# DOA ESTIMATION BY 'T'-TYPE ARRAY ANTENNA AND ITS EVALUATION

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## ABSTRACT

In this paper, 'T' character-type array antenna system is proposed which estimates the directions of arrival (DOA) by the virtual uniform rectangular arrays. The proposed system consists of 4 antenna elements distributed like the character 'T'. The performance of the proposed system in DOA estimation is evaluated by some simulation and experiments. First we show that DOA is estimated correctly by the proposed system in simulations. We also construct a trial experimental system and make some experiments with it. We experimentally show that DOA is estimated correctly. Throughout the simulations and experiments, we confirm the effectiveness of the proposed system.

## INTRODUCTION

The quality of mobile communication should be improved especially in urban districts, and it is important to know where is in a bad condition for the electric wave propagation. Adaptive array antenna system to estimate the DOA and the electric power can be a method to know such a condition for the electric wave propagation. Estimating the DOA and the electric power while moving inside a certain district by a car with installing the above system on it, the propagation condition can be obtained. In this situation, real-time operation of DOA and the electric power estimation is desired.
In urban districts, the DOA cannot be estimated by a linear array antenna system since electric waves can be reached from every direction. Hence uniform rectangular arrays would be desired for such DOA estimation, however the accurate estimation cannot be performed due to the influence of mutual coupling between antenna elements. Besides, array antennas with a fewer number of elements are desired because the cost of the receiver becomes large if there are many elements.
For such purpose, in this paper, a 'T' character-type array antenna system is studied and developed, which can construct virtual uniform rectangular arrays by shifting a horizontal linear array of 'T'-character array in parallel to the vertical array. We confirm if the 'T'-character array system can really estimate the DOA as well and the electric power similarly to the real rectangular arrays.

## THE VIRTUAL UNIFORM RECTANGULAR ARRAY ANTENNAS

Uniform rectangular arrays would be desired for DOA estimation, however accurate estimation cannot be performed due to the influence of mutual coupling and the cost of the receiver becomes large. In order to solve these problems, we propose 'T' character-type array antenna which estimate DOA by virtually constructing a uniform rectangular array antenna.

### How to Create the Virtual Data

How to synthesize the data of the virtual rectangular arrays by the 'T' character-type arrays is described. We propose the 'T' character-type arrays (linear arrays of three elements + one element) shown in Fig. 1. Figure 2 shows how to synthesize the data of the virtual rectangular arrays. The 'T' character-type array of Fig. 1 is shifted in parallel. In this case, the 'T' character-type array is shifted so that the central element of the original position and the outstanding element after movement may overlap (see Fig. 2). The overlapping data of two elements is compared and the data of the next line is synthesized. Repeating this operation three times, the data of the 3x4 virtual uniform rectangular arrays rectified the phase of each line is obtained.

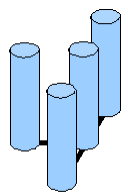

Fig. 1 The 4 elements 'T' character-type array antennas

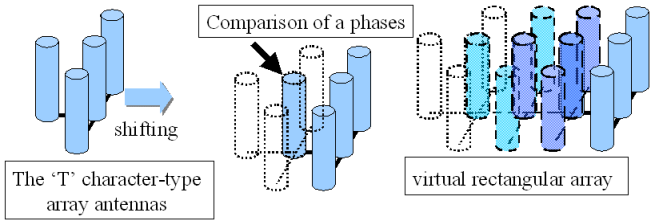


Fig. 2 The virtual rectangle array by the 'T' character-type array antennas

**Consideration on the Interval of Antenna Elements**

The Element interval of array antennas is generally half-wavelength in DOA estimation. However, when we estimate DOA by the MUSIC method [1] and the half-wavelength rectangular arrays, we cannot correctly estimate DOA in 0 degree, 180 degrees, -90 degrees, and 90 degrees. Fig 3 shows the result of simulation when DOA is 0 degree, using the array antenna whose element interval is the half-wavelength. We see that the spectrum arises not only at 0 degree but at 180 degrees. The reason is that the phases of 0 degree and 180 degrees becomes the same in the half-wavelength regular-intervals rectangular arrays. Equation (1) and (2) are the phases at the element of $m$ th-row $n$ th-column when DOA are 0 degree and 180 degrees. The phase characteristics of 0 degree and 180 degrees become the same.

$$\begin{aligned}\phi(0^\circ) &= \exp\{-jm\pi\cos(0^\circ) - jn\pi\sin(0^\circ)\} \\ &= \cos(m\pi)\end{aligned} \tag{1}$$

$$\begin{aligned}\phi(180^\circ) &= \exp\{-jm\pi\cos(180^\circ) - jn\pi\sin(180^\circ)\} \\ &= \cos(m\pi)\end{aligned} \tag{2}$$

Then, we change the element interval to 0.4 wavelengths so that the above equalities do not hold and the size of the antenna does not become large. Figure 4 shows the result of the same simulation by 0.4-wavelength regular-intervals rectangular array. We see that the spectrum of 180 degrees was eliminated and DOA is estimated correctly.

