A New Approach to Design High Directivity, Compact Omnidirectional CP Antenna Arrays

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***Abstract*— A new approach to design high directivty, compact omnidirectional circularly polarized (OCP) antenna arrays is presented in this paper. An array of collinear electric (*E*-) and magnetic (*M*-) radiators is realized by simply cascading copper loops and vertical strips to form an electrically long antenna structure. This array has two identical half sections that is excited in its center. The circumference of each loop and the length of each vertical strip are about a half-wavelength. The configuration facilitates the currents on all of the loop and the strip radiators to achieve the same phase and, hence, the array is a set of in-phase *E*- and *M*-radiators. Due to the fact that the phases of the magnetic radiator currents are 90° ahead of the electric ones, the 90° phase difference between the two subsets of radiators required to achieve OCP radiation is realized. An optimized prototype was fabricated and measured. The whole structure is compact and easily fabricated. It covers a 130 MHz bandwidth from 2.34 to 2.47 GHz and produces OCP radiation. The peak measured LHCP realized gain for the four-stage version is 5.1 dBic.**

***Index Terms*—Antenna array, circular polarization, electric radiators, high directivity, magnetic radiators, omnidirectional.**

I. Introduction

Omnidirectional circularly polarized (OCP) antennas have drawn much attention in recent years due to their large radiation coverage and their capacity of avoiding polarization mismatch problems. This is particularly true for Device-to-Device (D2D) communication systems [1] – [3]. The essential idea to realize OCP radiation is to excite a pair of parallel electric and magnetic radiators with equal magnitude and a 90° phase difference. This approach has been widely investigated and well implemented in many research works. Some OCP antenna examples are found in [4] – [6]. However, it is very challenging to realize high directivity OCP radiation from a compact structure. Only two designs have been reported to date [7], [8] that realize OCP directivity with values larger than 5 dBic. Nevertheless, they suffer from being complex structures that are bulky in size, which limits their use in practical applications.

In this paper, a new approach is introduced that realizes a collinear array of *E*- and *M*-radiators in a compact antenna structure with a simple feed. Its fabrication is easy and has a low cost. A four-stage array was prototyped and the predicted high directivity OCP radiation was confirmed. The antenna array system is highly efficient. The measured radiation efficiency is larger than 88% across its operating bandwidth. The measured peak gain was 5.1 dBic. This peak value has been further increased by cascading more stages. These experimental results are in agreement with their simulated values, thus verifying the new design approach.

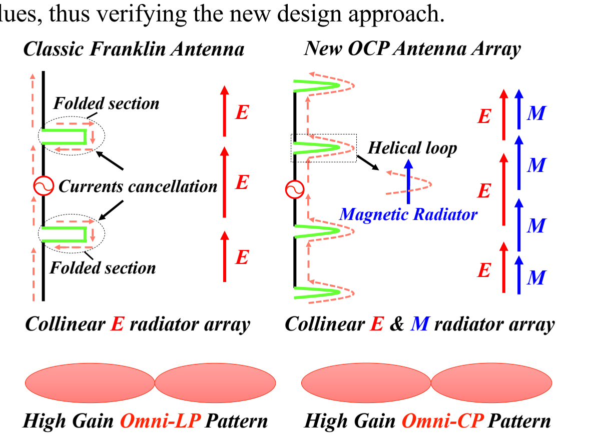

Fig. 1. Representation of the new approach to realize an omnidirectional CP antenna array.

II. Design Approach and Realization

The design is illustrated in Fig. 1. It was inspired by the classic Franklin antenna [9]. A Franklin antenna consists of an electrically long array of collinear electric radiators. Folded stubs, whose currents cancel out, are introduced at out-of-phase points to make those elements radiate in-phase. Thus, high directivity omnidirectional LP radiation is obtained. In the newly developed approach, the currents at the out-of-phase points are successfully utilized to drive magnetic radiators formed by twisting each half wavelength out-of-phase section into a loop structure. By simply cascading several half wavelength straight and loop radiators around a center axis, an array of collinear *E*- and *M*-radiators are realized that generate high directivity OCP radiation.

