ENHANCEMENT OF DIRECTIVITY FOR PLANAR ANTENNA ARRAY USING TUBULAR METALLIC FRAME

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The article is devoted to planar antenna arrays in which each radiating element is enclosed by metallic tubes. To provide radiation with circular polarization, open ends of square-section waveguides are used as radiating element. The proposed framing technique enhances the array's directivity and significantly suppresses backlobe radiation. Two design configurations are analyzed: in the first case, the tubes are not interconnected, while in the second, they are joined at the angle of 45°. Arrays consisting of 3×3, 4×4, and 5×5 elements are examined. The directivity dependences on the diameter of the framing tubes are presented. The optimal values of the diameters that ensure maximization of the directivity are determined.

Keywords: directivity, antenna array, tubular metallic frame, circular polarization, square waveguide.

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1. Introduction

A microwave wireless power transmission system [1] typically comprises transmitting and receiving subsystems. One of the primary challenges in such systems is to transfer energy efficiently over long distances with minimal power loss. This can be achieved by employing antenna arrays capable of generating highly directional beam [2]. The operating frequency selected for this study is 2.45 GHz, which is widely adopted in wireless power transmission experiments. This frequency falls within the Industrial, Scientific, and Medical (ISM) band and offers low atmospheric attenuation along with favorable propagation characteristics for microwave radiation. In modern wireless power transfer systems, circular polarization is commonly used in antenna arrays to ensure stable and efficient power delivery regardless of the receiver's orientation [3]. Compared to linear polarization, circular polarization provides reduced sensitivity to angular misalignment between the transmitter and receiver. Although increasing the number of radiating elements improves directivity, it also results in larger physical dimensions and a more complex feed network. Therefore, alternative techniques for enhancing directivity are actively being explored, including the use of dielectric superstrates [4], dielectric lenses [5], and metamaterials [6, 7]. Another approach is to use the idea of an aperture-matched horn [8]. The principal transformation of an ordinary horn to an aperture-matched horn is the attachment of curved-surface sections to the outside of the aperture edges. This action reduces the diffractions that occur at the sharp edges of the aperture and provides backlobe suppression. This approach was considered for circular aperture horn [9] and for rectangular aperture horn [10]. In the last case circular tubes have been used.

The purpose of this article is to determine the optimal diameter of the tubular metallic frame that maximizes the directivity of a planar antenna array while significantly reducing backlobe levels.

2. Simulation results

A planar, in-phase, uniform-amplitude, equidistant antenna array with metallic tubular framing was investigated. The radiating element was chosen to be the open end of a square waveguide with a cross-section of 86×86 mm^2. To generate circular polarization, two orthogonal fundamental modes, H_{10} and H_{01}, were excited in the square waveguide with a phase shift of $\pi/2$. Arrays consisting of 3×3, 4×4, and 5×5 elements were considered. The operating frequency of the array was 2.45 GHz which corresponded to the wavelength 12.24 cm in free space.

Electromagnetic modelling software was employed to analyze the radiation characteristics of the antenna array. Two design configurations of the tubular metallic framing were considered. In the first configuration, the metallic tubes surrounding each element were not interconnected (Fig. 1), while in the second configuration, the tubes were joined at a 45° angle (Fig. 2).

