Experimental Evaluation of Capon's Beam Former Applied to a Non-uniformly Arranged Distributed Array

#Kazufumi Hirata [1], Kazushi Nishizawa[1], Shoji Matsuda[2], Hiroaki Miyashita[1], and Shigeru Makino[1]
[1]Information Technology R & D Center, Mitsubishi Electric Corporation
5-1-1 Ofuna, Kamakura, Kanagawa 247-8501, Japan, Hirata.Kazufumi@bp.MitsubishiElectric.co.jp
[2]Communication Systems Center, Mitsubishi Electric Corporation
8-1-1 Tsukaguchi-Honmachi, Amagasaki, Hyogo 661-8661, Japan,

Abstract

A distributed array with a very large aperture can form a very narrow beam and has very high gain. A radar system with such a distributed array thus provides high resolution and long-distance detection. We study the Capon's beam former applied to a non-uniformly arranged distributed array to attain high resolution and long distance detection. It was found that the non-uniform arrangement can suppress the spatial correlation between the main lobe and the grating lobes. Accordingly, the Capon's beam former even can suppress grating lobes. Experiment results on antenna patterns and the null beam gain show that the grating lobes are successfully suppressed by the Capon's beam former.

1. Introduction

A very large aperture antenna can be formed by adding up the output signals of arrays distributed in a large area [1]. Such an antenna is called a distributed array. And each component of the array is called a sub array. The distributed array can form a very narrow beam and has very high gain owing to its large aperture. A radar system utilizing such an array will thus have high resolution and offer long-distance detection. It is, however, a problem that a distributed array has the grating lobes formed by the large intervals between the sub arrays. As the grating lobes exist near the main lobe, those cannot be suppressed by the sub-array pattern. A non-uniform arrangement can suppress such grating lobes near the main lobe. [2]

In this paper, we study Capon's beam former [3] applied to a non-uniformly arranged distributed array to suppress grating lobes more effectively. Capon's beam former keeps the response of the main beam direction and minimizes the output power. By this control, Capon's beam former can form the main beam and suppress an undesired wave that enters from a direction other than the main beam direction [4]. At that time, a null on the antenna pattern is formed in the direction of undesired wave. Therefore, if the undesired wave enters from the grating-lobe direction, the null is formed and this grating lobe is suppressed. Ordinarily, the grating lobe cannot be suppressed because the steering vector of the main lobe is the same as that of the grating lobe. However, the spatial correlation of the steering vectors of the main lobe and the grating lobe is decreased by a non-uniform arrangement. Capon's beam former can thus suppress the grating lobes.

Simulation and the experimental results on the antenna patterns show that the grating lobes are successfully suppressed by the proposed Capon's beam former applied to a non-uniform arranged distributed array.

2. Capon's Beam Former Applied to the Non-Uniformly Arranged Distributed Array

A. Non-Uniformly Arranged Distributed Array

Figure 1 shows a model of the antenna arrangement used to study a non-uniform arranged distributed array. In Fig. 1, the distributed array has six sub arrays, and a sub array has eight element antennas. The size of the distributed array is 50λ (λ is wavelength), as shown in Fig. 1, where both sides of the sub arrays are fixed, and the others can be stationed freely at 0.5λ-interval graduation. Each sub array has eight element antennas arranged at equal intervals of 0.5λ. And each sub array doesn't overlap with the next. Under these above conditions, the optimum arrangement is that which produces the minimum grating-lobe level in all capable arrangements [2]. Figures 2 and 3 show the antenna patterns in the six-sub-arrays-case and the eight-sub-arrays-case respectively. Each figure shows the antenna pattern of the equal space arrangement and the optimum arrangement. According to these figures, it is clear that the grating lobes are suppressed effectively and the side-lobe levels near the main lobe are almost the same in terms of optimum arrangement. Especially, in the eight-sub-arrays case, the grating lobe level is under -13 dB, that is, ULA (uniform linear array) side-lobe level. It can thus be concluded that the higher the number of sub arrays, the lower the grating level.

