PATTERN CALIBRATION FREE ANTENNA BY SUPPRESSING MUTUAL COUPLING BETWEEN ELEMENTS

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1. Introduction

In resent years, there are a lot of studies about beamcontrol or direction of arrival (DOA) estimation using an array antenna. The array element patterns are distorted and the results are often changed for the worse. Pattern distortion is caused by the mutual coupling, arrangement error of elements and amplitude and phase error of RF circuit [1]. Various calibration methods array antenna and RF circuit all together was proposed [2], but generally these methods need special mechanism and complex processing. In practice, the calibration should be treated separately dividing into antenna and RF circuit. Calibration of RF circuit is comparatively easy using the calibration reference circuit [3], but calibration of array antenna is not easy to conduct because a coupling matrix of the array antenna is changed seriously on measurement environments.

This paper investigates a liner array antenna suppressed mutual coupling and variation between elements. If the mutual coupling is suppressed, the distortion of the element pattern and the effect of arrangement error of elements could be suppressed, and good performance could be realized without calibration of antenna. The array antenna system is evaluated with DOA estimation of ESPRIT method [4] in this paper. In section 2, the relation between coupling matrix of an array antenna and DOA estimation error is evaluated in computer simulation, and clarify the range of mutual coupling to minimize the estimation error. In section 3, microstrip patch array antenna with boxy metallic wall is designed and estimation error in ESPRIT is examined in a measurement of DOA estimation in anechoic chamber using the array antenna.

2. Scattering Matrix of an Array Antenna and DOA Estimation Error

In this section, estimation error in ESPRIT is examined changing the parameters of the scattering matrix and element numbers using computer simulation. Fig. 1 shows the array antenna and direction definition. The array antenna is a uniform linear array with half wavelength interval. The error around 90° becomes very large due to a linear array, so maximum error E_{max} is selected from θ = 0° to 60° every 10°. The direction of θ = 0° is the broad side direction of the array. The element number M is changed from 4 to 20 every 4 elements.

Fig. 2 shows the setting of scattering matrix S. S is assumed a Toeplitz matrix neglecting noise matrix N. The first column ***s*** is defined as

$$\boldsymbol{s} = \begin{bmatrix} A_1 e^{j\phi_1} & A_2 e^{j\phi_2} & \cdots & A_M e^{j\phi_M} \end{bmatrix} \quad (1).$$

It supposed that the return loss of each element A_1 was -14dB. Mutual coupling between neighbor elements A_2 is changed from -10dB to -50dB and the other coupling $A_{3,4,\ldots,M}$ is in inverse proportion to the distance of the elements.

$$A_n = \frac{A_2}{n-1} \qquad \text{n=2, 3,…M} \quad (2)$$

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Phase of $\boldsymbol{s}$ $\phi_{1,2,,\ldots M}$ are uniform random numbers. Amplitude and phase of N is a normal distribution and the standard deviation is NA_{std} and $N\phi_{std}$, respectively.

Fig. 3 shows maximum value of estimation error E_{max} as a function of mutual coupling A_2. In this simulation, NA_{std} and $N\phi_{std}$ are 1dB and 5°, respectively and SNR is 20dB. E_{max} decreases steeply from A_2 = -10dB to -30dB and fluctuates subsequently. Fig. 4 shows E_{max} as a function of NA_{std}. $N\phi_{std}$ is set to NA_{std} [dB] × 5°. E_{max} become larger than 1° from the points that NA_{std} and $N\phi_{std}$ are 1dB and 5° respectively. From the above example, estimation error is minimized in $A_2 \leqq$ -30dB, $NA_{std} \leqq$ 1dB and $N\phi_{std} \leqq$ 5°.

