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# Dual-Band Circularly Polarized Micro-Array Synthesis Using Spherical Wave Expansion

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**Abstract**—This paper presents the design of a compact dual-band Right-Hand Circularly Polarized (RHCP) antenna for Global Navigation Satellite Systems (GNSS) applications. The design is based on two concentric parasitic micro ( $\mu$ )-arrays; each formed by three Inverted F-Antennas (IFA). For each  $\mu$ -array, only one IFA is driven, while the other elements are loaded with optimized parasitic loads. The parasitic load values are optimized using a Spherical Wave Expansion (SWE) approach. The proposed antenna configuration covers the GPS-L2 (1215 MHz - 1237 MHz), GPS-L1 (1563 MHz - 1587 MHz), and the GALILEO-E1 (1559 MHz - 1591 MHz) bands.

## I. INTRODUCTION

Circularly Polarized (CP) antennas have become necessary in a vast variety of wireless modules, especially after the advancement in the development and installation of GNSS constellations and services [1]. However, the increasing exigency of wireless devices implies the need for more compact, low-profile, lightweight, and low-cost antennas that could be easily integrated into a given module. Moreover, to enhance the navigation system performance, multiband antenna operation is required. This allows the simultaneous processing of signals emitted at different bands in order to provide a robust and extremely accurate localization.

Various multiband GNSS antenna designs have been reported in the literature [2-3]. However, the proposed configurations do not simultaneously satisfy the antenna requirement in terms of size, cost, and design complexity. In addition, the aforementioned designs incorporate a single RF access for the multiband operation. This implies the need for a duplexer in the RF front-end, which introduces additional losses to the system. This issue could be avoided by introducing multiple RF ports corresponding to the number of used bands, and their dedicated filtering and amplification radiofrequency chains.

This paper proposes the design of a dual-band dual-port GNSS antenna covering the GPS-L2 and the GALILEO-E1 (including the GPS-L1) bands. The dual-band performance is achieved using two co-localized  $\mu$ -arrays arranged in a concentric configuration. Each  $\mu$ -array is formed of 3-IFA antennas, where one element is driven and the others are terminated with parasitic loads. The parasitic load values are calculated based on a Spherical Wave Expansion (SWE) approach [4] to construct the radiation in shape and polarization. The pattern synthesis approach of the CP radiation is described in Section II. This approach is validated in Section III, where a

dual-band dual-port RHCP antenna is presented. Finally, conclusions and future perspectives are discussed in Section IV.

## II. CIRCULARLY POLARIZED PATTERN SYNTHESIS

In order to realize the CP radiation, two orthogonal modes with ideally equal magnitudes and  $90^\circ$  phase shift should be excited. From an SWE point of view, an ideal CP radiation could be achieved by combining the  $TE_{-11}$  and the  $TM_{-11}$  modes with equal magnitudes and a  $180^\circ$  phase shift [2]. This combination yields an ideal CP radiation with null cross-polarization levels (Axial Ratio,  $AR=0\text{dB}$ ).

Using the SWE, the synthesis of a CP radiation have been demonstrated in [4] for a single band  $\mu$ -array. The approach is based on defining a suitable objective function ( $Q_{smn}^{obj}$ ) which is shown in Figure 1. In order to relax the optimization problem, a slight contribution of higher-order modes is introduced in the objective function. This results in an increased Left Hand Circular polarization (LHCP) component, while however maintaining the desired CP radiation.

After defining the objective function, the optimized excitation coefficients  $\alpha_p$  are calculated based on (1). Consequently, the parasitic loads are calculated based on the scattering parameters of the array [5].

$$Q_{smn}^{obj} = \sum_{p=1}^P \alpha_p Q_{smnp} \quad (1)$$

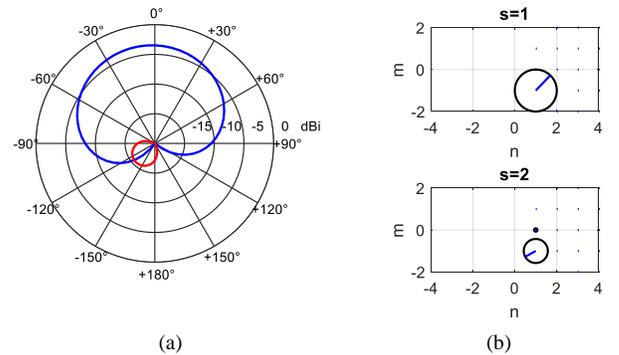


Figure 1. Objective function. (a) Radiation pattern, (b) spherical wave coefficients.

## III. DUAL-BAND PARASITIC $\mu$ -ARRAY

The geometry of the proposed antenna is shown in Figure 2. The antenna is composed of 2  $\mu$ -arrays occupying a cylindrical

circumference. The  $\mu$ -arrays are co-located in a concentric configuration, where the high-band (Ant\_L1)  $\mu$ -array is surrounded by the elements of the low-band (Ant\_L2)  $\mu$ -array. Each  $\mu$ -array is composed of 3-IFA elements with one driven component while loads are connected to the other parasitic elements. Ant\_L1 occupies a radius ( $R_1=15$  mm,  $\lambda_0/12.8$ ) while Ant\_L2 occupies a radius ( $R_2=22.5$  mm,  $\lambda_0/11$ ). In order to reduce the mutual coupling between Ant\_L1 and Ant\_L2, the IFAs of the Ant\_L2 are rotated  $60^\circ$  with respect to Ant\_L1. This configuration was found by carrying out a parametric study combining electromagnetic simulation and SWE optimizations in order to analyze the impact of the IFA positions on the radiation pattern of the  $\mu$ -arrays.

