OUTDOOR-CALIBRATION METHOD OF THE 3 × 3 PLANAR ARRAY ANTENNA

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1 Introduction

Recently, superresolution techniques for Direction of arrival (DOA) estimation, such as MUSIC (MUltiple SIgnal Classification) algorithm [1], have become indispensable. By the assumption of an ideal array antenna, following problems are caused in an actual measurement. Array elements often have gain and phase errors, and mutual coupling effects cannot be also ignored in general, which degrade performance of the superresolution techniques for DOA estimation. Therefore, array calibration is necessary to estimate DOA with high accuracy. A variety to calibration techniques has been proposed, [2]-[4], and is divided into methods of using measured data of array antenna parameters and using reference signals from known sources. The former is a technique to use the mutual impedance derived from S parameter measured by a network analyzer [2]-[3], and the later is to calibrate antenna and receiver simultaneously. These techniques are carried out in an ideal environment such as an anechoic chamber without interference waves. When the array antenna is used in the outdoor experiment, estimation errors increase due to multi-path propagation. It is needed to calibrate the array antenna at outdoor environments, however, it is difficult because of the existence of some interference waves.

In this paper, we propose the calibration technique using spreading sequence that is the reference signal for calibration. And we also propose a method of self-calibration using RF switches.

We consider these techniques as an example with 3 × 3 planar array antenna. However, these proposed methods are also applicable to the M × N planar array antenna.

2 Calibration technique for the array antenna

In this section, we explain the calibration technique with reference signals for 3 × 3 planar array [4]. Received signal r with array antenna are as follow.

$$\mathrm{r} = \mathrm{C}_\Gamma \mathrm{As} + \mathrm{n} \tag{1}$$

$$C_\Gamma = C \times \Gamma = \begin{bmatrix} C_{11} & C_{12} & \cdots & C_{19} \\ C_{21} & C_{22} & \cdots & C_{29} \\ \vdots & \vdots & \ddots & \vdots \\ C_{91} & C_{92} & \cdots & C_{99} \end{bmatrix} \begin{bmatrix} \gamma_1 & 0 & \cdots & 0 \\ 0 & \gamma_2 & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & \gamma_9 \end{bmatrix} = \begin{bmatrix} \gamma_1 C_{11} & \gamma_2 C_{12} & \cdots & \gamma_9 C_{19} \\ \gamma_1 C_{21} & \gamma_2 C_{22} & \cdots & \gamma_9 C_{29} \\ \vdots & \vdots & \ddots & \vdots \\ \gamma_1 C_{91} & \gamma_2 C_{92} & \cdots & \gamma_9 C_{99} \end{bmatrix} \tag{2}$$

where s is complex amplitude, n is noise, C and Γ denote the mutual coupling between antenna elements and the characteristic errors of each element, respectively. Noise eigenvector of e_j and mode vector a(θ) have the following relation for M being number of data sets for calibration.

$$e_j^{(m)} \mathrm{C}_\Gamma \mathrm{a}(\theta^{(m)}) = 0 \tag{3}$$

It is assumed that # 1 element is a reference element for the phase and we can rewrite C_Γ:$\gamma_1 C_{11}$=1. Therefore, the unknown component of C_Γ is 80. When one wave arrival at 3 × 3 planar array,

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it has eight noise eigenvectors. Therefore, 80 simultaneous equations consist if there is incidence from at least ten directions. After they are solved, C_Γ is derived directly [4]. The signal correlated matrix not influence by C_Γ is obtained for the equation (4).

$$R_{cal} = (C_\Gamma)^{-1}[R - \sigma^2 I]((C_\Gamma)^{-1})^H \qquad R = E[rr^H] \tag{4}$$

E[•] is an average of the ensemble, and σ^2 is noise electric power.

We propose the calibration method by the reference signals with a spreading sequence signal. In general, An advantage of spreading sequence is to decrease effects of multi-path fading and interferer. A simulation model is shown in Fig.1. The 3 × 3 planar array on the rotation table, the reference signal with the spreading sequence is transmitted from the reference. Then, received signal X that contains the reference signal D for the calibration, interference wave I, and noise N as follows.

$$X = C_\Gamma(D + I) + N \tag{5}$$

The eqn. (5) can be approximated as follows after dispreading for D.

$$X_S \approx C_{\Gamma S} D + N_S \tag{6}$$

where X_S is a spread received signal. And it becomes equivalent to the situation with reference signal only. The correlation matrix of X_S is calculated, and the calibration is conducted by the method in ref.[4].

