Design Method for Series-Fed Omnidirectional Filtenna Based on Full-Metal 3-D Printing

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***Abstract*—This paper proposed a design approach for a series-fed omnidirectional antenna based on 3D full-metal printing. A major issue when designing series-fed antennas is the radiation pattern lobing caused by the unique feeding mechanism. In this paper, necessary adjustments are made based on the phase relationships between the currents and electric fields of each radiating element, resulting in improved radiation characteristics for the series-fed antenna. To validate this idea, the paper designs a rod-shaped full-metal omnidirectional antenna, achieving a wide operating bandwidth and high gain. Additionally, a filtering antenna with omnidirectional radiation is designed, which achieves a high level of out-of-band suppression as well as good omnidirectional radiation performance.**

***Index Terms*—Full-Metal, Omnidirectional Antenna, 3-D Printing, filtering Antenna, Series-Fed.**

I. Introduction

Antennas are a crucial component in modern .communication systems. In certain specialized scenarios, such as large-scale signal search and target detection, directional antennas may be insufficient. In contrast, phased-array antennas and omnidirectional antennas [1]-[5] can meet the requirements. Compared to phased-array antennas, omnidirectional antennas offer lower cost and reduced design complexity.

To improve the gain of omnidirectional antennas, antenna arrays are often used. Among these, series-fed [6]-[12] is a straightforward feeding method because it does not require the design of a large power dividing network, which helps reduce the size of the antenna array. To enable omnidirectional antennas to handle higher input power and more demanding operating conditions, a full-metal design is a good alternative. This also indicates that full-metal omnidirectional antenna designs have significant research value.

This paper describes the phase design approach for a series-fed omnidirectional antenna array and presents a rod-shaped high-gain omnidirectional antenna and an omnidirectional filtering antenna to demonstrate the feasibility of this phase design method. Simulation results show that both antennas exhibit good performance.

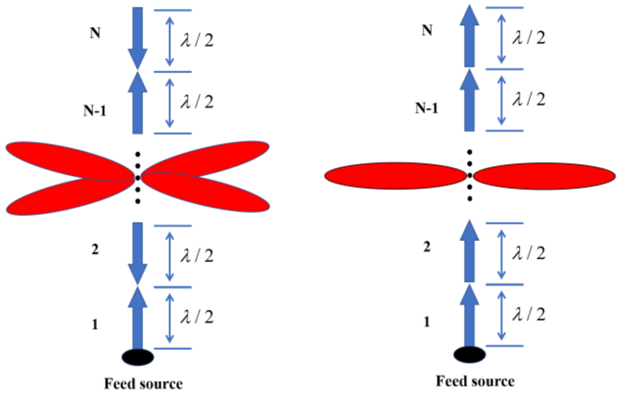

Fig. 1. Schematic diagram of a series-fed antenna array: (a) before phase correction, (b) after phase correction.

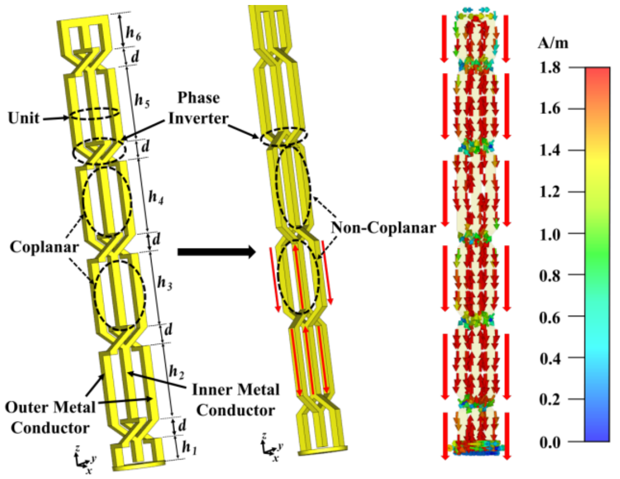

Fig. 2. (a) Coplanar structure antenna. (b) Non-coplanar structure antenna. (c) Simulated current distributions of the non-coplanar structure antenna. (Physical dimensions, all units are in mm: h1 = 17, h2 = 36, h3 = 34, h4 = 40, h5 = 34, h6 = 24, d = 9).