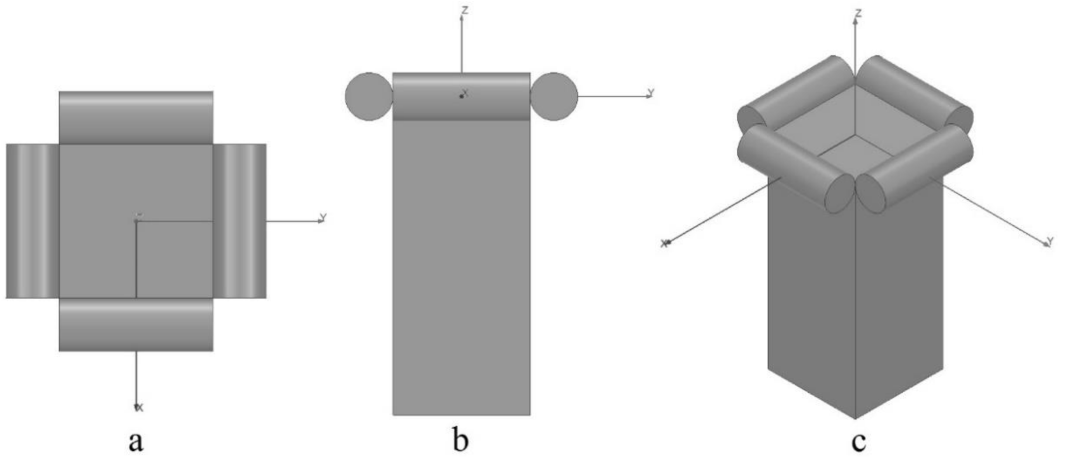

Fig. 1. First design of tubular framing around a single radiating element: a) top view, b) side view, c) isometric view.

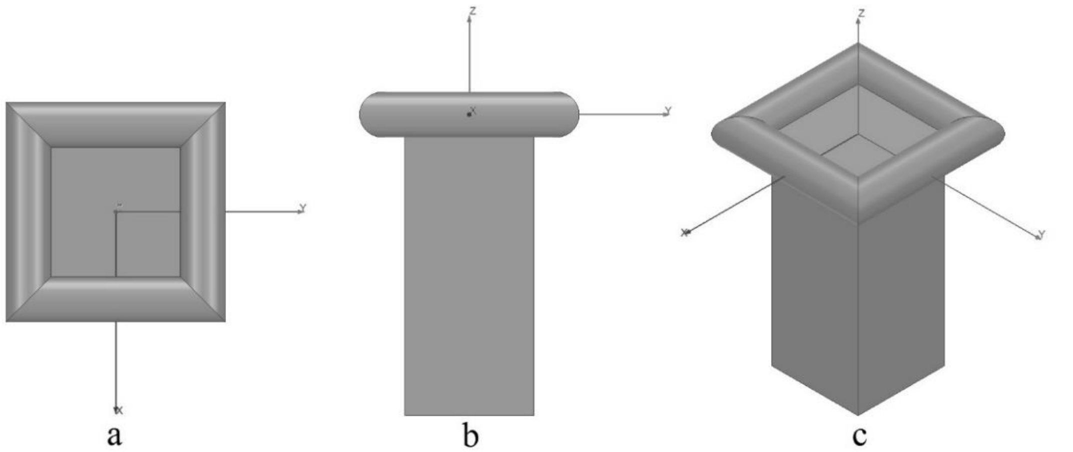

Fig. 2. Second design of tubular framing around a single radiating element: a) top view, b) side view, c) isometric view.

During the analysis, the spacing *d* between the edges of adjacent waveguide apertures was varied. This distance was also equal to the diameter of the surrounding metallic tubes.

From the plot below (Fig. 3) for array consisting of 3×3 radiating elements, it is observed that the array without framing achieves maximum directivity at d = 35 mm. This result corresponds to a distance between the centres of the radiating elements of 12.21 cm, which practically coincides with the wavelength in free space. For the array with the first and the second framing configuration, the peak directivity occurs at d = 50 mm and d = 85 mm respectively. The directivity at the optimal spacing *d* between radiating elements is shown in Fig. 4.

