RECTANGULAR APERTURE ANTENNA ARRAY WITH A TILTED BEAM

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1. Introduction

It has been revealed that the beam radiated from a square aperture antenna constructed with a triplate transmission line (TTL) can be tilted from the direction normal to the antenna plane, by changing the size of the square aperture [1]. However, an increase in aperture size is undesirable when constructing an array antenna composed of square apertures, because the distance between the array elements must also be increased and thus gives rise to undesired grating lobes. Recent study has shown that this drawback can be avoided by using a *rectangular* aperture [2].

This paper is a sequel to [2] and presents an antenna array composed of rectangular apertures, each being backed by a cavity to obtain high radiation efficiency [3]. The main purpose is to realize a fan beam tilted from the direction normal to the antenna plane. The radiation characteristics of the array are presented and discussed.

2. Configuration and analysis method

Fig. 1 shows a rectangular aperture antenna array constructed using a TTL. The TTL has N apertures in the top conducting plate, each having rectangular area $A_x \times A_y$. These apertures are backed by cavities with depth D_{cav}. The space inside the cavity is filled with air.

Strip line probes at z = –B, each having length L_{pro} and width W_{pro}, excite the apertures. These probes are extensions of the inner conductors of the TTL, which are embedded in a dielectric material of relative permittivity ε_r.

The following parameters are chosen and fixed: A_x = 16 mm = $0.664\lambda_{12.45}$, A_y = 18 mm = $0.747\lambda_{12.45}$, B = 2mm = $0.083\lambda_{12.45}$, ε_r = 1.2, $L_{pro} = A_y/2$ = 9 mm = $0.3734\lambda_{12.45}$, W_{pro} = 2 mm = $0.083\lambda_{12.45}$, and D_{cav} = 6 mm = $0.25\lambda_{12.45}$, where $\lambda_{12.45}$ (= 24.1 mm) is the free-space wavelength at a design frequency of f_0 =12.45 GHz. Note that, with the above parameters, an isolated element has a tilted beam of θ_{tilt} = 27° in the negative y-z plane (ϕ = 270°) and a gain of approximately 8 dB, as revealed in [2].

The finite-difference time domain method [4]-[6] is adopted for analysis of the array. The following assumptions are used: (1) the TTL is of infinite extent, (2) the conductors and the dielectric are loss-less, and (3) the inner conductors of the TTL and probes are infinitesimally thin.

Yee's algorithm is programmed with Liao's second order absorbing condition [7]. The array is symmetrical with respect to the y-z plane, as shown in Fig. 1. Due to the structural symmetry, the tangential magnetic fields H_y and H_z are zero in the y-z plane. Use of these magnetic field conditions can reduce the full analysis space by one-half.

3. Antenna arrays for fan beam formation

Preliminary investigations show that the port isolation $|S_{21}|$ of a two-element array (N = 2 case) is less than – 29 dB, provided that the array distance d_x is more than 0.79 $\lambda_{12.45}$. Based on this fact, an array distance of $d_x = 0.79\lambda_{12.45}$ is used in the following investigation.

Fig. 2 shows the radiation pattern as a function of the number of aperture antenna elements, N. As N increases, the radiation pattern in the x-z plane (H-plane) becomes narrower due to the array effect, while the tilted wide radiation pattern in the y-z plane (E-plane) remains unchanged. Thus, the array forms a tilted fan beam.

The gain is shown in Fig. 3 as a function of N. The gain is observed in a fixed direction of $\theta_{tilt} = 27°$ in the negative y-z plane ($\phi = 270°$). The gain G_N is approximately proportional to the number of array elements, N: $G_N \approx NG_1$, where G_1 is the gain for an isolated element. For N = 4, the gain enhancement in dB from G_1 is approximately 6 dB, which is close to a value of (10 log 4) for the situation where the mutual coupling is negligible (ideal case).

Further investigation is performed to reveal the frequency response of the input impedance with N = 4. Fig. 4 shows the input impedance evaluated at the aperture edge $(x, y) = ([N - (2m-1)]d_x/2, A_y/2)$, where m = 1, 2,.., 4. The resistance values of the four elements at f_0 = 12.45 GHz are 124 Ω for elements 1 and 4 and 119 Ω for elements 2 and 3 (only a 5 Ω variation). These values are close to the input impedance of an isolated element. Note that the presence of cavities behind the apertures leads to a radiation efficiency of more than 85% from 12.05 GHz to 12.95 GHz.

