Antenna Metamaterial EBG

Radiation Pattern Characteristics of Antennas with Periodically Arranged Mushroom-shaped Elements

With the aim of achieving high-performance antennas for indoor repeaters and other applications, we studied radiation pattern characteristics when placing periodic mushroom-shaped elements near a rectangular microstrip antenna. This research was conducted jointly with the Hori Laboratory (Professor Toshikazu Hori and Associate Professor Mitoshi Fujimoto), the Graduate School of Engineering, University of Fukui.

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1. Introduction

It is desirable that antennas used for indoor repeaters and similar applications have a planar type from the viewpoint of easy installation, and the Microstrip Antenna (MSA) has found widespread use in this regard. The MSA has a simple structure consisting of a metal patch (metal plate) situated above a groundplane with a coaxial feed applied from below. It is thin and lightweight and easy to fabricate (**Figure 1**). In the case of an indoor repeater, however, constraints on equipment dimensions results in diffraction at the edge of the groundplane giving rise to large sidelobes[*1] and the generation of radiation leaks to the backside (backlobes)[1]. One technique for resolving this issue is to use periodic arrays[*2] of metal elements each consisting of a flat plate and rod in a mushroom shape (hereinafter reffered to as "MR elements"). In the example of Fig. 1, MR elements are arranged periodically in two arrays with a narrow gap between each element. Such an arrangement of MR elements exhibits Electromagnetic Band Gap (EBG) characteristics by which the radiation and propagation of radio waves in a specific frequency band can be sup-

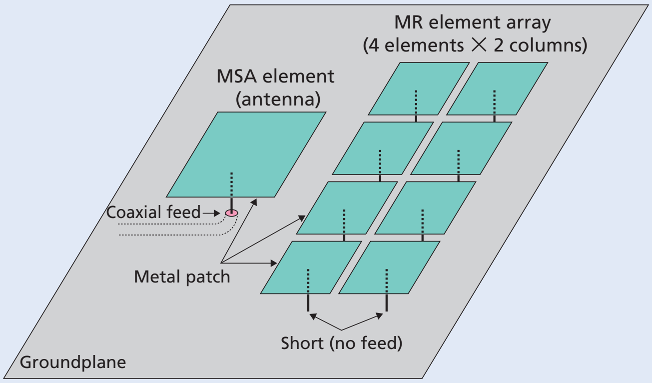


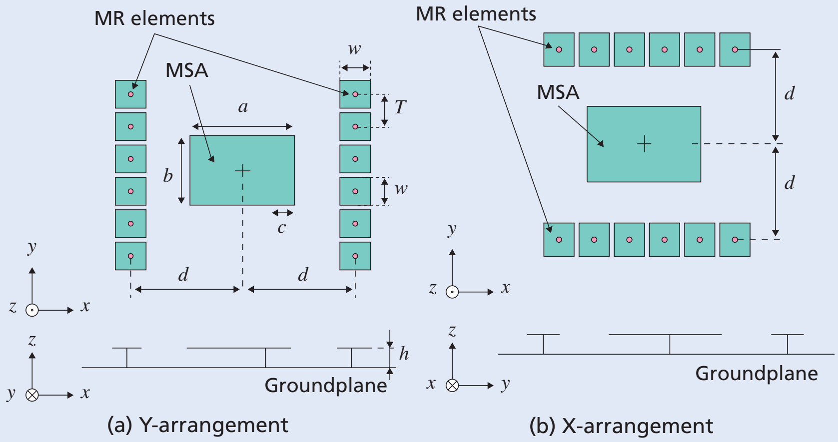
Figure 1 MSA and MR elements

[*1] **Sidelobe**: The lobes of the far field radiation pattern situated away from the main beam (see *4). The sidelobes are usually radiation in undesired directions and must therefore be suppressed.

[*2] **Periodic array**: the lining up of identical structures at equally spaced intervals, that is, with a fixed period.

pressed. Because of this property, the application of MR elements to antennas has been actively researched in recent years [2][3].

In this article, we study the radiation pattern characteristics of a rectangular MSA placed near MR elements with the aim of achieving an antenna with low-sidelobe and high-gain characteristics for such as indoor repeaters [4]. We examined, in particular, how the distance between the rectangular MSA and the arrays of MR elements and the method of arranging MR elements affect MSA radiation pattern characteristics. We also evaluated analysis results by constructing a prototype MSA with MR elements and performing experiments. This research was conducted jointly with the Hori Laboratory of the University of Fukui, which has many achievements in MSA research.



