Development of Omnidirectional CP Antennas and Arrays

(Invited)

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***Abstract*— This paper summarizes the design concepts, operating principles, and application examples of advanced omnidirectional circularly polarized (OCP) antennas and arrays. The design of an OCP antenna with a figure eight-shaped pattern is introduced. It is realized by exciting two parallel-oriented electric and magnetic radiators with a 90° phase difference. The diameter of the loop current that generates the magnetic radiator is small, $D \approx \lambda/10$. As an applications example, a 28 GHz highly compact OCP antenna is reported for 5G Device-to-Device (D2D) communications. The design of an OCP antenna having a conical pattern is also discussed. The conical OCP pattern is realized when both the electric and magnetic radiators are placed above a ground plane. The diameter of the loop current is large, $D \approx 1\ \lambda$. An example of a low profile and wideband OCP antenna radiating a conical pattern is demonstrated and its reconfigurable version is also discussed. Finally, an OCP array is presented that achieves high broadside directivity. It is based on an innovative method to realize collinear electric and magnetic radiators.**

***Index Terms*—Antenna array, circular polarization, conical pattern, high directivity, monopolar patch, omnidirectional, reconfigurable.**

I. Introduction

Omnidirectional circularly polarized (OCP) antennas have drawn much attention in modern wireless communication systems due to their merits of avoiding polarization mismatch [1] and having a large radiation coverage [2]. OCP antennas are particularly important for many emerging wireless applications such as Device-to-Device (D2D) communications in the next generation (5G) wireless systems and satellite communication applications [3]. For example, D2D communication requires wireless devices that are able to interact with their surrounding counterparts. OCP antennas with figure eight-shaped patterns that have their maximum pointing along the horizontal plane are highly desired in such applications. On the other hand, OCP antennas with conical radiation patterns are important for geostationary satellite communications [4]. They are suitable for mounting on earth vehicles for communications with a stationary satellite in orbit without any need for a tracking scheme. In particular, the maximum of the OCP conical pattern can always point to the satellite regardless of the vehicle's movements.

This paper summarizes the design concepts, operating principles, and implementations of OCP antennas with both figure eight-shaped and conical radiation patterns. Several practical OCP antenna designs will be introduced. In addition to these OCP antennas operating as single-element radiators, an innovative method is introduced to realize an efficient, high directivity collinear OCP array with a compact volume.

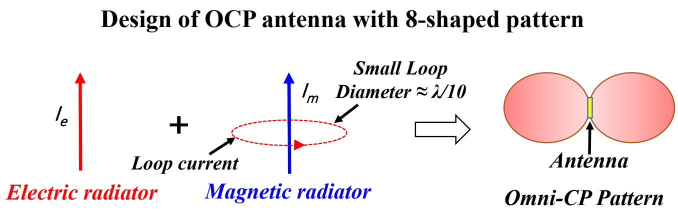

Fig. 1. Design concept of an OCP antenna that radiates a figure eight-shaped pattern with its maximum along the horizontal plane.

II. OCP Antenna with Figure Eight-Shaped Pattern

The design concept of an OCP antenna that radiates a figure eight-shaped pattern is illustrated in Fig. 1. OCP radiation with its maximum pointing along the horizontal plane is produced by exciting two parallel-oriented electric and magnetic radiators with a 90° phase difference. The magnetic radiator is usually created by a loop current that has a small diameter, around D ~ $\lambda/10$. Based on this concept, a 28 GHz version was developed for 5G D2D communication applications in [5]. It is highly compact. It has a cylindrical volume of only $\pi\ (4)^2 \times 1.57\ mm^3$ and covers the entire 27.5 to 28.35 GHz band for 5G applications. It is an ideal candidate for compact 5G mobile terminals such as smart phones and watches. Moreover, such an OCP antenna is in high demand for Satcube communications because of its superior compactness and light weight.