4. Conclusions

An array of N rectangular apertures, each being backed by a cavity, is analyzed. As N increases, the radiation pattern in the x-z plane (H-plane) becomes narrower, while the tilted wide radiation pattern in the y-z plane (E-plane) remains unchanged, realizing a fan beam. The gain G_N is approximately proportional to N. For N = 4 with an array distance of $d_x = 0.79\lambda_{12.45}$, the gain enhancement from G_1 (isolated element gain) is approximately 6 dB, which is close to the value for which the mutual coupling is negligible.

References

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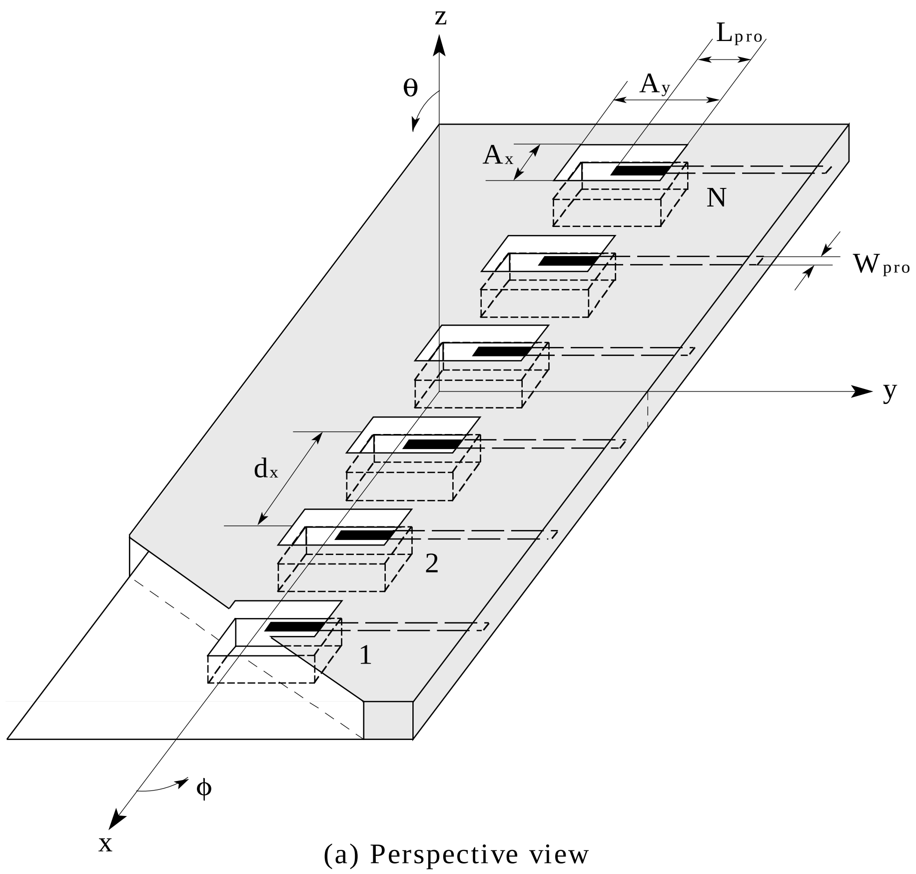
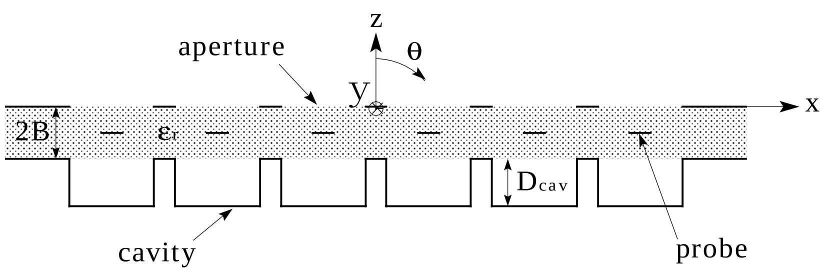


(a) Perspective view



(b) Cross-sectional view (x-z plane)

Fig.1 Configuration and coordinate system of a rectangular aperture antenna array