(a) Y-arrangement (b) X-arrangement

Figure 2 Analysis model

2. Analysis Model

The analysis model of a rectangular MSA placed near MR elements in two types of arrangements is shown in **Figure 2**. In one type called a "Y-arrangement," MR-element arrays (six elements) are placed on both sides of the MSA parallel to the y-axis (Fig. 2(a)). In the other type called an "X-arrangement," MR-element arrays (six elements) are placed on both sides of the MSA parallel to the x-axis (Fig. 2(b)). Although only one array is shown on either side of the MSA in the figure, we also study the use of multiple MR-element arrays.

The distance *d* between an MR-element array and the rectangular MSA is defined as the distance between the center of the MSA and the center of the nearest MR-element array. The MSA is designed to resonate at 2 GHz. The width *w* of an MR-element (square) metal patch is 30 mm and a short circuit to the groundplane is established by a metal pin of radius 1 mm and length 11 mm. The array period *T* is 32 mm. These parameters are chosen so that the band-gap characteristics occur at the resonant frequency of the MSA. Furthermore, to negate the effects of groundplane size so that the effects of the MR-element array can be focused on, an infinite groundplane is used. Taking distance *d*, the number of MR-element arrays, and the method of array arrangement to be the key parameters of this model, we performed an analysis of MSA radiation pattern characteristics while varying each of these parameters. Specifically, we varied distance *d* from 0.4 to 1.0 λ (where λ is the wavelength of MSA resonant frequency) and the number of MR-element arrays from one to four. We used the method of moments[*3] in electromagnetic field analysis.

3. Effects of MR-element Arrays on the Radiation Pattern Characteristics of a Rectangular MSA

3.1 Effects of Number of MR-element Arrays and Distance *d*

Radiation patterns in the E-plane (x-z plane) for the Y-arrangement are shown in **Figure 3**. These results show that, for one MR-element array, directive gain is less than that for MSA only and that sidelobe level is large indicating that MSA radiation pattern characteristics deteriorate because of the MR-element

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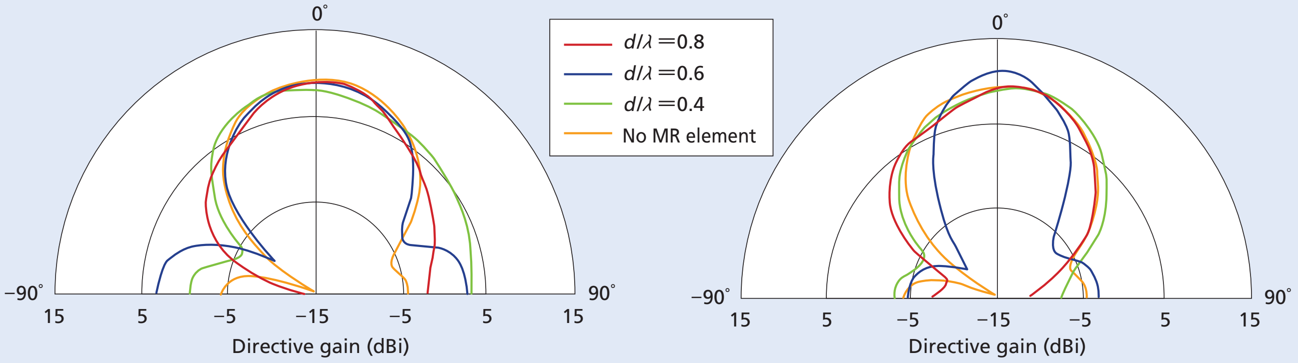
[*3] **Method of moments**: A method for analyzing electromagnetic fields. It can efficiently calculate the current flowing in metal and use that value to calculate the far field radiation pattern.