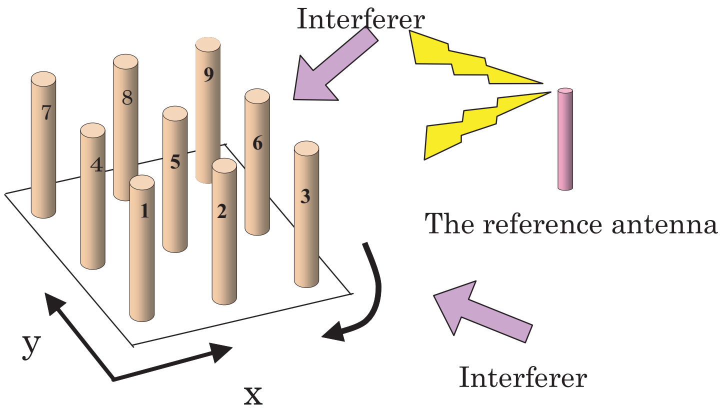
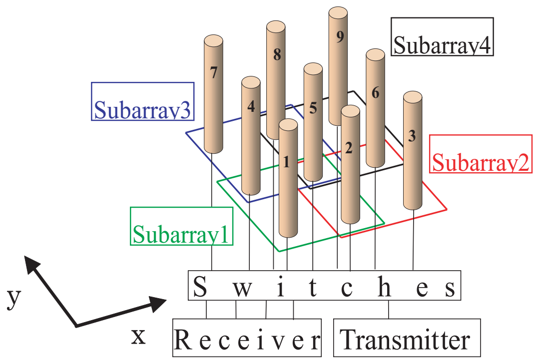
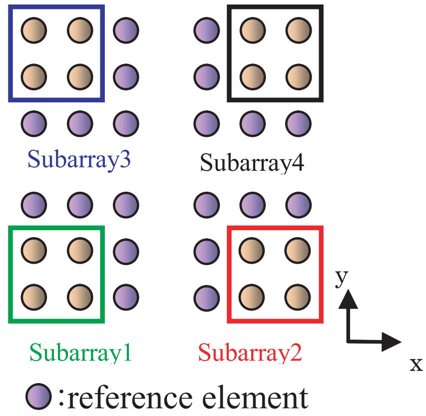


*Fig.*1 : *Simulation model*

We propose a method of self-calibration with switches for a low cost and the reduction of the scale of system. The model shown in Fig.2 needs several reference antennas and rotation table. For these problems, we propose only a part of switching of the 3 × 3 planar array antenna without several reference antennas as shown in Fig.2 (a). Then, each subarray is calibrated as shown in Fig.2 (b). The elements not included in the subarray are switched and the reference signal is radiated. For example, to calibrate subarray1, #3 element and #6-#9 elements become reference antenna. Thus, it is possible to achieve a low cost and the reduction of the scale of system. The DOA estimation for evaluation applies to Spatial Smoothing Preprocessing (SSP). At this time, C , Γ and directivity of each element that the error factors are given.



(a)Configuration image

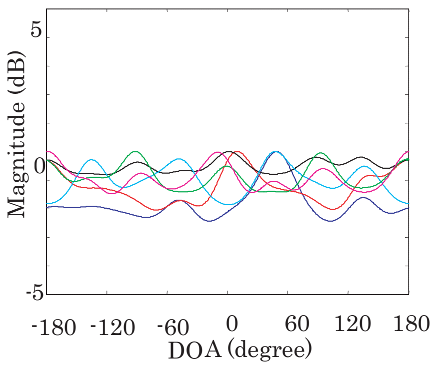


(b)Calibration of subarray

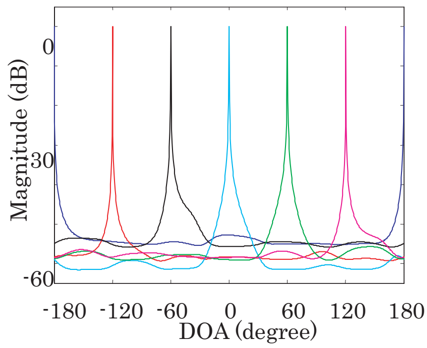
Fig.2 : Consideration model

3 Simulation

The simulation results are shown in Figs 3 and 4. Figure 4 is a result of two interference waves when reference signals are radiated. DOA angle are 0°, ± 60°, ± 120° and ± 180°, and MUSIC spectrum with/without the calibration are shown in Figs 3 (a) and (b), respectively. These figures show that the shape of spectrum peak and resolution are improved. Figure 4 shows the DOA estimation error at all the directions. These errors are less than 0.5°, and Root Mean Square Error (RMSE) is 0.14°. Figure 5 shows RMSE as a function of number of the interference wave. The DOA can be estimated correctly because RMSE is less than 0.5° in Fig.5. These results confirm that the calibration with spreading code is effective under the outdoor environment.