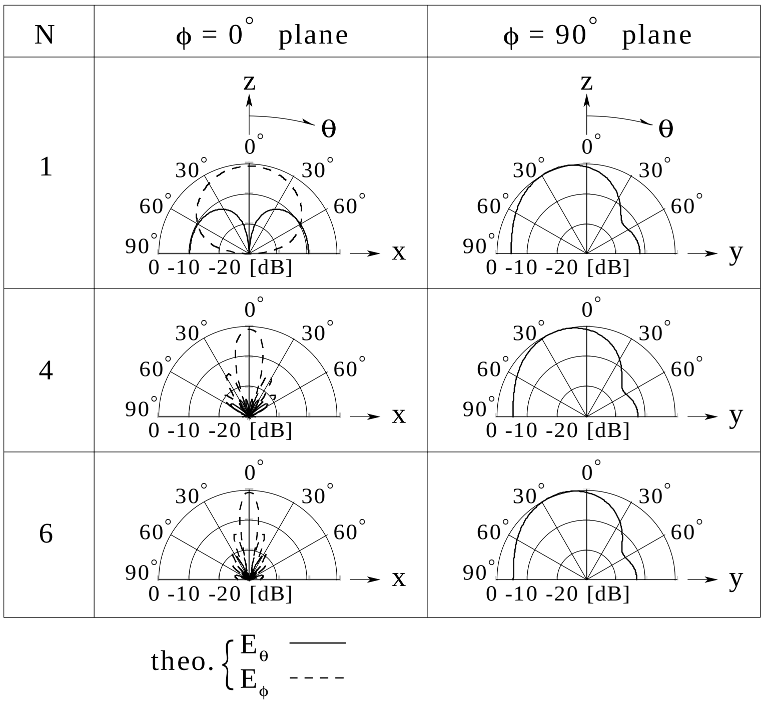


Fig.2 Radiation pattern as a function of N

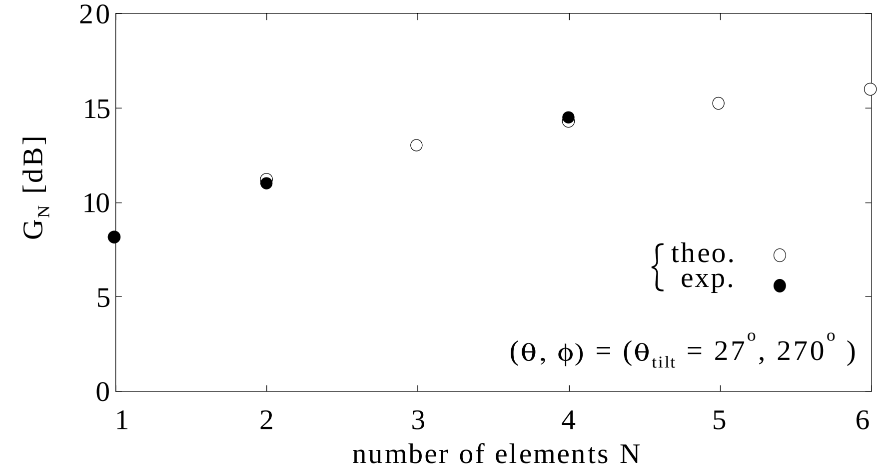


Fig.3 Gain as a function of N

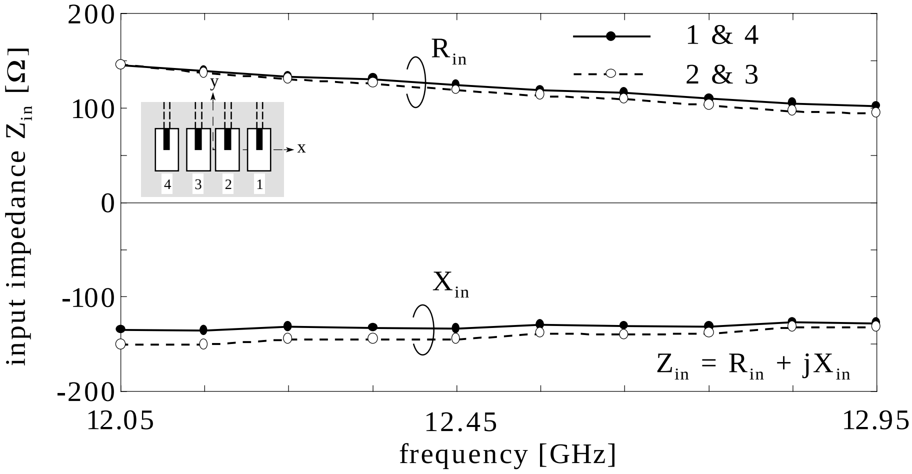


Fig.4 Input impedance as a function of frequency