3. Measurement of the DOA estimation using a microstrip patch array antenna with boxy metallic wall

To achieve the specification of section 2, a low coupling patch array antenna is designed. Fig. 5 shows the configuration of an element of the array antenna. Mutual coupling of this antenna is suppressed by the boxy metallic wall around the microstrip patch. The wall is connected to the ground plane of the microstrip antenna. These antenna elements are arrayed by half wave length interval (Fig. 6). The size of the wall L_x, L_y, h_x and h_y was optimized with computer simulation to achieve -30dB of mutual coupling between neighboring elements. The optimized parameter is L_x=0.4λ, L_y=0.5λ, h_x=0.25λ and h_y=0.2λ to obtain -33dB of maximum of mutual coupling in experiment at 5GHz. Fig. 7 shows the S parameter between #2 and #3 of the array antenna. The characteristics were same and achieve -33dB of mutual coupling.

Using the array antenna with boxy metallic wall, the estimation errors of ESPRIT are evaluated using 4 channel DBF array antenna at 5GHz inside of an anechoic chamber. Fig.8 shows the measurement setup. One transmission source installed in front of the array and the array antenna set on a rotator to change DOA. The receiver is calibrated with on the condition of $\theta = 0°$ and patterns of the array antenna are not calibrated. The array antenna is changed to normal microstrip patch antenna (a) and with boxy metallic wall (b). The relation between DOA and the estimation error is shown in Fig.9. The maximum value of estimation error of (b) is 0.4° for θ<25° and is reduced 0.8° from (a), but the error of 25°<θ<60° is not reduced because the half power width of pattern is about 50° (Fig.10). From the above, low coupling microstrip patch array antenna with boxy metallic wall is effective for reduction of estimation error in ESPRIT.

4. Conclusion

This paper clarified relation between coupling matrix of array antenna and DOA estimation error in computer simulation and showed estimation error was minimized in $A_2 \leqq$ -30dB, $NA_{std} \leqq$ 1dB and $N\phi_{std} \leqq$ 5°. A microstrip patch array antenna with boxy metallic wall was designed and estimation error in ESPRIT was examined in a measurement of DOA estimation in anechoic chamber. The error using the array antenna with boxy metallic wall was 0.4° for θ<25° and was reduced 0.8° from normal patch antenna.

Reference

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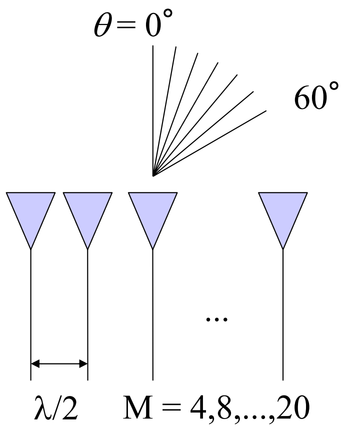

Fig. 1: Array antenna and direction.

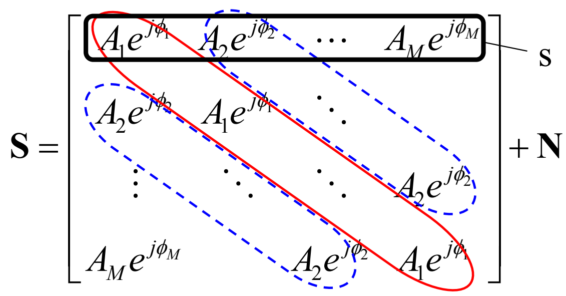

Fig. 2: Scattering matrix.

