Experimental Investigations into Grating Lobe Suppression in Distributed Array Antennas

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Abstract

The appearance of grating lobes is one of the major issues concerning distributed array antennas (DAA) since the lobes cause antenna gain reduction. This study presents an experimental verification of grating lobe suppression in DAA. A prototype model of the antenna is a linear array and comprises eight subarrays, each of which includes eight elements at intervals of half the wavelength. An optimal subarray arrangement of low sidelobe that is extracted from all the cases under the conditions that the number of subarrays and their size are fixed is determined and applied to the experimental distributed array. The radiation pattern results of this array confirmed that the arrangement could achieve a lower sidelobe level than that achieved by the equal interval arrangement.

1. INTRODUCTION

The technical capabilities of a distributed array antenna (DAA) have been studied for its application to a distributed array radar (DAR) [1], [2]. This is because DAAs offer the following significant advantages: low cost, small scale, and the dispersal and coherent networking of multiple subarrays for digital signal processing. Because of this, an equivalent digital beam forming (DBF) array with a very large antenna aperture is achieved, as shown in Fig. 1 (schematic of the DAA concept). This technology enables high performances in the monitoring range, resolution in all radar systems, and cost reduction. In addition, the array exhibits excellent redundancy because its form can be changed easily to suit various situations and each subarray can be transported separately.
However, the serious issue of the drop in the antenna gain persists. This is because the interval between each subarray results in the formation of grating lobes in the synthesized radiation pattern of this array. In the particular case of a highly thinned subarray, the grating lobes also form inside the main lobe of the array radiation pattern, thereby making their moderate removal very difficult.
In general, unequally spaced arrays with a random spaced interval and a definite rate shifted interval have been applied as antenna systems to suppress the grating lobes [3]. However, since the subarray position in the former arrays are determined probabilistically, it is not guaranteed that they will always be capable of suppressing undesired lobes. In order to achieve a lower sidelobe level, non-uniform excitation, namely, tapered aperture distribution, is also applied to the array [4]. However, in the highly thinned DAA, the grating lobe level cannot be controlled using this technique.

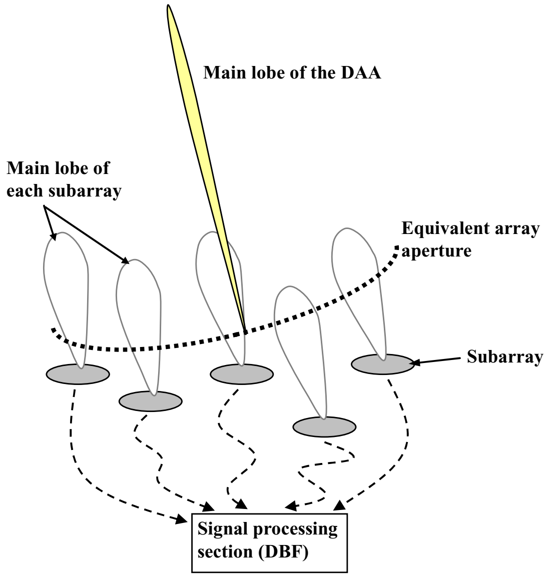

Fig. 1: Concept of a distributed array antenna

In this paper, the results of the experiment to prove the effect of grating lobe suppression are investigated by using a DAA prototype. Here, a subarray arrangement with an unequal interval is attempted to achieve the lowest sidelobe level under the limited conditions of the number of subarrays and their size in a linear array antenna. The advantage of this unequal arrangement is clearly confirmed from the comparison of this array with a uniform array of the same scale.

2. GEOMETRY OF DISTRIBUTED ARRAY

This section provides a detailed description of the geometry of the DAA used in this experiment. The structure of the prototype is also shown.

