FAN-SHAPED ANTENNAS

H. Nakano, N. Nishizaka, H. Mimaki, and J. Yamauchi
Wireless Network Communications Research Center, Hosei University
3-7-2, Kajino-cho, Koganei, Tokyo 184-8584, Japan
nakano@k.hosei.ac.jp

1. Introduction

A half-moon antenna composed of upper and lower conducting plates, both being semi-circular (inner angle $\alpha = 180°$ in Fig. 1), has been analyzed [1]-[3]. The analysis shows that the half-moon antenna has a wide radiation beam of linear polarization. The half-power beam width (HPBW) is approximately 180° in the E plane and 120° in the H plane.

This paper is an extension of work on the half-moon antenna [1]-[3], where the inner angle α shown in Fig. 1 is decreased from 180° to a certain value. The antenna, therefore, is referred to as a fan-shaped antenna (FS antenna). The purpose of this paper is to reveal the radiation characteristics of the FS antenna in a frequency band around 76.5 GHz. The effects of the inner angle α on the radiation characteristics are revealed using a finite-difference time domain (FDTD) method, which is based on cylindrical coordinates [4].

First, effects of varying the inner angle α on the radiation pattern is investigated under the condition that the upper and lower conducting plates are infinitesimally thin ($B \rightarrow 0$ in Fig. 1). Second, the backlobe level is reduced by increasing the thickness B. Third, to further reduce the backlobe level, the upper and lower plates are modified using chokes and corrugation. Finally, the frequency response of the gain is presented and discussed.

2. Configuration and numerical analysis method

Fig. 1 shows the configuration of an FS antenna, which is fed by a strip probe excited at point F. For convenience, this antenna structure is designated as "a prototype FS antenna". As seen later (see Fig. 4), the upper and lower plates of the prototype FS antenna are modified using chokes and corrugation.

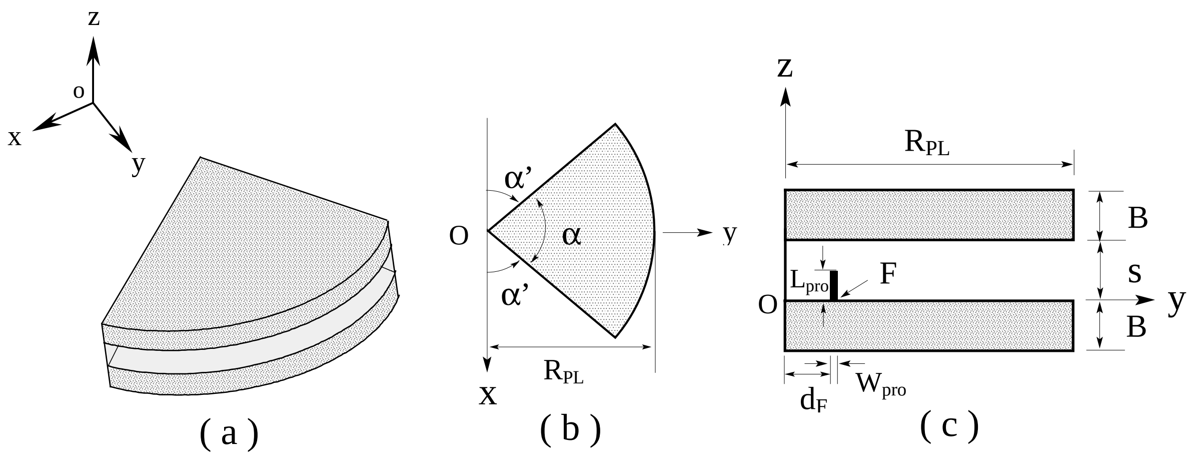

Fig. 1 Prototype fan-shaped antenna. (a) Perspective view. (b) Top view. (c) Side view

The notation of the prototype FS antenna is as follows: R_{PL} and B are, respectively, the radius and thickness of the upper and lower plates; s is the spacing between the upper and lower plates; α is the inner angle of the upper and lower plates; L_{pro} and W_{pro} are the length and width of the strip feed probe, respectively; and d_F is the distance from the origin o to the edge of the strip probe.

The analysis of the FS antenna is performed using an FDTD method, where Maxwell's equations are transformed into finite-difference equations using the cylindrical coordinates (r, φ, z) = (iΔr, jΔφ, kΔz) instead of using the rectangular coordinates (x, y, z) = (iΔx, jΔy, kΔz) [4]. The use of cylindrical coordinates has the advantage that there is no staircase error. Note that, if an FDTD method based on rectangular coordinates is used for the FS antenna, numerical errors, which result from the approximation of the curved and linear edges by staircases, appear.