II. Antenna Design

Fig. 1(a) shows an N-element antenna array using a series-fed configuration, with blue arrows representing the array elements. The element spacing is half a wavelength at the center frequency, and the red area represents the antenna array's radiation pattern. It is observed that

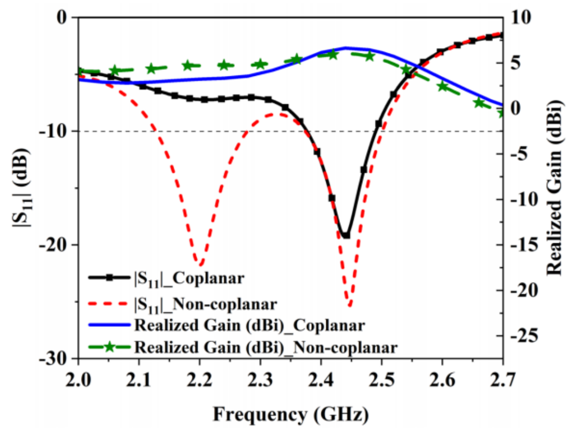

Fig. 3. Simulated |S11| and realized gain of coplanar structure antenna and non-coplanar structure antenna.

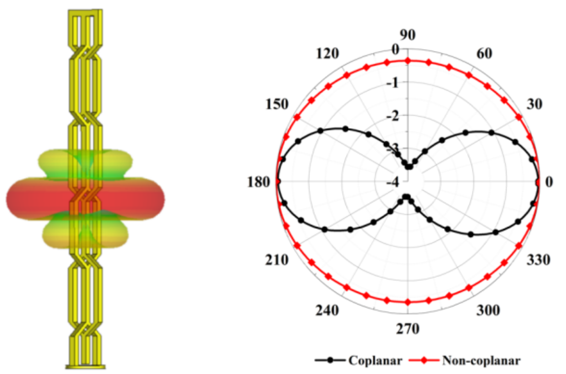

Fig. 4. (a) Simulated 3-D radiation pattern of non-coplanar structure antenna. (b) H-plane radiation patterns of coplanar and non-coplanar structure antenna.

adjacent elements have naturally opposite phases, leading to lobing in the array's radiation pattern and poorer performance. To improve radiation performance, the phase relationship between elements needs to be corrected so that the gains of all elements add in phase. Fig. 1(b) illustrates the ideal schematic of this solution, where the final radiation pattern of the antenna array has no lobes and achieves better performance.

A. rod-shaped full-metal omnidirectional antenna

Fig. 2 shows the proposed rod-shaped high-gain omnidirectional antenna. This antenna consists of a metal strip bent into a single unit, forming an alternating structure of inner and outer conductors. This is a non-planar structure, with adjacent elements positioned in two orthogonal planes, as shown in Fig. 2(b). The main radiating component is the outer metal strip of each element. The inner metal strip of the i-th element connects with the outer metal strip of the $(i+1)$-th element. The current distribution at the center frequency is depicted in Fig. 2(c), where the current direction on the outer metal strips is consistent, ensuring phase alignment among the radiating elements and achieving good omnidirectional radiation characteristics.

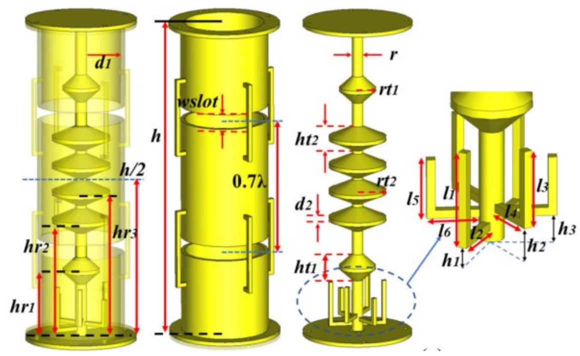

Fig. 5. Structural diagram of the filtering antenna. (a) Three-dimensional view. (b) External structural diagram. (c) Internal structural diagram.