The optimized parasitic loads of Ant\_L1 and Ant\_L2 are given in Table 1. The optimization process is realized in two steps. In the first step, the parasitic loads of the external antenna (Ant\_L2) are optimized, while the ports of Ant\_L1 are terminated by 50 Ohm loads. Similarly, the parasitic loads of Ant\_L2 are calculated using the same objective function while the ports of Ant\_L2 are terminated with 50 Ohm loads. Finally, all the parasitic loads are integrated in the 3D model with ports 1 and 2 connected to the driven IFAs of Ant\_L1 and Ant\_L2 respectively. Ant\_L1 exhibits a 43% radiation efficiency with the given loading configuration at the central frequency of 1.575 GHz. On the other hand, Ant\_L2 exhibits a 95% radiation efficiency at the central frequency 1.215 GHz. The reduced radiation efficiency of Ant\_L1 is due to the presence of resistive parasitic loads, contrary to Ant\_L2 where only reactive loads are needed to realize the desired circular polarization.

The radiation performance of the proposed  $\mu$ -array is given in Figure 3. In the GPS-L2 band, Ant\_L2 exhibits a 4 dBic Gain and a low AR at the central frequency in the broadside direction. However, the AR increased at the extremity of the band. This is due to the high sensitivity of the compact  $\mu$ -array. On the other hand, Ant\_L1 exhibits a lower Gain in the broadside direction (1dBic), which is due to its reduced radiation efficiency. However, the AR maintains low levels over the GALILEO-E1 band.

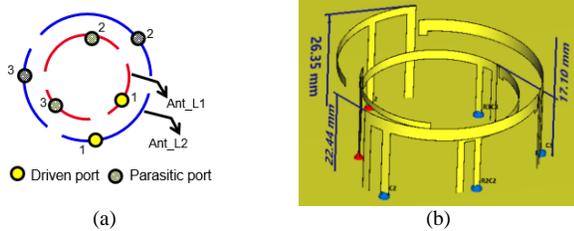


Figure 2. Geometry of the proposed dual-band  $\mu$ -array. (a) Top View illustration, (b) model 3D view.

Table 1 Optimized parasitic loads

Parasitic port	R [Ohm]	C [pF]
Ant_L1: IFA_2	3.7	2.72
Ant_L1: IFA_3	5.9	2.37
Ant_L2: IFA_2	0	3.9
Ant_L2: IFA_3	0	2.55

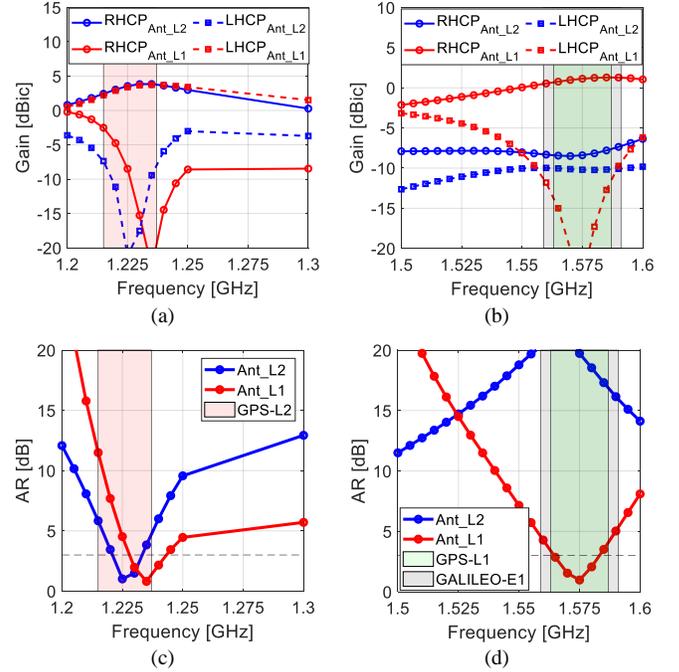


Figure 3. Radiation performance of the  $\mu$ -array. (a) IEEE-Gain in the broadside direction (GPS-L2 band), (b) IEEE-Gain in the broadside direction (GALILEO-E1), (c) axial ratio in the broadside direction (GPS-L2 band), (d) axial ratio in the broadside direction (GALILEO-E1).

#### IV. CONCLUSION

A compact dual-band dual-port RHCP antenna is proposed in this paper. The design is composed of two  $\mu$ -arrays formed of circularly shaped IFAs. The  $\mu$ -arrays are placed in a concentric configuration where the outer  $\mu$ -array operates in the low-band (GPS-L2) and the inner  $\mu$ -array operates in the upper band. For each  $\mu$ -array, only one IFA is driven while the other antennas are terminated with parasitic loads. These loads are optimized using an SWE synthesis technique by properly choosing the objective function. The simulation results show promising dual band CP performance with a compact dual port antenna structure easy to fabricate and to connect to multiband GNSS receiver.

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