Throughout this paper some values are fixed to simplify the discussion: R_{PL}= 50Δr, s = 9Δz, L_{pro} = 6Δz, W_{pro}= 1Δr, and d_F = 6Δr, where Δr = 0.042$\lambda_{76.5}$ and Δz = 0.029$\lambda_{76.5}$ with $\lambda_{76.5}$ being the wavelength at a frequency of 76.5 GHz. Thickness B and inner angle α are varied subject to the objectives of the analysis.

3. Antenna characteristics

A. Prototype FS antenna

Fig. 2 shows the radiation pattern as a function of the inner angle α at a frequency of 76.5 GHz, where the thickness is chosen to be infinitesimal (B → 0). It is found that, as the inner angle α decreases, the radiation pattern in the x-y plane becomes narrower. The narrowness of the radiation pattern leads to an increase in the gain in the y-direction. The gain at α = 80° increases to 7.8 dBi from 2.6 dBi at α = 180° (half-moon antenna).

As seen from Fig. 2, the backlobe level of the prototype FS antenna is large. The backlobe level on the minus y-axis is – 6.2 dB at α = 80°. The next consideration, therefore, is directed to reducing the backlobe level and increasing the gain, focusing on an FS antenna with α = 80° as a representative test antenna.

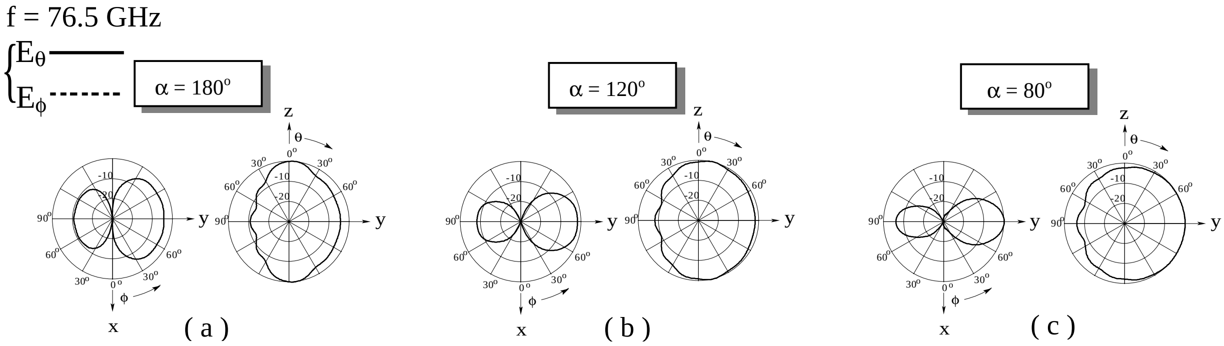

Fig. 2 Radiation pattern as a function of α at a frequency of 76.5 GHz, where the thickness B is infinitesimal. (a) α =180°. (b) α =120°. (c) α = 80°.

Detailed analysis shows that the backlobe level of the FS antenna is reduced when the thickness B of the upper and lower plates is increased. Fig. 3 shows the radiation pattern for a thickness of B = 0.292$\lambda_{76.5}$ at 76. 5 GHz, where the backlobe level on the minus y-axis is – 13.9 dB, which results in an improvement of 7.7 dB, compared with the backlobe for the infinitesimal case (B → 0, α = 80° in Fig. 2). This improvement leads to a gain enhancement of approximately 2.2 dBi.

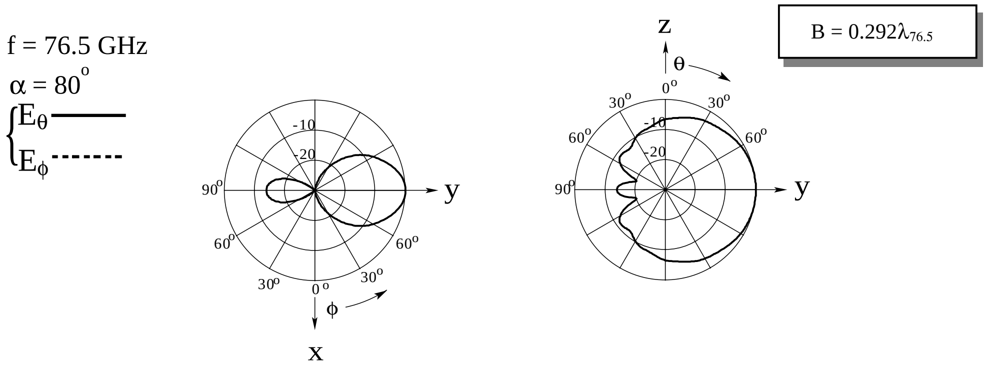

Fig. 3 Radiation pattern of a prototype FS antenna with α = 80° and B = 0.292$\lambda_{76.5}$ at a frequency of 76.5 GHz.