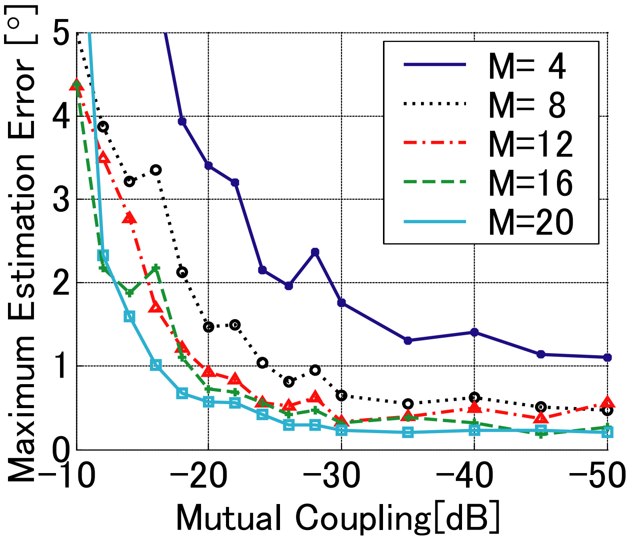

Fig.3: Maximum value of estimation error as a function of mutual coupling (NA_{std}: 1dB, $N\phi_{std}$: 5°).

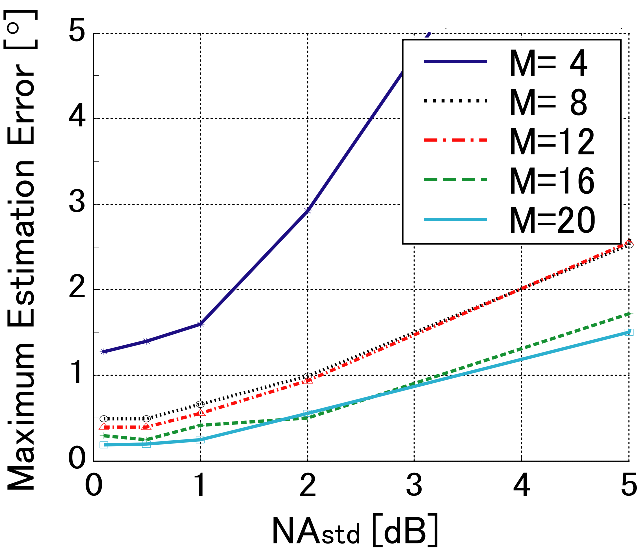

Fig.4: Maximum value of estimation error as a function of NA_{std} (A_2: -30dB).

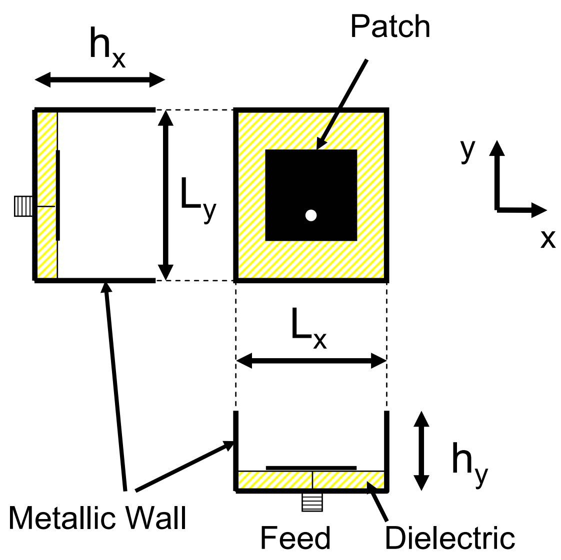

Fig.5: Boxy metallic wall microstrip antenna.

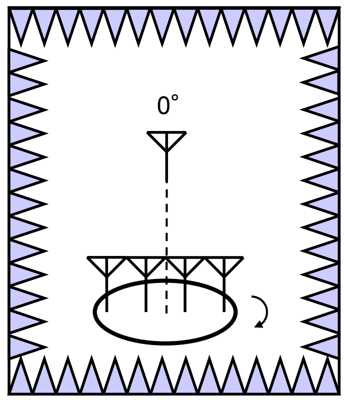

Fig.8: Measurement setup.