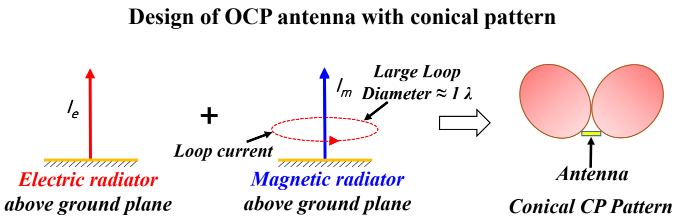

Fig. 2. Design concept of an OCP antenna that radiates a conical pattern.

III. OCP Antenna that Radiates a Conical Pattern

The design concept of an OCP antenna that radiates a conical pattern is a slightly different with the previous system. It also requires two parallel-orientated electric and magnetic radiators excited with a 90° phase difference. However, in contrast, both the *E*- and *M*-radiators need to be placed above a ground plane to achieve the conical pattern and the diameter of the loop current should be around D ~ 1 λ. The latter requirement causes the radiation pattern of the loop current to be dependent on its diameter. The pattern will change from a figure eight shape to a conical beam when the diameter increases from λ /10 to 1 λ. Based on this concept, a low profile and wideband OCP antenna that radiates a conical pattern was developed in [6]. This design organically combined a center-fed monopolar patch as the electric radiator with eight surrounding parasitic loop stubs as the magnetic radiator. The bandwidth enhancement is significant when compared to previously reported designs. In addition, the entire profile of the system is only 0.06 λ and the system is suitable for mass production. It is an ideal candidate for mounting on earth vehicles for geostationary satellite communications.

A reconfigurable wheel-shaped OCP antenna with conical pattern was developed in [7] based on the original design to enlarge the channel capacity by utilizing dual states of CP polarization. This design was realized by introducing two sets of PIN diodes as RF switches on its parasitic loop stubs. The orientation of the loop stubs were reconfigured from clockwise to anti-clockwise simply by controlling the ON/OFF status of those diodes. The result was switchable LHCP and RHCP conical radiation. It was the first OCP conical pattern antenna that achieved such polarization reconfigurability over a wide bandwidth.

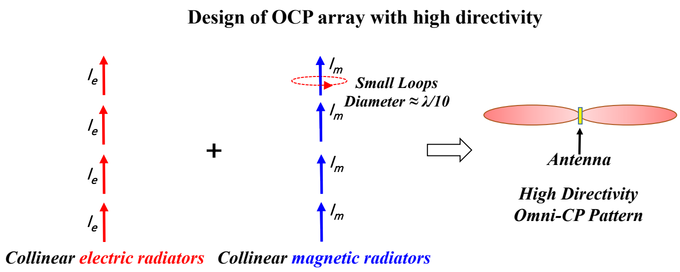

Fig. 3. Design concept of an OCP array that radiates a broadside pattern with high directivity.

IV. OCP Array with High Directivity

Most single-element radiators that are electrically small have limited peak directivities. An array configuration is required to obtain an OCP system with high directivity. As shown in Fig. 3, high directivity OCP radiation is produced if two sets of collinear electric and magnetic radiators are placed in parallel and are coherently excited with equal magnitudes and appropriate 90° phase differences. However, it is challenging to design such an OCP array in a compact volume. The two OCP arrays in [8] and [9] are the only ones reported to date. However, they are complex in structure and bulky in size. A new method to realize an OCP array with high directivity in a highly compact volume is developed in [10]. Multiple collinear electric (vertical strip) and magnetic (helical loop) radiators with proper phase differences are generated along an electrically-long radiator. It is excited in its middle. Leaky-wave behavior is observed along both pieces of the radiator. A four-stage OCP array with mechanically-fabricated folded loops and a six-stage OCP array facilitated by all-metal 3D printing technologies have been successfully designed, fabricated and measured to verify their design concepts. The achieved maximum realized OCP gain is larger than 7 dBic. Compared with the design in [9] that has a peak realized gain of 6.7 dBic, the entire volume of our developed OCP design is only 7% of that design. The design advances associated with these new OCP array will be described in our presentation.

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