A four-stage design was implemented in the compact volume structure shown in Fig. 2. Three vertical electric radiators are realized by the half-wavelength copper strips (Strips#1 to #3). Four magnetic radiators are realized by the copper loops (Loop#1 to #4). Each loop radiator is formed by simply folding an annular copper sheet twice in the middle. Collinear *E*- and *M*-radiators are realized when the entire structure is differentially excited in the center. The dimensions of the vertical strips and the folded loops are: l_s = 66 mm; w_s = 3 mm; w_l = 9.6 mm; h = 4 mm; r = 9 mm. It should be noted that the dimensions of the folded loops are critical to achieving the OCP radiation performance. In addition, the orientation of two middle loops is intentionally rotated 180° respect to the loops at the two ends. A comprehensive analysis of the OCP array is found in [10].

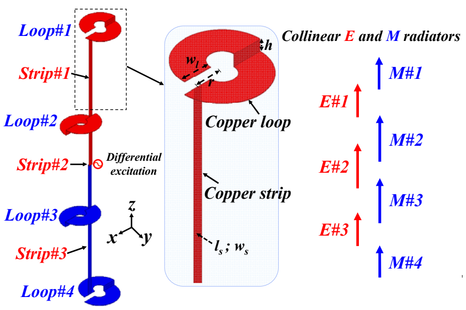

Fig. 2. Realization of the OCP antenna array.

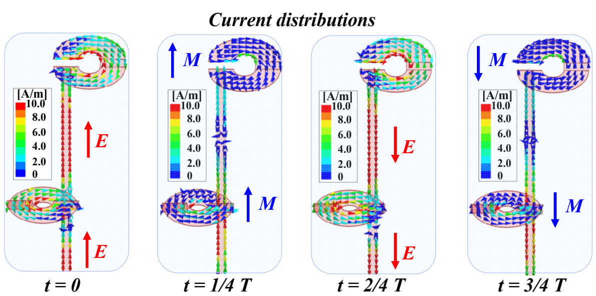

Fig. 3. Current distributions on the OCP structure over one time period.

The current distributions on the upper half of the array are shown in Fig. 3 over one time period. They clearly demonstrate the realization of the collinear *E*- and *M*-radiators. At t = 0, the currents on the strips are vertically oriented upwards and, hence, the electric dipole moments are. After a half-period at t = 2/4 T, they change to the downward direction. The magnetic dipole moments are 90° ahead in phase of the loop currents from which they originate. The corresponding magnetic dipole moments thus appear at the timeslots t = 1/4 T and t = 3/4 T. In this manner, the requisite 90° phase difference between the *E*- and *M*-radiators is naturally attained for OCP radiation.

An optimized prototype was fabricated and measured. As seen in Fig. 4, the measured overlapped $|S_{11}|$ and AR bandwidth covers 130 MHz from 2.34 to 2.47 GHz. The peak realized LHCP gain is 5.1 dBic. The measured OCP radiation patterns are shown Fig. 5. The AR values over 360° in the omni-plane are all less than 3 dB. These results successfully confirm the efficacy of the OCP array design.

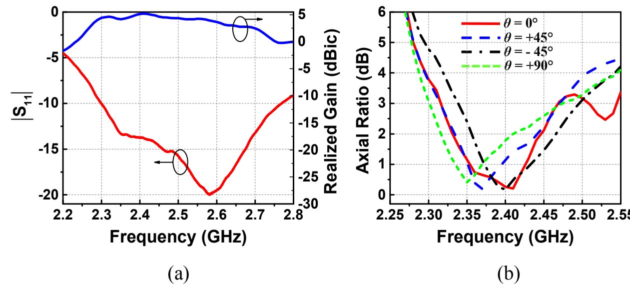

Fig. 4. Measured results. (a) $|S_{11}|$ and realized gain. (b) Axial ratio.

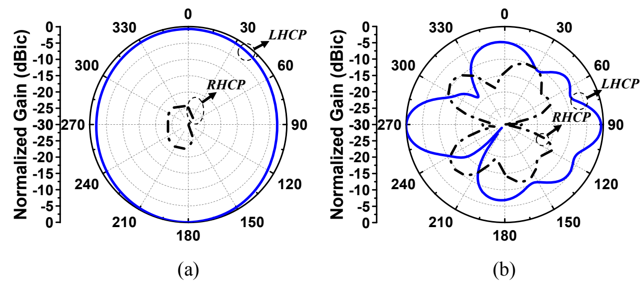

Fig. 5. Measured (a) omni and (b) vertical radiation patterns at 2.41 GHz.

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