(a)Without calibration



(b)With calibration

Fig.3 : MUSIC spectrum of simulation

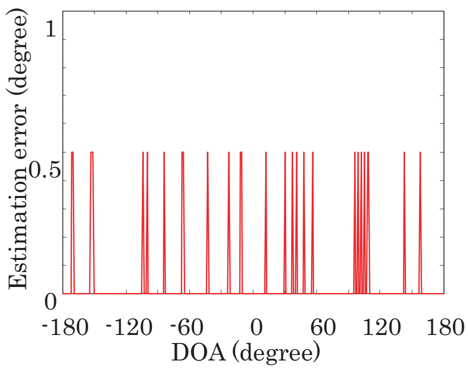


Fig.4 : DOA estimation error

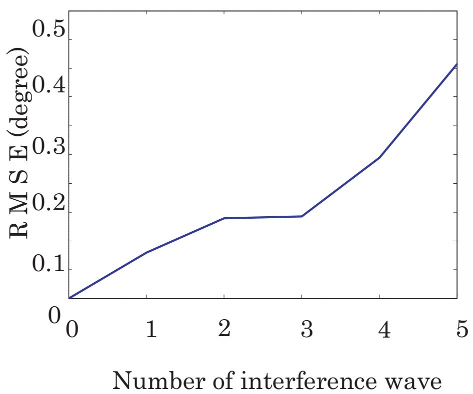


Fig.5 : Estimation accuracy with calibration

In the next step, we examine the self-calibration method with switches by 16 patterns that combine of each dividing both the amplitude and the phase of the receiver dispersion ranges into four respectively, because it depend on the performance of the receiver and the amplitude and the phase of the receiver change in this calibration technique. Figure 6 shows DOA estimation error with the calibration method for the receiver with no dispersion. The RMSE is 1.1°, thus it can be said that it is possible to calibrate with switches [5]. Table.1 shows RMSE of each pattern. The dispersion of the phase of the receiver is within ± 45° when RMSE is within 3°. In other words, this calibration technique is applicable if the dispersion of the phase of the receiver is within ± 45°. Therefore, the proposed technique is effective to adjust the dispersion of the phase of the receiver to ± 45° on the hardware side.

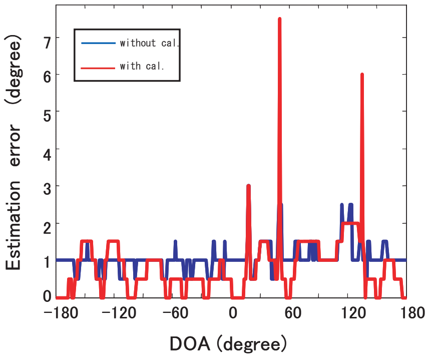


Fig.6 : DOA estimation error

Table.1 : Result of RMSE

Phase/Amplitude	0dB	0-1dB	0-2dB	0-3dB
± 0	1.1	1.0	1.0	1.0
± 45	1.7	2.9	2.8	2.6
± 90	2.6	3.2	3.6	3.8
± 180	4.3	4.3	3.9	5.2

4 Conclusion

In this paper, we proposed the calibration technique using spreading sequence for the reference signal of calibration and a method of self-calibration with switches. The calibration method with spreading sequence can calibrate array antennas in the situation of five interference waves so that RMSE is 0.4°. The method of self-calibration with switches showed good result of the SSP value of RMSE becoming less than 3°, when the dispersion of the phase of the receiver is range of ± 45°. The DOA estimation errors with calibration vary in Fig.6. This is because the range of DOA of the reference signals are limited and accuracy outside the range is deteriorated. Thus, the calibrating accuracy of other subarrays with SSP cannot supplement a large error outside the range.

We will verify the effectiveness of these proposal techniques by experiment and obtain the problem in the future.

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References

[1] R.O.Schimidt,"Multiple Emitter Location and Signal Parameter Estimation",*IEEE Trans*,vol.AP-34,no.3,pp.276-280,Mar.1986

[2] I.J.Gupta and A.A.Ksienski,"Effect of mutual coupling on the performance of adaptive arrays",*IEEE Trans*,vol.AP-31,no.5,pp.785-791,Sept.1983

[3] R.S.Adve and T.K.Sarkar,"Compensation for the Effects of Mutual Coupling on Direct Data Domain Adaptive Algorithm",*IEEE Trans*,vol.48,no1,pp.86-94,Jan.2000

[4] T.ARAI,R.HARA,H.YAMADA and Y.YAMAGUCHI,"Calibration Technique for Superresolution Array",*IEICE Trans.* A.P2002-28,May.2002

[5] E.MATSUZAKI and H.ARAI, "The wave number and DOA estimation with Beam Former algorithm under multi-path environment",Proceedings of the 2004 *IEICE General Conference.*