COMPACT PLANAR FOUR-SECTOR ANTENNA COMPRISING PATCH YAGI-UDA ARRAYS IN A SQUARE CONFIGURATION

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1. *Introduction*

A sector antenna reduces multipath fading and interference in broadband wireless communications [1], [2]. Recently, planar-type sector antennas have been studied that employ monopole Yagi-Uda antennas, patch Yagi-Uda antennas, or slot array antennas, and the feasibility of planar sector antennas has been clarified [3]-[5]. The planar antenna is effective for a portable terminal; however, smaller antennas are needed so that they can be used in recent compact user terminals. However, it is difficult to downsize the sector antenna because each sector requires individual array elements.

A planar multi-sector antenna employing the patch Yagi-Uda array, whose parasitic elements are commonly shared between other sectors, achieves a significant size reduction [6]. However, the termination conditions of the non-active feed elements of other sectors must be controlled properly to prevent reductions in gain and the front-to-back (F/B) ratio, which are caused by the oscillation of the non-active feed elements. Due to this, the control circuit is complex. Moreover, the switch for changing termination has an insertion loss.

In this paper, a simple four-sector antenna configuration is proposed that has a square configuration of patch Yagi-Uda arrays and has common parasitic elements with terminations at the corners of the square. The square arrangement of four patch Yagi-Uda arrays and commonly shared elements enable downsizing of the antenna, and the termination of commonly shared element enables high F/B without the control circuit.

The antenna configuration is described in Section 2. In Section 3, numerical analyses of the radiation pattern under termination conditions and the shape of shared parasitic elements are given. In Section 4, the validity of the electrical characteristics and the effect of downsizing without a termination control function by means of comparison with the conventional configuration are shown.

2. *Configuration of Proposed Antenna*

Figure 1 shows the antenna configuration. The line array inside the dotted line is a patch Yagi-Uda array that has a reflector element and two director elements. Four patch Yagi-Uda arrays are arranged in a square configuration, and two nearby arrays share the corner elements. The square configuration enables two influential opposite sector arrays to be separated, and the narrow rectangular shape of the non-shared elements achieves a high degree of isolation between orthogonal sectors. The shared elements are rectangular, and they work as reflectors when the oscillation direction is parallel to the long side of the rectangle. That is, the reflector element and end director element are the same shape, and the difference between them is only the direction in which they oscillate. Moreover, the shared elements have termination loads to obtain a high F/B [2], which is caused by the attenuation of the traveling wave reflection at the end of line array, and the termination

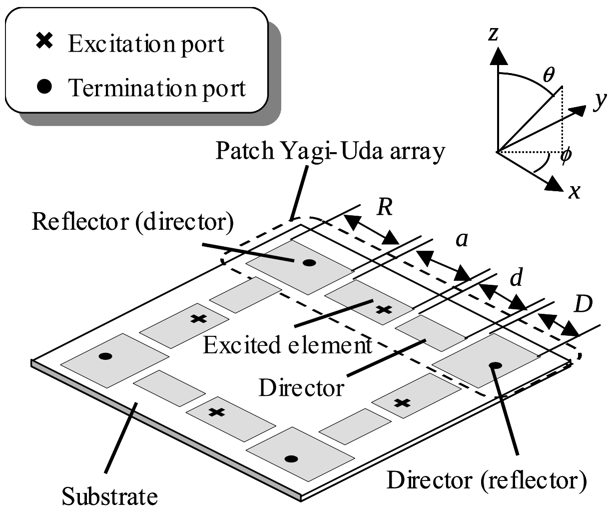


Fig. 1 Antenna configuration.

ports work only when the elements are directors. The location of the termination port must be determined properly to be able to obtain a high degree of isolation between modes, the oscillating directions of which are at right angles to each other. To achieve this, the port must be placed at a point, which is the exact middle line between the two short sides of the rectangle, and it must be shifted from the center of the rectangle along the line to match the termination and the impedance of the element. This mechanism achieves a high F/B without termination control of the shared elements. For the reasons described above, the size reduction, high F/B, and the simplification of the control circuit are achieved.

3. *Optimization of Common Element Shape and Evaluation of Termination Effect by Numerical Analysis of One Patch Yagi-Uda Array*

In this section, focusing on the F/B, the optimization of the shape of the common elements and the termination effect are presented. Figure 2 shows the configuration of the analysis model of one patch Yagi-Uda array. Here, the moment method analysis is employed. The substrate dielectric constant is $\varepsilon_r = 9.6$, the loss tangent is $\tan\delta = 1.1\times10^{-4}$, the thickness is 0.013 λ_0 (λ_0 is wavelength in free space), the gap width between elements is 0.003 λ_0, and d/a = 97%.