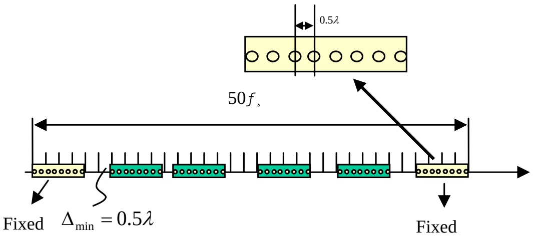

Fig. 1: Arrangement model of non-uniformly arranged distributed array.

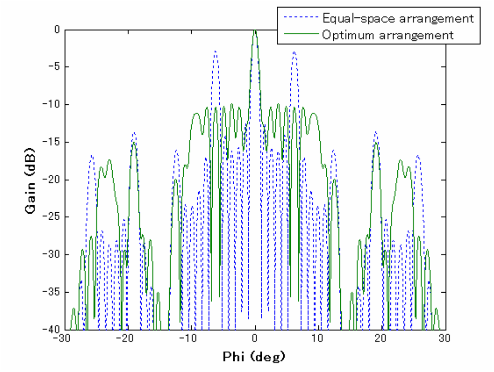

Fig. 2: Antenna patterns (simulation results).
Equal-space arrangement and optimum arrangement:
number of sub arrays is six.

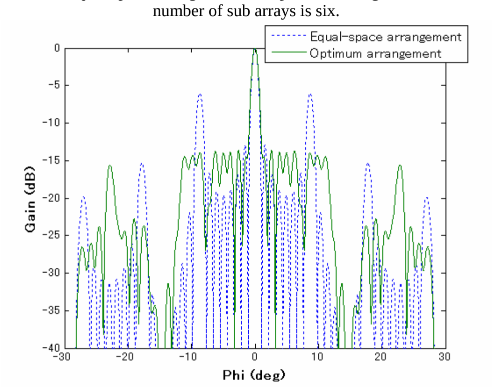

Fig. 3: Antenna patterns (simulation results).
Equal-space arrangement and optimum arrangement:
number of sub arrays is eight.

B. Capon's Beam Former

The algorithm used for Capon's beam former (CBF) [3] is explained in the following. CBF keeps the response of the main beam direction and minimizes output power. By applying this operation, CBF can form the main beam and suppress any undesired wave that enters from any direction other than that of the main beam. CBF can thus form a null in the direction of the grating lobe when an undesired wave enters from that direction.

Figure 4 shows a basic array antenna model that has M element antennas and the same number of weights for controlling the phase and the amplitude of the received signals. The array output signal is given by adding up the weighted received signals. The array antenna can control the directionality of the gain by changing the weight. The role of CBF is thus to calculate the beam-forming weights and to form the beam and the null.

Here, the steering vector $\mathbf{a}_0$ of the main beam direction is defined as follows:

$$\mathbf{a}_0 = \left[\exp\left(j\phi_1\right) \quad \exp\left(j\phi_2\right) \quad \cdots \quad \exp\left(j\phi_M\right)\right]^T \quad (1)$$

where superscript T denotes transpose. In Eq. (1), ϕ_m is the received phase difference between antenna $\#m$ and the original point. Weight vector $\mathbf{w}$ and received signal vector X are defined as

$$\mathbf{w} = \left[w_1 \quad w_2 \quad \cdots \quad w_M\right]^T \quad (2)$$

$$X = \left[x_1(t) \quad x_2(t) \quad \cdots \quad x_M(t)\right]^T \quad (3)$$

where w_m is the weight for antenna $\#m$, and $x_m(t)$ is the received signal. And array output signal $y(t)$ is given by

$$y(t) = \mathbf{w}^T X \quad (4)$$

The correlation matrix of X is given by

$$R = E\left[X^* X^T\right] \quad (5)$$

where $E[\ ]$ denotes the time average, and superscript * means conjugate. In CBF, the constrained condition to keep the response of the main beam direction is given as

$$\mathbf{a}_0{}^T \mathbf{w} = 1 \quad (6)$$

Under the above condition, the weight $\mathbf{w}_{opt}$ by which the power of array output signal $\mathbf{w}^H R \mathbf{w}$ is minimized is given as

$$\mathbf{w}_{opt} = \frac{R^{-1}\mathbf{a}_0^{\ *}}{\mathbf{a}_0^{\ T} R^{-1}\mathbf{a}_0^{\ *}} \qquad (7)$$