B. Modified FS antennas

For further reduction of the backlobe level and enhancement of the gain of the FS antenna, the upper and lower plates are modified, as shown in Fig. 4, which shows two cases of modification; (a) chokes inside the upper and lower plates; (b) a combination of chokes and corrugation on the upper and lower plates. The notation is as follows; t_{ch} is the choke thickness, d_{ch} is the choke depth, p_{cr} is the corrugation pitch, d_{cr} is the corrugation depth, and n_{cr} is the number of corrugations.

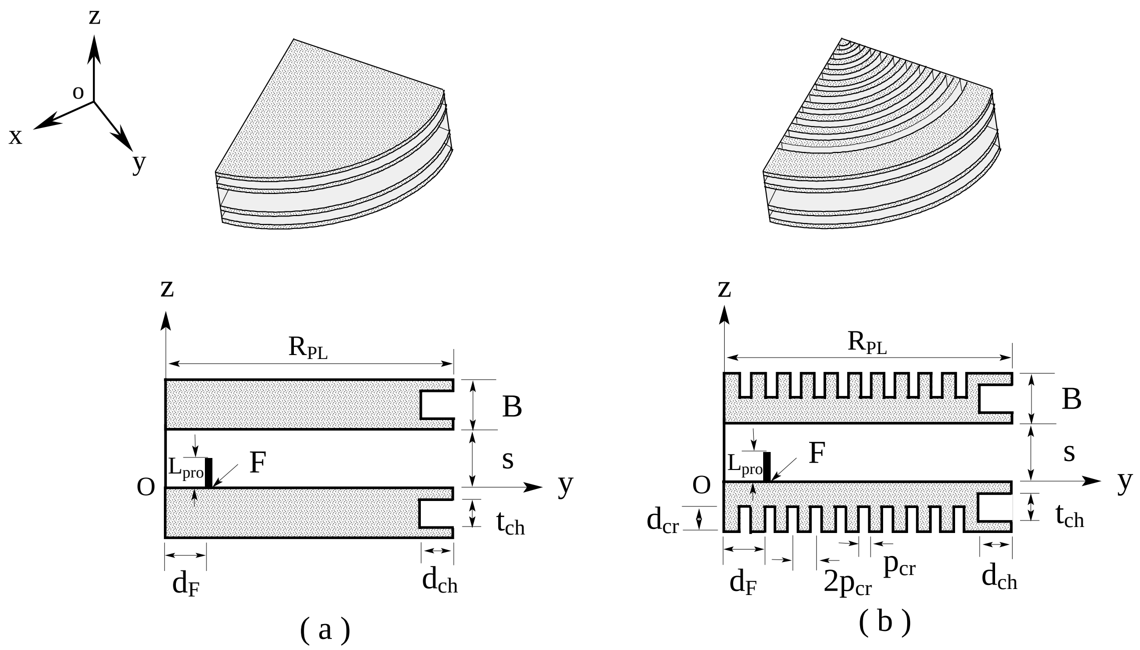

Fig. 4 Modified FS antennas. (a) FS antenna with chokes. (b) FS antenna with chokes and corrugation.

We investigate the effects of the modifications on the radiation pattern, using the previous prototype FS antenna with $\alpha = 80°$ and $B = 0.292\lambda_{76.5}$. Fig. 5 shows a comparison of the radiation patterns of the two modified antennas at a frequency of 76.5 GHz. It is clearly shown that the backlobe level on the minus y-axis is reduced, as desired. The backlobe level for the prototype FS antenna with infinitesimally thin plates ($B \rightarrow 0$) is reduced from – 6.2 dB to approximately – 16 dB by using chokes and – 22 dB by using chokes and corrugation. This means that the radiation in the minus y-region is due to the radiation from the currents flowing on the surfaces of the upper and lower plates. Although not shown in this paper, a detailed calculation reveals that the currents on the surfaces of the upper and lower plates are reduced with either chokes or corrugation.