(a) 1 MR-element array

(b) 3 MR-element arrays

Figure 3 E-plane radiation patterns (Y-arrangement)

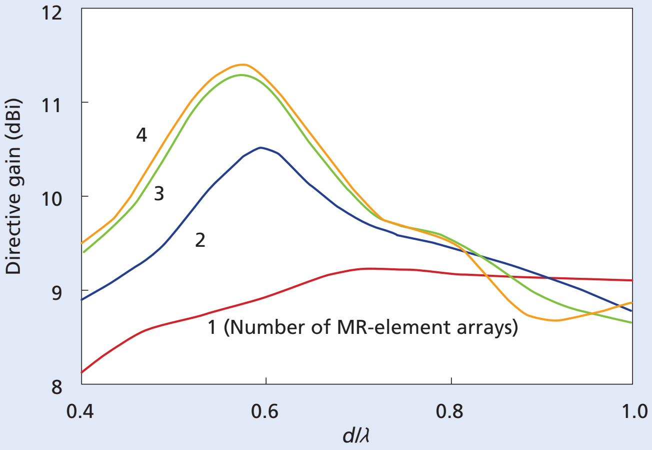


Figure 4 Relationship between distance d and directive gain (Y-arrangement)

array (Fig. 3(a)). For three MR-element arrays, however, sidelobes are suppressed for distance d = 0.6 λ and directive gain is improved indicating that MSA radiation pattern characteristics are improved (Fig. 3(b)). We consider that the reason for the deterioration in radiation pattern characteristics in the case of one MR-element array is that a periodic structure cannot be realized with only one array and that radio waves cannot be suppressed as a result. The relationship between directive gain and distance d between the MSA and the nearest MR element in the Y-arrangement is shown in **Figure 4** with the number of MR-element arrays as a parameter. These results show that MSA directive gain takes on a maximum value for distance d in the range 0.55 - 0.60 λ for two - four MR-element arrays, and that this maximum value rises as the number of MR-element arrays increases. The maximum value of MSA directive gain with MR elements is about 2 dB higher than that of MSA only (9.2 dBi). However, in the case of one MR-element array, no gain-increase effect by MR elements can be seen. As described above, we consider the reason for this is that a periodic structure cannot be realized with only one MR-element array.

3.2 Effects of Array Arrangement Method

The relationship between the number of MR-element arrays and maximum MSA directive gain is shown in **Figure 5**. For the Y-arrangement, it can be seen that the maximum value of directive gain rises as the number of MR-element arrays increases. However, for the X-arrangement, it can be seen that the maximum value of directive gain hardly varies regardless of the number of MR-element arrays. It can also be seen that arranging MR-element arrays near the MSA increases directive gain compared to that of MSA only. In particular, four MR-element arrays in a Y-arrangement increases directive gain by 2.1 dB. Next, the relationship between the number of MR-element arrays and distance d_{opt} for which directive gain is maximum is shown in **Figure 6**. These results show that distance d_{opt} depends on the MR-element arrangement method. In the X-arrangement, we see that distance d_{opt} is 0.8 λ for two - four arrays, but in the Y-arrangement, we see that the required area can be made smaller than that of the X-arrangement.

Radiation patterns for the MSA corresponding to the maximum directive gain are shown in **Figure 7**. For the Y-arrangement, the main beam[*4] becomes sharper as the number of MR-element arrays increases, but for the X-arrangement, that effect is small.

3.3 Experimental Evaluation

To evaluate the validity of the analysis results described in the previous section, we constructed a prototype MSA with MR elements placing three arrays of MR elements on both sides of the MSA in a Y-arrangement. The prototype MSA is shown in **Photo 1**. We used brass for the MSA element and MR elements and used a groundplane 400×400 mm in size. The thickness of the MSA-element and MR-element patches was 1.0 mm. Experimental results for directive gain when placing three MR-element arrays on both sides of the MSA in a Y-arrangement are shown in **Figure 8** together with analysis results for comparison purposes. These results show that experimental results reveal a distance d_{opt} for which directive gain is maximum the same as in analysis results and that the two values agree well. These findings demonstrate the validity of the results obtained by analysis.

