HALF-MOON ANTENNA ARRAY

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ABSTRACT

Half-moon antenna arrays classified into O-type arrays (where array elements are simply stacked) and P-type arrays (where the stacked array elements are connected by auxiliary plates) are investigated. First, a two-element array is analyzed. An improvement is found in the radiation pattern of the P-type array, compared with that of the O-type array. Next, a four-element array is investigated. The investigation shows that the P-type array has a maximum gain of 12.2 dB, which is 9.5 dB higher than the gain of a single element, by virtue of the auxiliary plates.

INTRODUCTION

Recently, the half-moon antenna (HMA)[1][2][3], which consists of half of a radial transmission line excited by a probe, has been proposed as a modification of the radial-mode horn [4]. The investigation shows that the HMA has wide radiation patterns in both E and H planes. Based on the investigation of the HMA, we propose the HMA arrays shown in Fig. 1 and investigate the radiation characteristics.

For the investigation, we use the finite-difference time domain (FDTD) method [5]. Therefore, first, we briefly summarize the FDTD method, which is formulated using a cylindrical coordinate system. Second, we investigate an HMA array antenna composed of two elements. Effects of an auxiliary plate (AXP in Fig. 1, which connects the elements) on the radiation pattern are revealed. The gains with and without the auxiliary plate are also evaluated and discussed. Finally, a four-element HMA array is analyzed and the radiation characteristics, including the radiation pattern and gain, are revealed.

CONFIGURATION

Fig. 1(a) shows the perspective and side views of an HMA array element. The linear edges of the upper and lower conducting plates of the HMA (each plate having a semi-circular shape with linear and round edges) are shorted with a conducting wall. The HMA is excited by a strip probe near the conducting wall.

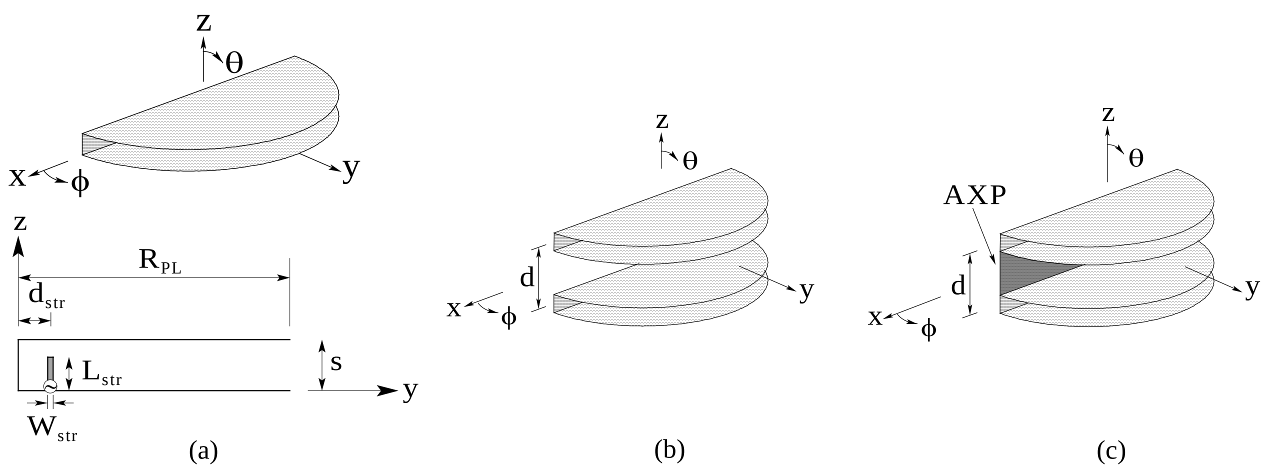

Fig.1 Configuration. (a) Element antenna. (b) O-type array. (c) P-type array.

The notation for the HMA is as follows: R_{PL} is the radius of the upper and lower plates, s is the spacing between the upper and lower plates, L_{str} is the length of the strip probe, W_{str} is the width of the strip probe, and d_{str} is the distance from the conducting wall to the center of the strip probe.

