes an Antenna-in-Package design based on a microstrip patch volumetric array. The system consists of six circular patch antenna elements with perturbation segments. The patches work on the 2.4 GHz ISM band. Each element is placed on one face of a 3D hollow cube, and the internal walls are covered in metal, acting as a shielded core for the embedded electronics and ground for the patch elements. The design simultaneously demonstrates a 7 dB gain variation in 95% of the 3D sphere and a circular polarization coverage in 84%.**

Index Terms—Volumetric array, Antenna-in-Package, core shielding, circular polarization, quasi-isotropic antenna.

I. Introduction

The diversity of scenarios in the Internet of things (IoT) require sturdy antenna designs that are cheap to manufacture in large numbers and highly integrated with the rest of the device for space optimization. Accordingly, the Antenna- in-Package (AiP) concept proposes that the package used to contain electronics and batteries can double as the substrate for the radiating element of wireless devices. When combined with additive manufacturing techniques, AiP designs can be mass-produced at a very low cost. Nevertheless, this integration presents challenges for designers as proximity to electronics interferes with the radiating structures [1]. To overcome this, approaches for core shielding like that in [2] become highly relevant.

On the other hand, given the multi-path nature of indoor environments, circularly polarized (CP) radiation increases the resilience of the AiP to communicate with the base station. Efforts to achieve broad CP radiation are limited by the generation of deep nulls in the gain patter [3]- [4]. Thus, omnidirectional CP antennas have been proposed as a tradeoff of isotropy and polarization coverage [5]- [7]. Nevertheless, none of the reviewed works tackles a complete rounded solution of comprehensive power gain coverage, simultaneous CP radiation and, a full shielded core that protects from detuning effects.

Thus, this paper proposes an AiP with high resilience to package contents change while keeping a quasi-isotropic radiation pattern and broad CP coverage on the whole 3D sphere. For this, a cubic AiP with six microstrip patches, one in each face of the cube, and a shielded hollow core is designed. Full electromagnetic wave simulations were carried out in Ansys HFSS to find the excitation conditions that will yield CP and quasi-isotropy radiation at the same time in the largest possible portion of the far-field sphere. The obtained simulation results vow for this design to work as a platform AiP in common IoT scenarios.

II. Circularly polarized AiP configuration

The proposed AiP is the result of optimizing the design presented in [2].Different from it, this new design exhibits right-hand CP in a wide portion of the far-field sphere. As shown in Fig.1, this design consists of six antenna elements, one in each face of a hollow cube.

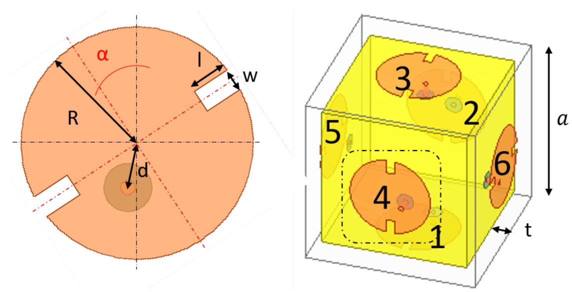

Fig. 1. Proposed radiating structure and radiating element with dimensions.

The system is designed to be compatible with additive manufacturing techniques (a combination of 3D and screen printing). That is why ABS filament from Premix is selected as a dielectric material. The filament properties from the manufacturer are given as $\epsilon_r = 5.4$ and $tan\delta = 0.0039$ [8]. However, when this material is 3D printed, the properties in the form of a substrate are different due to the small air pockets that remain in the structure. Measured properties of a printed sample resulted in $\epsilon_r = 4.8$ and $tan\delta = 0.008$, values taken into account for the design presented here. The cube has a side length of $a = 62.4\ mm$, thickness of $t = 4.5\ mm$, and is coated on the inside with metal that acts as the ground for the antenna elements and shielded core for the package contents (electronics, batteries, and sensors). The radiating elements are circular microstrip patch antennas with perturbation segments

[9]. After optimizing for impedance matching an CP when in the small volumetric structure, the patch dimension is $R = 14.5\ mm$ with an off-center feed pin at $d = 5.6\ mm$, and the perturbation is $l = 10\ mm\ w =\ 3mm$. The tilting angle α is referenced normal to each face.