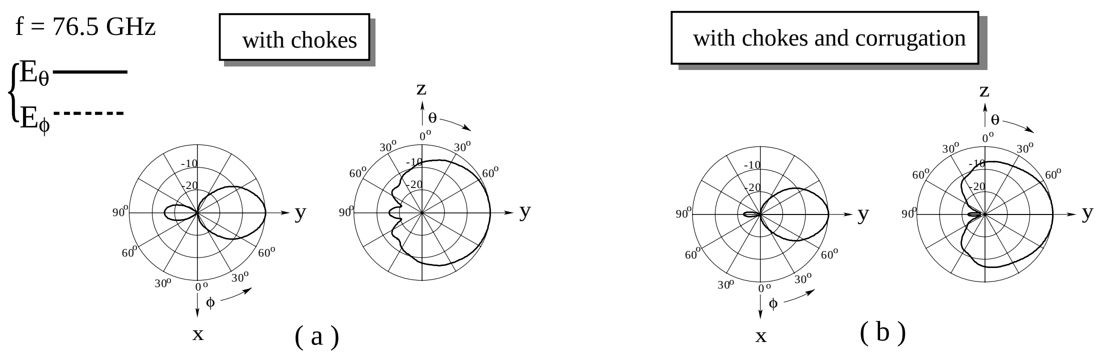

Fig. 5 A comparison of radiation patterns at 76.5 GHz. (a) FS antenna with chokes of $t_{ch} = 0.175\lambda_{76.5}$ and $d_{ch} = (1/4)\lambda_{76.5}$. (b) FS antenna with chokes and corrugation, where $t_{ch} = 0.175\lambda_{76.5}$, $d_{ch} = (1/4)\lambda_{76.5}$, $p_{cr} = 0.083\lambda_{76.5}$, $d_{cr} = 0.204\lambda_{76.5}$ and $n_{cr} = 10$.

So far the radiation patterns of the modified FS antennas have been investigated at a frequency of 76.5 GHz. Attention is paid to revealing the frequency response of the gain of the modified FS antenna shown in Fig. 4(b). The inner angle α is again set to be 80°. Fig. 6 shows the gain as a function of frequency. It is found that the gain is 10.9 dBi at 76.5 GHz and relatively constant within an analysis range of 75.5 GHz to 77.5 GHz. In other words, the modified FS-antenna has a wide band characteristic with respect to the gain.

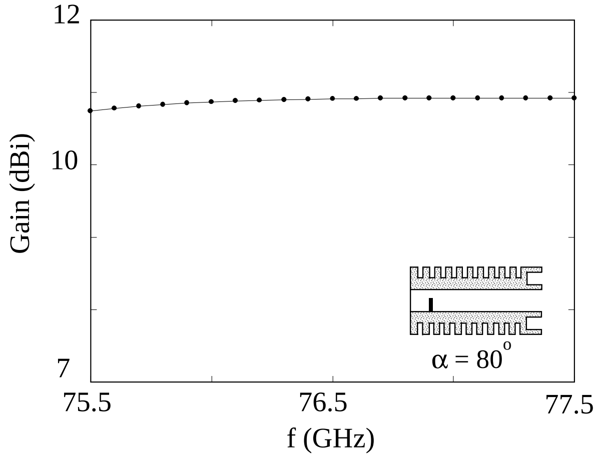

Fig. 6 Gain of a modified fan-shaped antenna as a function of frequency, where $t_{ch} = 0.175\lambda_{76.5}$, $d_{ch} = (1/4)\lambda_{76.5}$, $p_{cr} = 0.083\lambda_{76.5}$, $d_{cr} = 0.204\lambda_{76.5}$ and $n_{cr} = 10$.

4. Conclusions

A fan-shaped antenna has been analyzed using a finite-difference time domain method based on cylindrical coordinates. The radiation characteristics for an inner angle of α = 80° are revealed as a representative fan-shaped antenna. When the thickness B of the upper and lower plates is infinitesimally thin (B→0), the backlobe level is large (– 6.2 dB). However, the large backlobe level is reduced by increasing the thickness B. A backlobe level of approximately – 14 dB is obtained with B = $0.292\lambda_{76.5}$. Further reduction of the backlobe level is realized by adding chokes and corrugation to the upper and lower plates. It is found that the backlobe level is reduced to – 22 dB. The analysis also reveals that the gain at a test frequency of 76.5 GHz is approximately 10.9 dBi. The gain is relatively constant in an analysis range of 75.5 GHz to 77.5 GHz.

Acknowledgements

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