Fig. 1(b) shows an HMA array, where the HMA elements are simply stacked linearly in the z-direction. The spacing between neighboring HMA elements is denoted as d. Fig. 1(c) shows a modified version of the array in Fig. 1(b), where the elements are shorted with an auxiliary plate (AXP). For convenience, the arrays of Figs. 1(b) and (c) are called O-type and P-type arrays, respectively.

ANALYSIS TECHNIQUES

We analyze the HMA arrays using the finite-difference time-domain method, where the cylindrical coordinate system $(r, \phi, z) = (i\Delta r, j\Delta\phi, k\Delta z)$ is used. The r-component of the electric field is expressed as

$$\begin{aligned} E_r^n\left(i+\tfrac{1}{2}, j, k\right) &= E_r^{n-1}\left(i+\tfrac{1}{2}, j, k\right) \\ &+ \frac{\Delta t}{\varepsilon\left(i+\tfrac{1}{2}\right)\Delta r\,\Delta\phi}\left[H_z^{n-\frac{1}{2}}\left(i+\tfrac{1}{2}, j+\tfrac{1}{2}, k\right) - H_z^{n-\frac{1}{2}}\left(i+\tfrac{1}{2}, j-\tfrac{1}{2}, k\right)\right] \\ &- \frac{\Delta t}{\varepsilon\,\Delta z}\left[H_\phi^{n-\frac{1}{2}}\left(i+\tfrac{1}{2}, j, k+\tfrac{1}{2}\right) - H_\phi^{n-\frac{1}{2}}\left(i+\tfrac{1}{2}, j, k-\tfrac{1}{2}\right)\right] \end{aligned} \tag{1}$$

where time t is expressed as $t = n\,\Delta t$. The other components H_r, E_ϕ, H_ϕ, E_z, and H_z are similarly formulated.

An absorbing boundary condition based on Newton's backward-difference polynomial is used to truncate the computation space [5]. The second-order tangential electric field components at the outer boundary $\varsigma = \varsigma_{max}$ are expressed as $E(t + \Delta t, \varsigma_{max}) = 2E(t, \varsigma_{max} - \alpha c\Delta t) - E(t - \Delta t, \varsigma_{max} - 2\alpha c\Delta t)$, where c and α are the speed of light and a scaling factor, respectively.

NUMERICAL RESULTS

The following configuration parameters are fixed throughout this paper: $R_{PL} = 2.08\lambda_{12.5}$, $s = 0.26\lambda_{12.5}$, $L_{str} = 0.175\lambda_{12.5}$, $W_{str} = 0.04\lambda_{12.5}$, and $d_{str} = 0.25\lambda_{12.5}$, where $\lambda_{12.5}$ is the wavelength at a frequency of 12.5 GHz. The array spacing d is varied subject to the objectives of the analysis.

Two-Element Array

Fig. 2 shows the radiation pattern of a two-element array as a function of the array spacing d at a test frequency of 12.5 GHz. Note that the left column is for the O-type array and the right column is for the P-type array. Also, note that the two array elements are in contact with each other when $d = 0.26\lambda_{12.5}$ (called the "contact case"). It is found that the auxiliary plate improves the radiation pattern. The P-type array has lower backlobes than the O-type array, as desired.

Array effects clearly appear in the radiation pattern in the y-z plane (E plane). The half-power beam width (HPBW) in the y-z plane of the P-type array is narrowed to 68 degrees at $d = 0.5\lambda_{12.5}$ from 196 degrees at $d = 0.26\lambda_{12.5}$. This leads to an increase in the gain. Note that both O- and P-type arrays have a similar HPBW of approximately 120 degrees in the x-y plane (H plane).

Fig. 3 shows the gain of the P-type array as a function of the array spacing d at 12.5 GHz. The gain of the P-type array is always higher than that of the O-type array. The P-type array shows a maximum gain of approximately 8.1 dB at $d = 0.73\lambda_{12.5}$, which is 1.1 dB higher than that of the O-type array.

The input impedance $Z_{in} = R_{in} + jX_{in}$ is also affected by the array spacing d. Detailed evaluation as a function of d reveals that the O- and P-type arrays have similar input impedances. Fig. 4 shows the input impedance of the P-type array as a function of d at 12.5 GHz. The resistive component R_{in} varies from 50 Ω to 25 Ω within the analysis range.