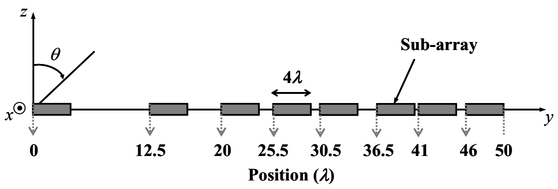

Fig. 2: DAA geometry

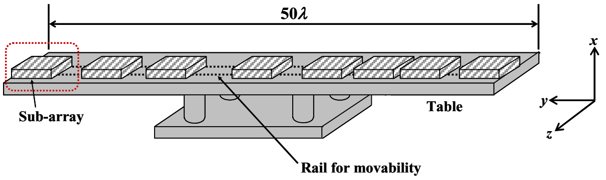

Fig. 4: Outline structure of the DAA prototype

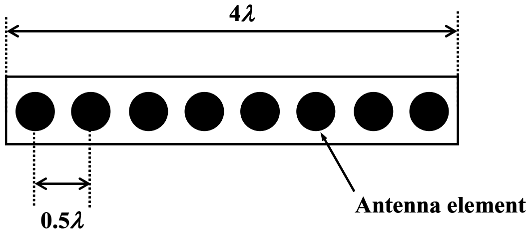

Fig. 3: Subarray antenna configuration

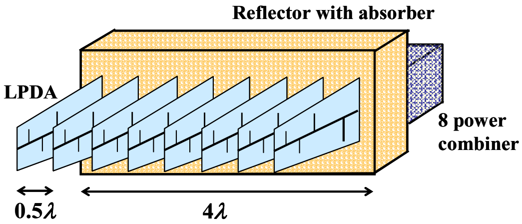

Fig. 5: Experimental model of the subarray antenna

A. Subarray Structure

The experimental DAA model is shown in Fig. 2. It comprises a one-dimensional linear array. The entire antenna consists of eight subarrays, and the subarray position of both the ends is fixed so that the aperture length of the array becomes 50 wavelengths. Thus, six remaining subarrays can be arbitrarily arranged between both the ends. Each subarray comprises eight elements arranged at intervals of 0.5 wavelengths, and the aperture size is 4 wavelengths, as shown in Fig. 3. These sparse linear arrays are uniformly excited and can be rearranged by removing the inner subarrays at intervals of 0.5 wavelengths.

B. Subarray Arrangement and Sidelobe Level

As a result of considering all the cases of subarray arrangement under these conditions, it is confirmed that the DAA with unequal intervals, as shown in Fig. 2, is an example of lowest sidelobe level achievement [5]. In reference [5], an interactive, visual, and convenient browser is proposed and developed in order to easily extract the configurations of a sparse linear array with the lowest sidelobe levels. An exhaustive search using the browser yields another subarray arrangement with substantially lower peak sidelobe levels (–17.2 dB) than the non-sparse case (–13.2 dB) from among all the DAAs consisting of 10 subarrays.

C. DAA prototype

Fig. 4 shows the outline structure of the DAA prototype used in this study. Eight subarrays are arranged on a table with movable rails; their individual positions along the rails can be changed. Furthermore, a large variety of DAAs can be reproduced by controlling the individual subarray positions.

Fig. 5 shows a detailed structure of the subarray. The structure is composed of eight elements at intervals of 0.5 wavelengths and an 8-to-1 power combiner. By directly connecting each element and 8 combiner, we obtain a subarray with a compact and easy composition. A log-periodic dipole array antenna (LPDA) is applied to the antenna element. Microwave absorbers are used for eliminating rear radiation. The details of the prototype are as follows:

<u>DAA</u>

- Aperture length … 50λ
- Number of subarrays … 8
- Subarray arrangement … equally/unequally spaced
- Excitation … uniformly excited

<u>Subarray</u>

- Antenna element … LPDA
- Number of elements … 8
- Element arrangement ... intervals of 0.5λ on the H-plane
- Polarization … vertical

(λ denotes the wavelength in free space)

3. Experimental Results

A. Radiation Pattern of the Subarray

Fig. 6 shows the radiation pattern in the H-plane of the LPDA. On placing the microwave absorber behind the element, the radiation pattern becomes nearly omnidirectional within the range of ±30°. Fig. 7 shows the radiation pattern in the direction of the azimuth (*yz*-plane) of the subarray. The main lobe is in the range of ±15°. Furthermore, the antenna element pattern within this range is almost omni-directional. Based on these results, we can analyze the radiation pattern of the DAA

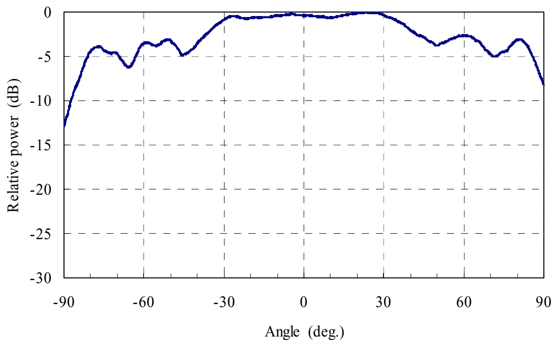

Fig. 6: Measured radiation pattern of the LPDA

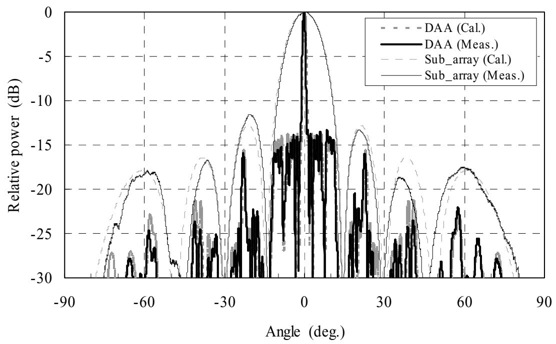

Fig. 8: Radiation pattern of the DAA in Fig. 1 (*yz*-plane)