As each microstrip patch element has its independent activation port, simulations were carried out to find the conditions that will simultaneously maximize quasi-isotropic and CP coverage.

III. Simulated volumetric array performance

Both quasi-isotropic and CP coverage percentages are based on [4]. For quasi-isotropy it represents the portion of the 3D sphere with Gain $>$ MaxGain $-$ 7 dB as the limit set on [10], and for CP, it represents the portion of the 3D sphere with $1/mag(AR) > \frac{1}{\sqrt{2}}\ (AR < 3\ dB)$.

In the first approach, the radiators were kept with no tilting on each face ($\alpha = 0°$). Elements 1 to 4 are kept in phase while elements 5 and 6 are excited with $65°$, the optimum conditions found in [2]. This setup resulted in a quasi-isotropic coverage of 94.5%. Simultaneously, due to the change on radiators to CP patches, the resulting CP coverage is $79.82\ \%$.

Based on this result, both the phase and tilt angles for the six elements were studied with HFSS sequential nonlinear programming optimizer. The best combination in terms of quasi-isotropic and CP coverage is shown in Fig.2(a). In this case, elements 1 to 4 are excited in phase but not tilted; element 5 is tilted $45°$ with a phase of $30°$ and, element 6 is tilted $-45°$ with a phase of $250°$. The resulting coverage percentages are 94.88% and 83.65% for quasi-isotropy and CP, respectively.

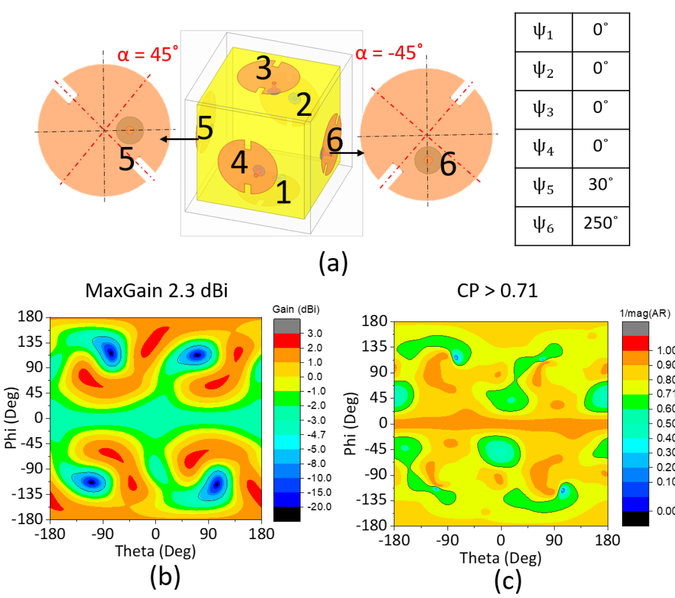

Fig. 2. Structure with optimized orientation and phases. (a) Structure geometry and phases applied to each element. (b) Gain pattern contour for the 3D sphere, values higher than -4.7 dBi obey the 7 dB isotropy condition of [4]. (c) CP contour, values higher than 0.71 are circularly polarized.

As summarized in Table I, this design shows the largest CP coverage while compromising less than 5% of the sphere into nulls.

TABLE I
Comparison of simulated 3D CP and isotropy coverage

Reference	Isotropic Coverage (%)	CP Coverage (%)	Shielded Core
[4]	92	22	NO
[2]	100	0	YES
This work	95	84	YES

IV. Conclusion

This paper proposed an AiP compatible with IoT protocols and additive manufacturing techniques. By combining the radiation of six microstrip patches, the volumetric array can radiate quasi-isotropically with broad CP coverage, as shown by full EM simulations. Besides that, the proposed design shows good resilience to package contents by avoiding detuning of the radiating elements due to its fully shielded core. This characteristic makes the design highly suitable for varied IoT scenarios where electronics or sensors are changed depending on the applications. This design can then be implemented as an AiP platform for different wireless devices without redesigning the radiating element.

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