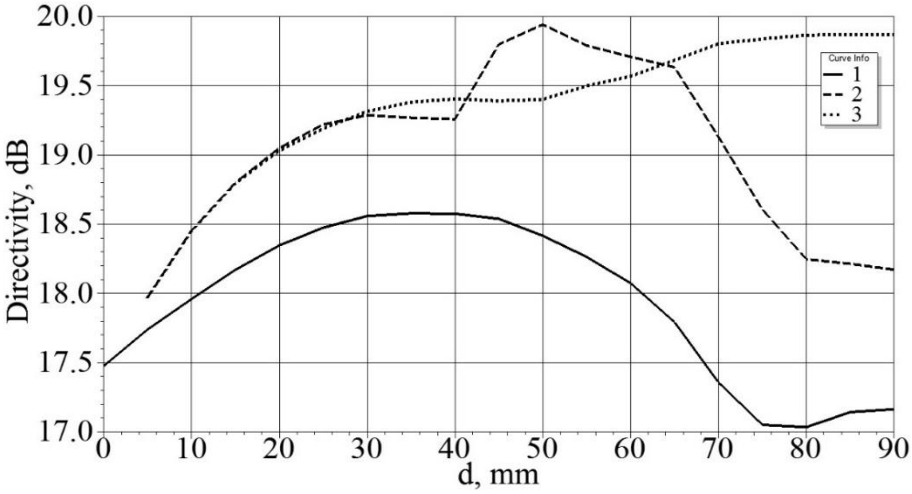

Fig. 3. Directivity ($\varphi = 0°$, $\theta = 0°$) against waveguide edge-to-edge spacing *d* for a 3×3 antenna array: 1 – array without framing, 2 – array with the first framing design, 3 – array with the second framing design.

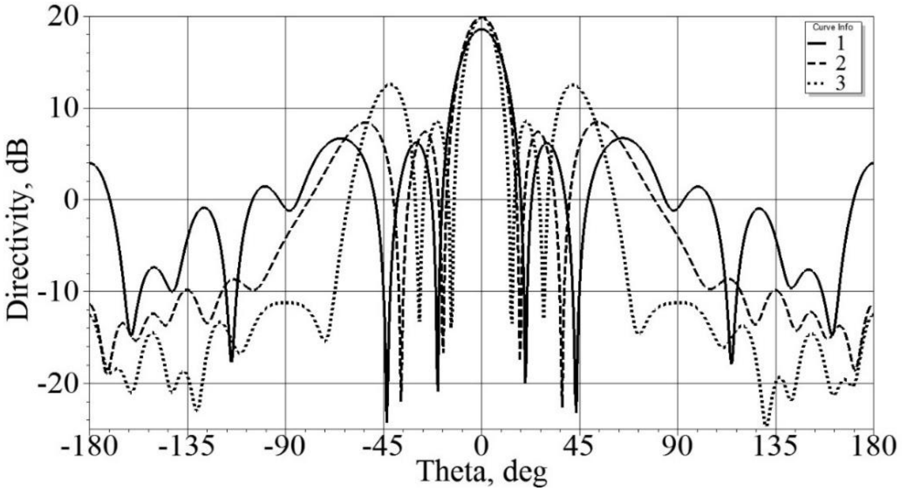

Fig. 4. Directivity against angle θ in the *XZ*-plane for a 3×3 antenna array: 1 – array without framing, 2 – array with the first framing design, 3 – array with the second framing design.

As seen from the plot, increasing the spacing between waveguides beyond the wavelength leads to the appearance of grating lobes, especially in the range between 40 and 55 degrees. The maximum directivity for the first framing design is 1.36 dB higher, and in the second design is 1.29 dB higher compared to the unframed array. Moreover, the use of the first framing configuration reduces the backlobe level by 15.3 dB, while the second configuration provides a reduction of 16.5 dB relative to the unframed case.