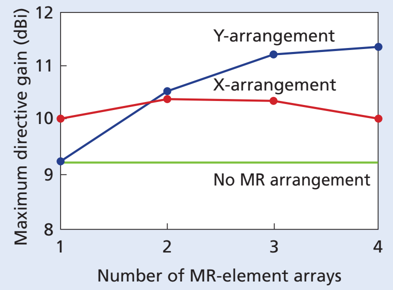


Figure 5 Relationship between the number of MR-element arrays and directive gain

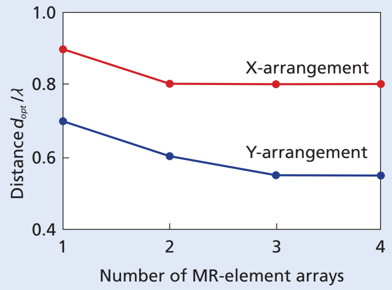
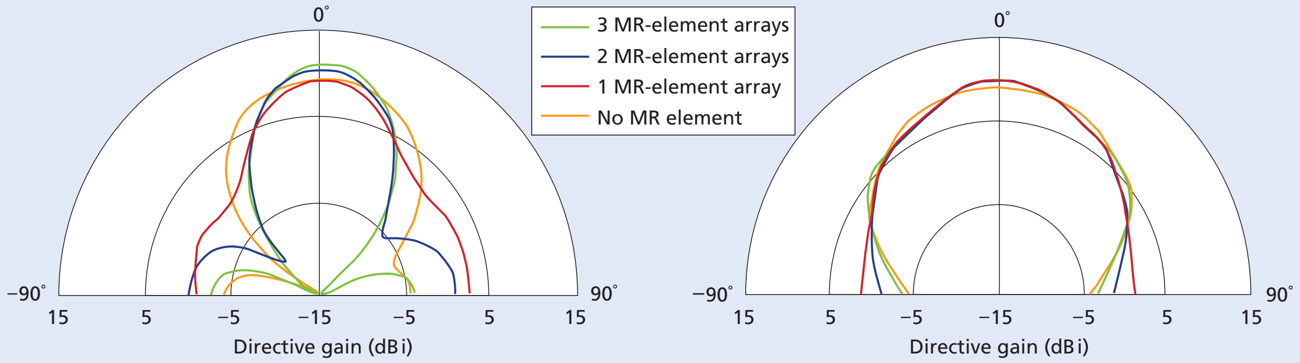


Figure 6 Relationship between the number of MR-element arrays and distance d_{opt}

4. Conclusion

With the aim of achieving a high-performance indoor repeater antenna, we studied the radiation pattern characteristics of a rectangular MSA placed near MR elements. It was found that periodically-arranged MR elements



(a) Y-arrangement, E-plane patterns

(b) X-arrangement, H-plane patterns

Figure 7 MSA radiation patterns corresponding to maximum directive gain

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[*4] **Main beam**: The lobe of the far field radiation pattern containing the maximum radio wave power among various directions in which radio waves are radiated from an antenna. It is important to orient the main beam in the desired direction.

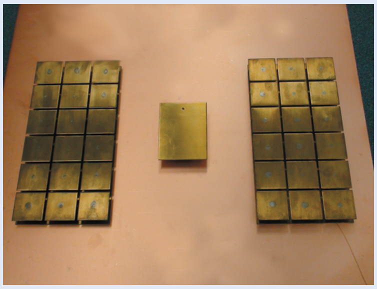

Photo 1 MSA prototype

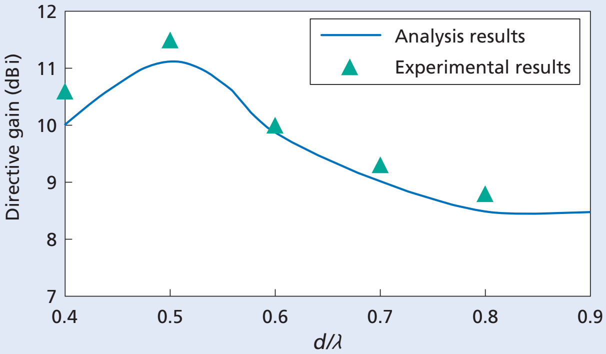

Figure 8 Change in directive gain (3 arrays in a Y-arrangement)

near a rectangular MSA reduced MSA sidelobes and increased directive gain. Specifically, it was found that four arrays of MR elements in a Y-arrangement increased directive gain by 2.1 dB and that distance d_{opt} corresponding to the maximum gain was 0.6 λ for two - four MR-element arrays. Finally, to evaluate these analysis results, we constructed a prototype MSA with three arrays of MR elements placed on both sides of the MSA patch. It was found that experimental and analysis results agreed well indicating that the latter were valid. Looking forward, we plan to apply these basic characteristics to improving the performance of repeater antennas to even higher levels.

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