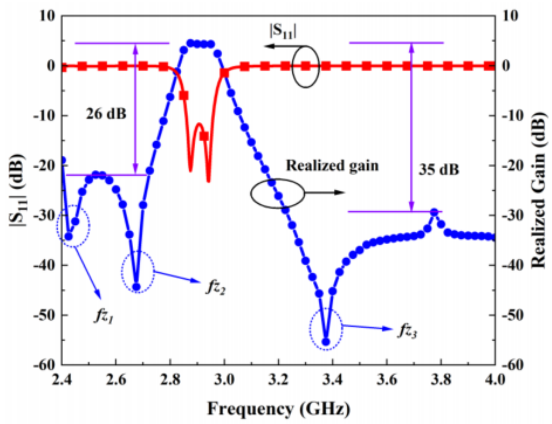

Fig. 6. Simulation S parameter and gain curve of the filtering antenna.

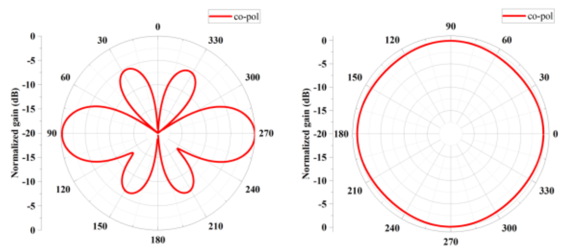

Fig. 7. (a) E-plane radiation patterns of the filtering antenna. (b) H-plane radiation patterns of the filtering antenna.

The radiation performance of the antenna elements is similar to that of monopole antennas. This will be presented in Section III, "Analysis of Simulation Results.".

B. Filtenna

Fig. 5 shows the proposed omnidirectional filtenna. This antenna consists of a metal outer conductor and a metal inner conductor, with one segment of the inner conductor fed and the other end short-circuited to the outer conductor.

The radiating element is an annular slot. To balance impedance matching and radiation performance, the element spacing is selected as $\lambda/2$, where λ is the wavelength at the center frequency. The filtering performance of this omnidirectional filtenna is achieved using three sets of open-circuit stubs. When using series-fed excitation, maintaining an element spacing of one wavelength is usually required for in-phase radiation. However, in the proposed antenna, protruding structures (EBG) are introduced to shorten the element spacing while keeping the current path length constant, ensuring in-phase addition of the elements.

III. Analysis of Simulation Result

This section will focus on analyzing the simulation results of the two antennas. Fig. 3 shows the simulation S-parameters and gain curves for the rod-shaped omnidirectional antenna. It can be observed that the non-planar rod-shaped antenna has a wider bandwidth compared to the planar rod-shaped antenna, while both achieve a nearly identical peak gain of 6 dBi in omnidirectional radiation. Fig. 4 shows the radiation patterns of the rod-shaped omnidirectional antenna. Both the planar and non-planar structures have radiation patterns similar to those of monopole antennas. As seen in the H-plane radiation pattern in Fig. 4(b), the non-planar structure exhibits better omnidirectional radiation performance compared to the planar structure, with the planar structure having a deviation greater than 3 dB, while the non-planar structure's deviation is less than 0.5 dB.

Fig. 6 shows the simulation S-parameters and gain curves of the omnidirectional filtering antenna. The antenna achieves an out-of-band suppression level of 26 dB, with each of the three sets of open-circuit stubs creating a radiation null. Fig. 7 displays the E-plane and H-plane radiation patterns of the antenna, revealing excellent omnidirectional radiation performance with low deviation.

IV. Conclusion

This paper proposes two types of full-metal omnidirectional antenna arrays based on phase correction of adjacent elements. Both arrays use a series-fed configuration without a large feeding network. Through clever design, the phases of adjacent elements are kept consistent, resulting in in-phase addition of radiation patterns in the far field, thereby improving the antenna's radiation performance. The proposed rod-shaped omnidirectional antenna achieves a wide matching bandwidth and high peak gain. The proposed omnidirectional filtering antenna not only provides good omnidirectional radiation performance but also features high out-of-band suppression. Ultimately, this paper offers two feasible design solutions for full-metal series-fed omnidirectional antenna arrays.

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