By applying weight $\mathbf{w}_{opt}$, CBF can suppress the undesired wave, while the response of main beam direction is kept. Ordinarily, the steering vectors of the main lobe and the grating lobe are the same. For this reason, CBF cannot suppress the grating lobes. However, CBF applied to non-uniform array can suppress the grating lobes because the spatial correlation between the main lobe and the grating lobe is decreased by the non-uniform arrangement.

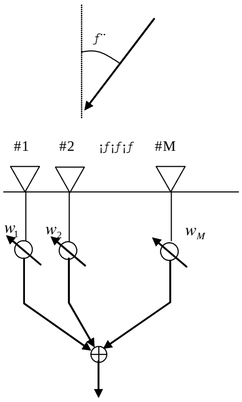

Fig.4: Array antenna model.

3. EXPERIMENTAL RESULTS

A. Experimental Conditions

Figure 5 shows the configuration of the experiment for evaluating the distributed array. In this configuration, each sub-array has eight element antennas arranged at equal intervals of 0.5 λ. Each sub-array is set on the table, and both side sub-arrays are fixed. The size of distributed array is 50 λ. The other sub-arrays can move on the rail. And all sub arrays do not overlap each other. Every element antenna is log periodic dipole antenna (LPDA) type. The parameters used in the experiment are listed in Table 1. The optimum antenna arrangements for the six- and eight-sub array cases are shown in Figs. 6 and 7, respectively. These arrangements have the minimum grating lobe level in all capable arrangements under the above conditions. The antenna patterns of these optimum arrangements and equal-space arrangements are measured in the chamber. We calculated the weights for CBF using these antenna patterns, and apply them to the array output in off-line processing. We evaluated the CBF performance by calculating the null beam gain.

TABLE 1: PARAMETERS USED IN EXPERIMENT

Parameters of distributed array	
Aperture	50 λ
Number of sub arrays	6 or 8
Arrangement method	Equal-space arrangement or optimum arrangement
Parameters of sub array	
Aperture	4 λ
Number of sub elements	8
Intervals of elements	0.5 λ
Element antenna	Log Periodic Dipole Antenna (LPDA)

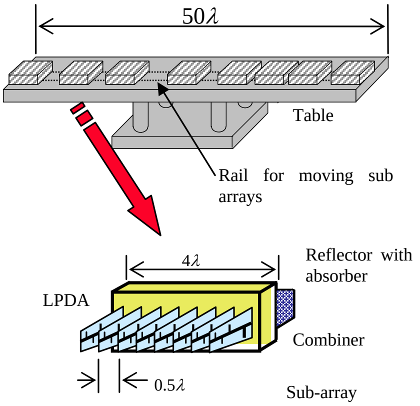

Fig. 5: Experiment configuration of distributed array.

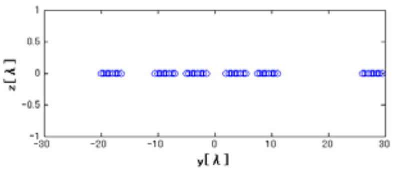

Fig.6: Optimum arrangement of distributed array. (six sub arrays)

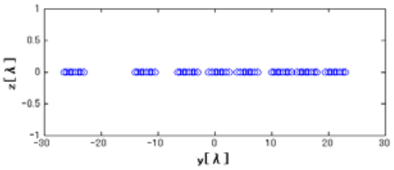

Fig.7: Optimum arrangement of distributed array. (eight sub arrays)