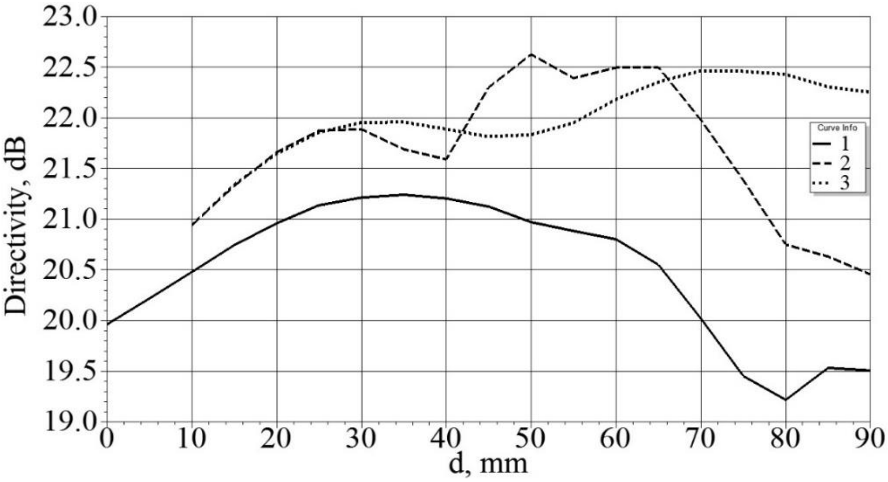

Fig. 5. Directivity ($\varphi = 0°$, $\theta = 0°$) against waveguide edge-to-edge spacing *d* for a 4×4 antenna array: 1 – array without framing, 2 – array with the first framing design, 3 – array with the second framing design.

The array consisting of 4×4 radiating elements without framing reaches peak directivity at $d = 35$ mm, with the first framing design at $d = 50$ mm, and the second design at $d = 70$ mm (Fig. 5). The directivity at the optimal spacing *d* between radiating elements is shown in Fig. 6.

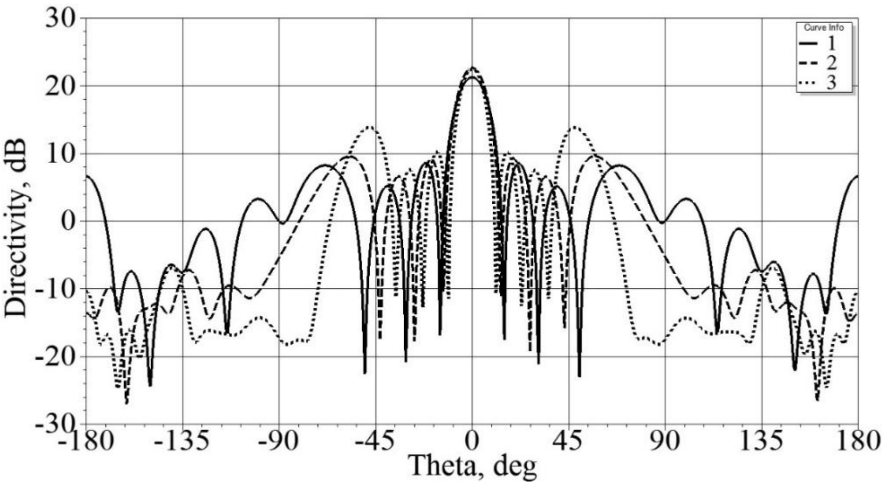

Fig. 6. Directivity against angle θ in the *XZ*-plane for a 4×4 antenna array: 1 – array without framing, 2 – array with the first framing design, 3 – array with the second framing design.

The results indicate that the first framing configuration yields a 1.38 dB increase in maximum directivity, while the second configuration provides a 1.22 dB gain over the unframed array. Additionally, the first framing option results in a 20 dB reduction in backlobe level, whereas the second option achieves a 17 dB reduction. It is interesting to note that for the unframed array the optimal distance between the centres of the radiating elements was the same, and for the framed arrays the best results were shown for the first configuration, in contrast to the case of the array consisting of 3×3 elements. It should be mentioned that for the 4×4 element array it is impossible to define the truly central element, in contrast to an array with odd number of elements along the side.