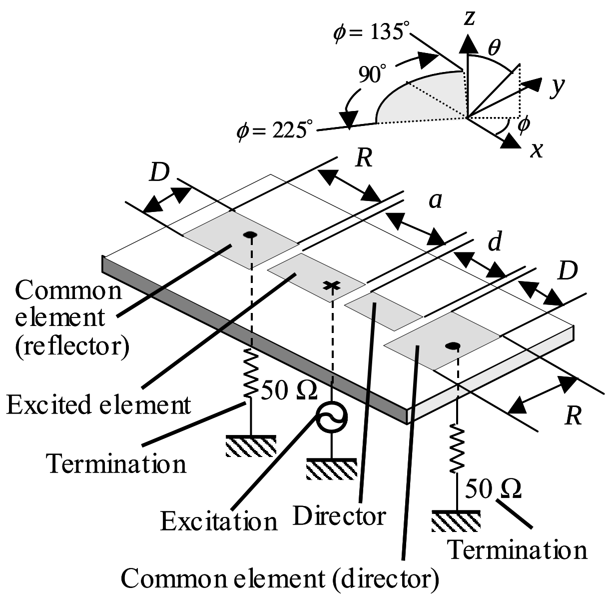


Fig. 2 Configuration of single line array.

Figure 3 shows the analysis results of the gain and F/B versus the length of short sides of the common parasitic element, *D*, when the length of the other sides, *R/a,* is 114%. Here, the definition of F/B is the ratio of the main lobe maximum level to the maximum level at the range of 90 degrees (135 deg. ≤ ϕ ≤ 225 deg.) in a conical plane, opposite to the main lobe. From these results, we found that F/B has the maximum value of 17 dB when the length of the short sides is *D/a* = 96.2%. Furthermore, the results showing that the antenna with termination has an 10-dB higher F/B than that without termination indicate the effectiveness of the end director termination. However, the maximum condition of the gain is different from that of F/B, the difference in the gain under these conditions is less than 1 dB. Because the transition of F/B is greater than that of the gain, we optimize the condition based on the F/B in the following.

Figure 4 shows the results of the maximum F/B versus the length of the long sides, *R/a*. The maximum F/B is obtained by optimizing *D* for each long side length, *R,* in the process described above. From these results, we found that the gain transition versus *R* is very slight and the conditions of *R/a* = 114% and *D/a* =

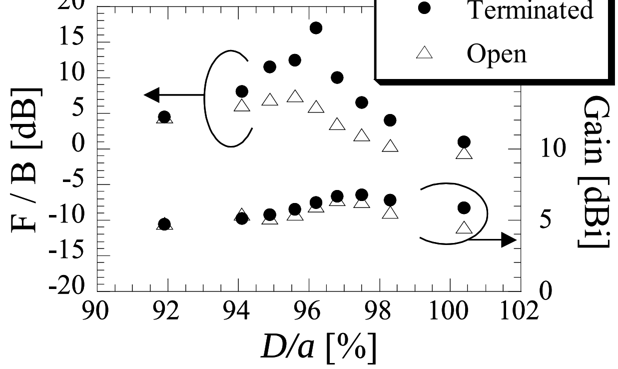


Fig. 3 F/B and gain versus parasitic element width *D*.

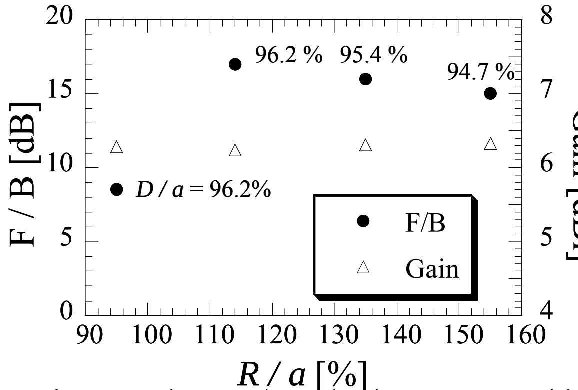


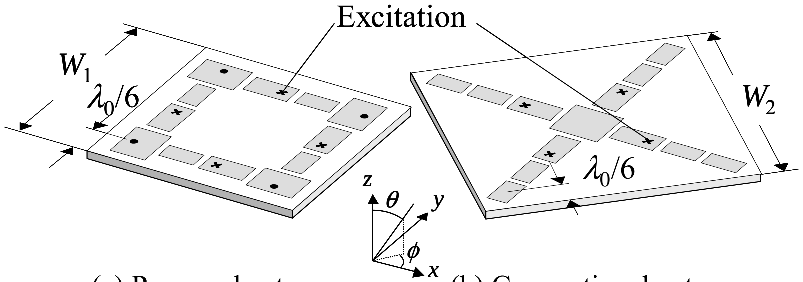
Fig. 4 Maximum F/B and gain versus parasitic element width *R*.

96.2% give the highest F/B.

Based on the above analysis, we find that the high F/B of 17 dB is obtained by the termination and shape optimization of the common parasitic element. We adopt these conditions in the following analysis.

4. *Effectiveness of Proposed Antenna*

In this section, to clarify the effectiveness of the square configuration, the analysis results of radiation patterns and the evaluation of the effect of size reduction are presented based on comparison to the conventional antenna in the entire configuration including all other sectors.