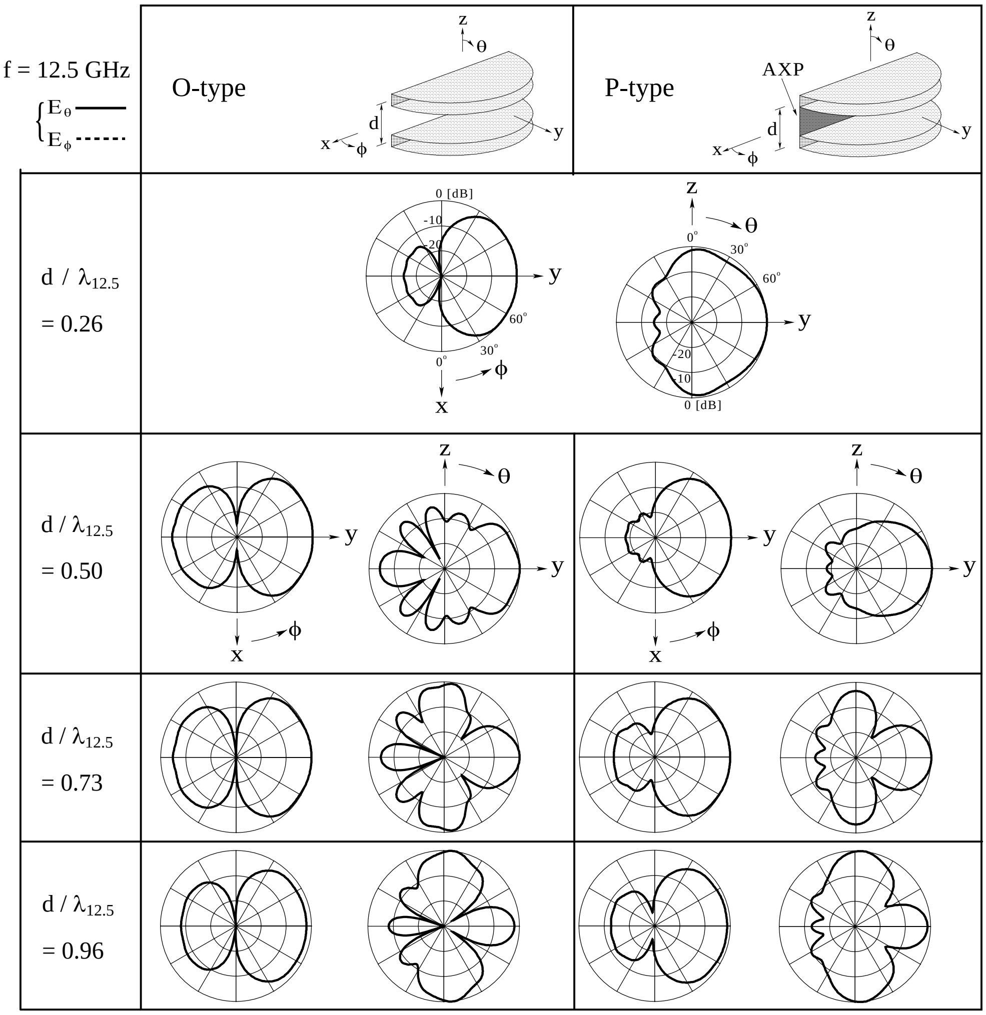

Fig. 2 Radiation patterns with and without an auxiliary plate.

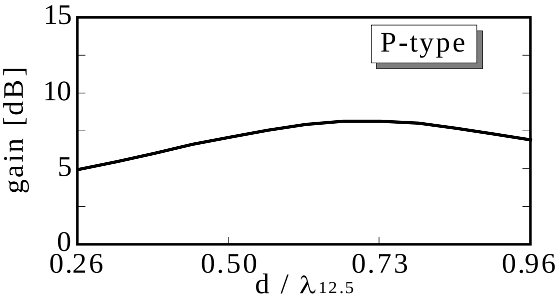

Fig. 3 Gain vs. the array spacing d.