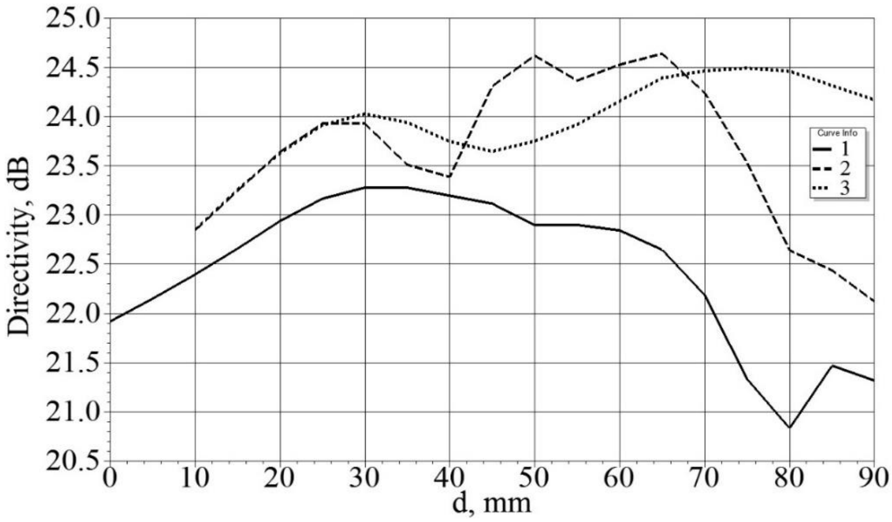

Fig. 7. Directivity (φ = 0°, θ = 0°) against waveguide edge-to-edge spacing *d* for a 5×5 antenna array: 1 – array without framing, 2 – array with the first framing design, 3 – array with the second framing design.

For the array with 5×5 radiating elements, the optimal spacing for maximum directivity is *d* = 35 mm for the unframed array as in both previous cases, *d* = 65 mm for the first framing variant, and *d* = 75 mm for the second (Fig. 7). The directivity at the optimal spacing *d* between radiating elements is shown in Fig. 8.

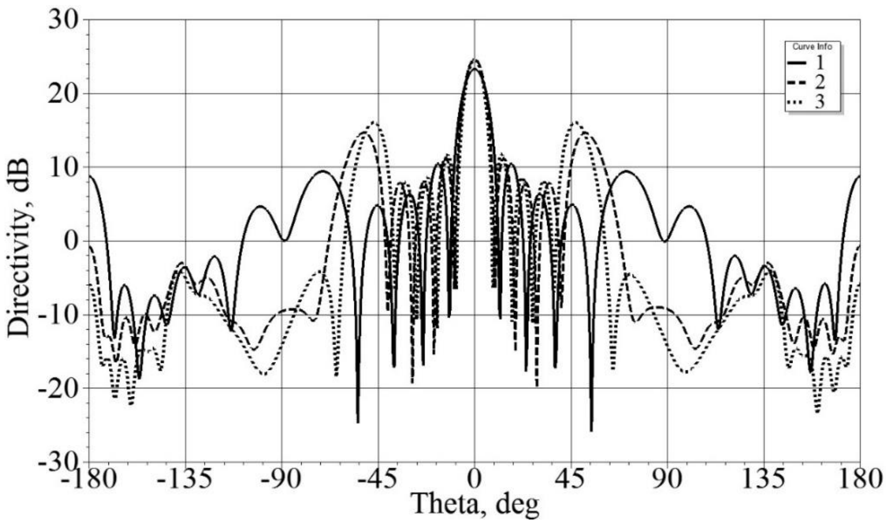

Fig. 8. Directivity against angle θ in the *XZ*-plane for a 5×5 antenna array: 1 – array without framing, 2 – array with the first framing design, 3 – array with the second framing design.

From the plot, it can be seen that the first framing configuration results in a 1.36 dB increase in maximum directivity, and the second configuration gives a 1.21 dB improvement compared to the unframed case. Furthermore, the use of the first framing variant leads to a

9.4 dB reduction in backlobe level, while the second framing variant achieves a 14.5 dB reduction.

3. Conclusions

The implementation of tubular metallic frame (both configurations) enhances the directivity of the antenna array and significantly suppresses the back lobe level. For an odd number of radiating elements along each side of the array, the second design provides greater back lobe suppression. Directivity increases by an average of 1.3 dB, while back lobe level drops by an average of approximately 15 dB. This fact can be beneficial for increasing the main lobe gain in wireless microwave power transmission systems.

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