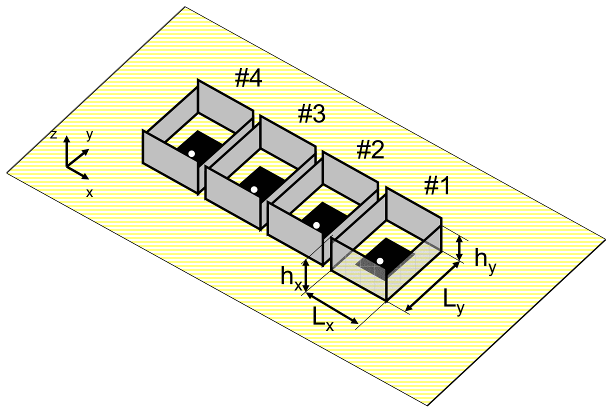

Fig.6: 4 elements liner array antenna with half wavelength interval.

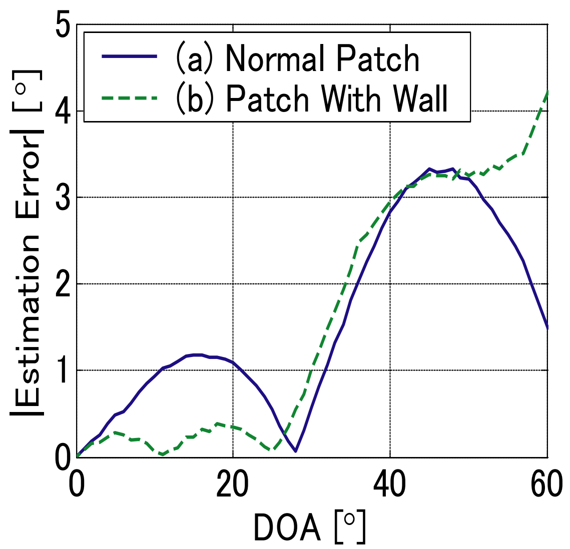

Fig.9: Estimation error.

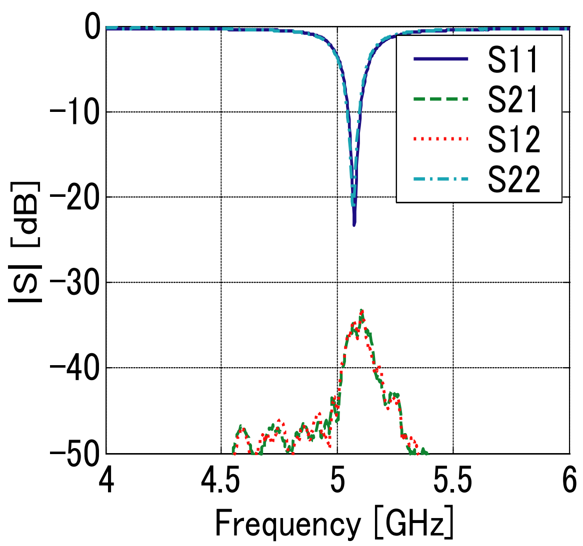

Fig.7: S parameters between #2 and #3.

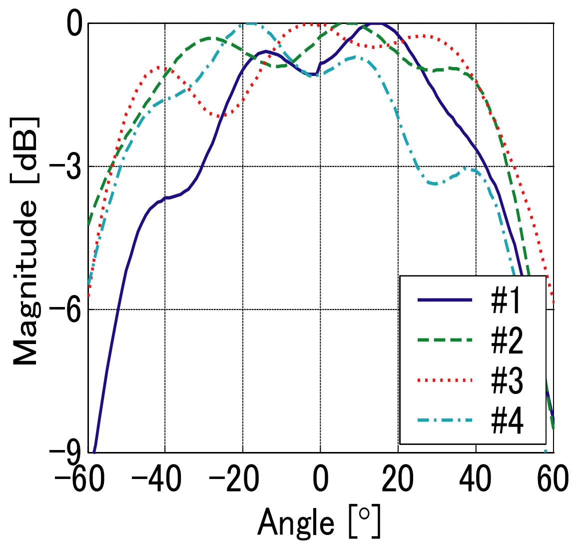

Fig.10: Element pattern. (xz-plane)