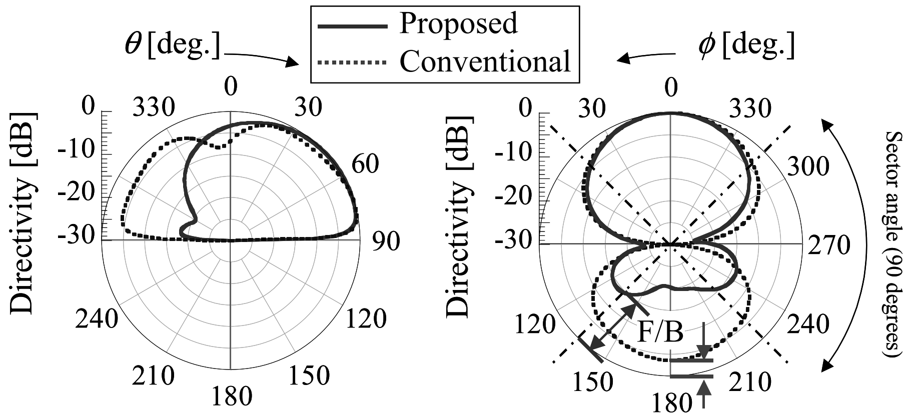


(a) Proposed antenna (b) Conventional antenna

Fig. 5 Configuration of analysis model.

Figure 5 is a sketch of the antenna configurations of the proposed and conventional methods [4]. The conventional antenna has four radially-configured patch Yagi-Uda antennas, the center element, which works as a reflector, is commonly shared, and there are no termination ports in the director elements. The configuration parameters are given based on the analysis in the previous section.

Figure 6 shows the radiation patterns obtained from the above models. We obtain a sector beam with a beam width of about 80 degrees. We also find that the proposed antenna improves the F/B remarkably. These results indicate that other sector elements have very little electrical influence on our antenna configuration, and a sector beam with a high degree of F/B is obtained without termination control of other sectors.



(i) xz-plane (ϕ = 0 degrees) (ii) Conical plane (θ = 60 degrees)

Fig. 6 Radiation pattern of two types of antennas.

Table 1. Comparison of Two Types of Antennas.

	Proposed method	Conventional method
Absolute gain	6.24 dBi	5.49 dBi
Efficiency	60 %	70 %
3-dB conical beam width	80 degrees	80 degrees
F/B	15.0 dB	4.2 dB
Substrate area ($W \times W$)	0.5 ($0.64\lambda_0^2$)	1.0 ($1.28\,\lambda_0^2$)

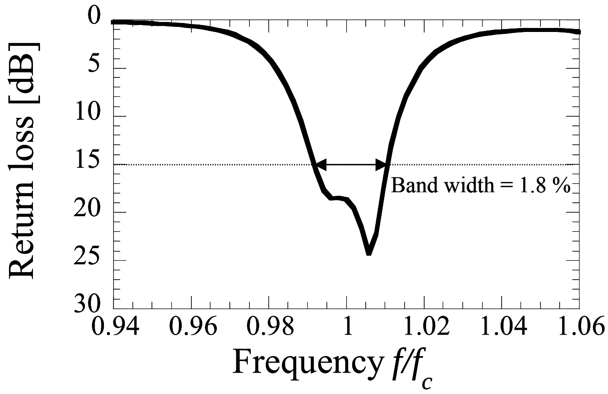


Fig. 7 Return loss of proposed antenna.

Table 1 shows a comparison of the analyzed results of the antennas based on the electrical properties and size. The sizes of the substrates are determined to be from the edge of the substrate to the center of the end element, 1/6 λ_0. The F/B of the proposed antenna in this table is lower than that in the previous section due to the influence of the other sectors, but the effect on our antenna is slight. These results show that the F/B is improved by 11 dB, and a 50% antenna area reduction is simultaneously achieved.

Figure 7 shows the return loss of the proposed antenna. We found that the bandwidth, which gives a return loss under 15 dB, is about 1.8%. This is because the two oscillation frequencies of the excited element and director element differ slightly, and this difference provides a wide bandwidth.

As described above, the proposed antenna decreases the antenna size. Moreover, the proposed antenna generates a sector beam that is affected only slightly by other sectors, that is, simplification of the antenna circuit is achieved because termination control is not necessary.

5. *Conclusion*

This paper proposed a novel compact four-sector antenna comprising patch Yagi-Uda arrays in a square configuration. This antenna decreases the size and has high F/B without termination control circuits of excited elements.

From the results of numerical analysis of the radiation pattern under termination conditions and the shape of shared parasitic elements, we found that the proposed antenna with termination achieves the high F/B of 17 dB, an 10 dB increase compared to that without termination. The analysis results of the radiation pattern of the entire configuration indicates that the effect from other sectors is slight, and the conical beam width of 80 degrees, which is suitable for a four sector antenna, is obtained. This intends that the proposed antenna requires no termination control, enabling simplification of the antenna circuit. We also found that the proposed antenna achieves a 50% antenna area reduction compared with the conventional configuration, which shares only the reflector element.

These results show that the proposed antenna achieves F/B improvement, control circuit simplification, and antenna area reduction at the same time.

Acknowledgment

The authors thank Dr. Toshikazu Hori of Fukui University for his constant encouragement and advice.

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