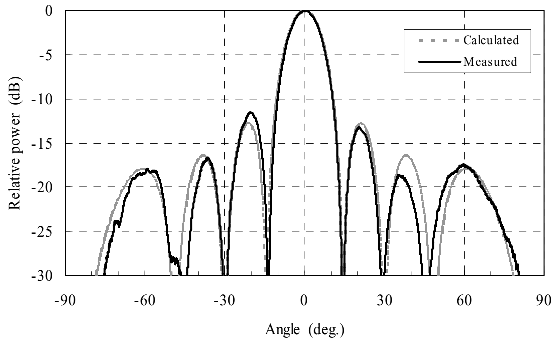

Fig. 7: Radiation pattern of the subarray (*yz*-plane)

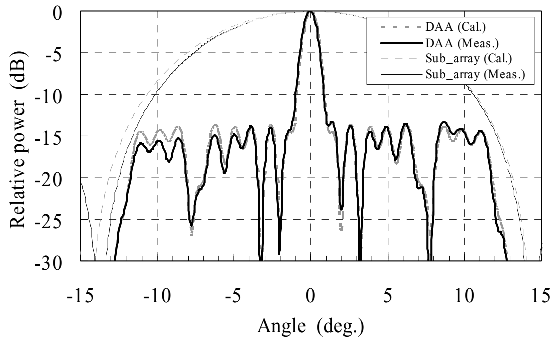

Fig. 9: Close-up view of Fig. 8

by assuming the element to be a point source. The calculated pattern of the uniformly excited eight point sources is also described in this figure, and it corresponds well to the measured pattern.

B. Radiation Pattern of DAA

The experiment involving a subarray arrangement with equal intervals was conducted for comparison with the DAA. In this experiment, the received signal to which the RF signal from each subarray is synthesized with a power combiner is measured. Figs. 8 and 9 (close-up view) indicate the measured radiation pattern of the DAA with the arrangement, as shown in Fig. 1. The calculated pattern of the same sparse array comprised eight point sources and the measured and calculated patterns of the single subarray are also described in each figure. From these, sidelobe levels lower than –13.5 dB were achieved within the visible region, especially in the subarray main lobe. Further, the calculated and measured patterns are in good agreement.

Fig. 10 shows the comparison of the DAA radiation pattern, which is similar to the pattern shown in Fig. 9, with that of the equal interval arrangement case. It can be confirmed that the grating lobes formed because of the subarray interval over one wavelength have been suppressed by about 7 dB.

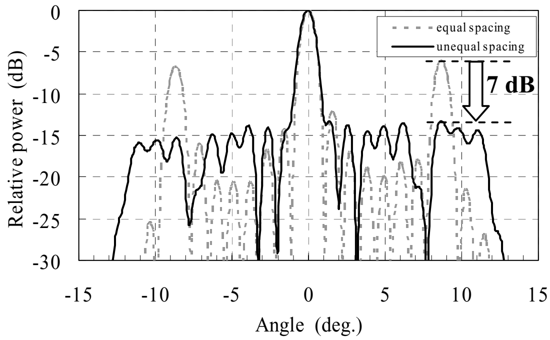

Fig. 10: Comparison between equally/unequally spaced intervals

It is believed that the grating lobe suppression by the subarray arrangement of the DAA shown in Fig. 1 is closely related to the following:

- Due to the tapered aperture distribution caused by the rarefaction and condensation of the subarrays located along the entire length of the DAA, the sidelobes of the main lobe neighborhood are suppressed.

- The grating lobe is generated at the wider angle rather than that of being assumed from the average interval, and then it is suppressed by superimposed with the subarray pattern.

In addition, it is confirmed that the application of the Capon beamformer technique to this DAA would improve the suppression of the grating lobes; these results will be published in this proceeding [6].

4. CONCLUSIONS

An experiment for grating lobe suppression in the distributed array was carried out, and the effectiveness of the unequal interval of subarray arrangement that was found by exhaustive searching was confirmed.

For future study, the mechanism that suppresses the grating lobes will be theoretically clarified so as to apply this technology to a prospective radar field.

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