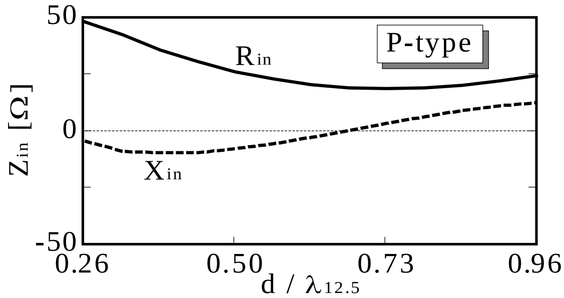

Fig. 4 Input impedance vs. the array spacing d.

Four-Element Array

We next analyze a four-element P-type array, with the expectation of a further increase in gain. According to the analysis at a test frequency of 12.5 GHz, a maximum gain of approximately 12.2 dB is obtained at an array spacing of $d = 0.79\lambda_{12.5}$, with the radiation pattern shown in Fig. 5. The HPBW in the *y*-*z* plane is approximately 18 degrees, while that in the *x*-*y* plane remains approximately 120 degrees. Fig. 6 shows the frequency response of the gain, with the array spacing fixed at $d = 0.79\lambda_{12.5}$. It is found that the variation in the gain within this frequency range is small (approximately 1 dB).

CONCLUSIONS

Half-moon antenna arrays have been analyzed using the finite-difference time domain method. The element antenna has a wide half-power beam width of 120 degrees in the H plane and a gain of approximately 2.7 dB. An array composed of two elements, stacked in the *z*-direction, shows that an auxiliary plate connecting the two elements decreases the backlobe intensity. This also holds true for a four-element P-type array. The four-element P-type array realizes a gain of 12.2 dB, which is 9.5 dB higher than the gain of a single element.

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REFERENCES

[1] I. Wako, T. Yagi, and H. Nakano, “Half-moon antenna”, B-1-45, Proc. of the 1999 Communications Society Conference of IECE, Funabashi, Japan, Sept. 1999.
[2] Y. Yamamoto, M. Sugama, J. Yamauchi, and H. Nakano, “Numerical analysis of a half-moon antenna”, Proc. of the 1999 Communications Society Conference of IEICE, p. B-1-46, Funabashi, Japan, Sept. 1999.
[3] H. Nakano, Y. Yamamoto, M. Ikeda, and J. Yamauchi, “A half-moon antenna”, Digest of IEEE AP-S Int. Symp., San Antonio, June 2002 (in press).
[4] J. J. Epis and F. E. Robels, “Partial radial-line antenna”, U. S. Patent 3,831,176, 1974
[5] A. Taflove, *Computational Electrodynamics*, Norwood, MA, Artech House, 1995.

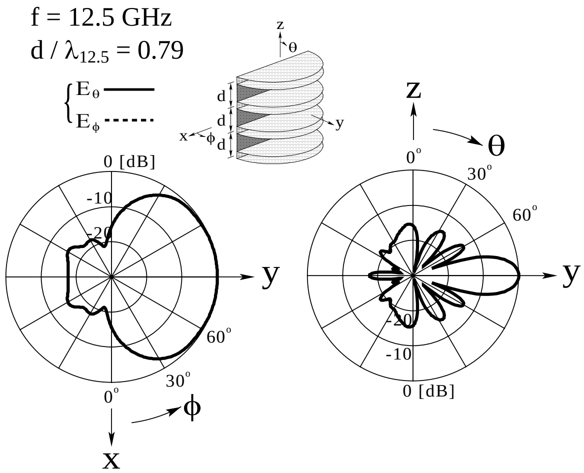

Fig. 5 Radiation pattern of a four-element P-type array.

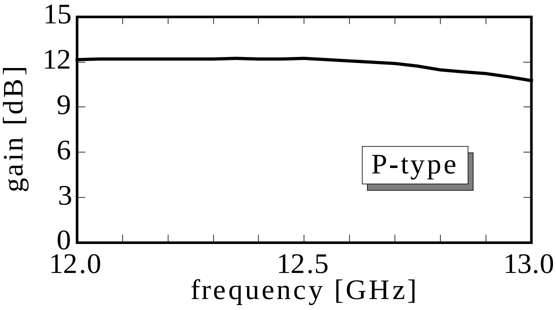

Fig. 6 Frequency response of the gain.