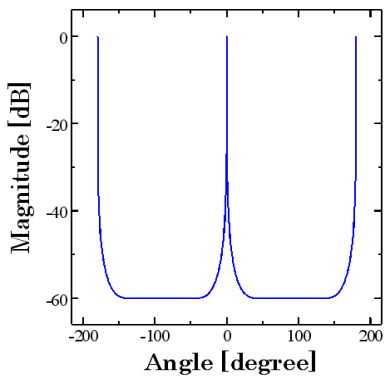


Fig. 3 MUSIC Spectrum (half-wavelength)

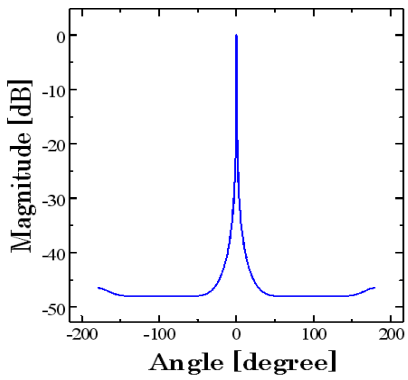


Fig. 4 MUSIC Spectrum (0.4-wavelength)

**SIMULATION**

In order to evaluate the effectiveness of the virtual uniform rectangular arrays, we conduct simulations. The number of arrival waves is six, and we use the MUSIC method as DOA estimation algorithm. Figures 5 and 6 show the results in the case of real rectangular array, and the case of virtual rectangular array. Although the dynamic range of MUSIC spectrum is in virtual rectangular array, these figures show that the virtual rectangular array can estimate DOA with almost the same accuracy as the real rectangular array. The results of these simulations show the effectiveness of the proposed system.

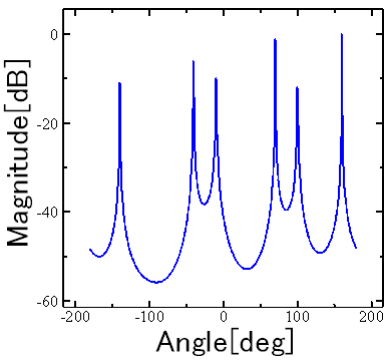


Fig. 5 MUSIC Spectrum (real rectangular arrays)

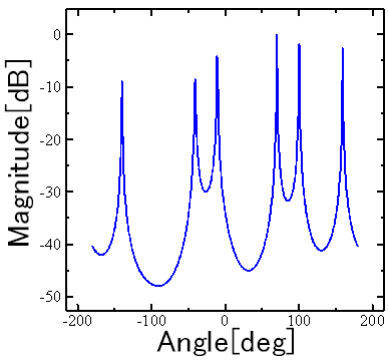


Fig. 6 MUSIC Spectrum (virtual rectangular arrays)

## THE TRIAL IMPLEMENTATION OF THE RECEIVING SYSTEM

In order to evaluate the performance of the proposed system, we construct the trial receiving system [2] and make some experiments of DOA estimation with it. The specifications of the trial system used in the experiment are as follows. The trial system consists of an antenna part, a receiver, and a PC. The receiver consists of the RF section and the IF section. The output of the IF section is translated to a digital signal by the A/D converter, and the data is taken in to PC. The career frequency of this system is 2.666GHz. I-component and Q-component are downconverted to 426MHz at the RF section, and then they are re-converted into 1MHz.

## EXPERIMENTS

The performance of the proposed system in DOA estimation is evaluated by some experiments. Although two or more waves usually come to the antenna in the actual scene, we investigated the case of one wave as a first report. Table. 1 shows specifications of experiments. We conduct the experiments in an anechonic chamber as shown in Fig. 7. The MUSIC spectrums of experiments are shown in Fig. 8-10 as examples. Moreover, the estimation error for each DOA angle is summarized in Fig. 11. These figures show that DOA has been estimated accurately. From these results, the performance of the proposed system in DOA estimation is confirmed experimentally.

Table 1 Specifications of experiments

| | |
|---|---|
| Environment of experiments | Inside anechonic chamber |
| Number of arrival waves | 1 |
| Distance between transmitting and receiving antennas | About 3 m |
| Array form | The ‘T’ character-type array antenna (3+1 elements) |
| Frequency | 2.666GHz |
| Sampling frequency | 5MHz |
| DOA estimation algorithm | MUSIC method |

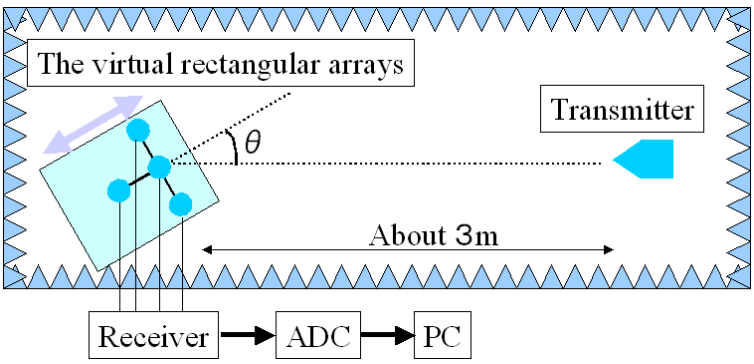


Fig. 7 The situation of experiments

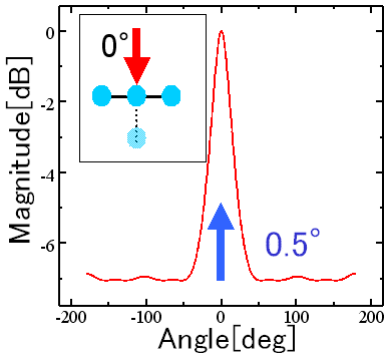


Fig. 8 Spectrum (DOA =0 deg)

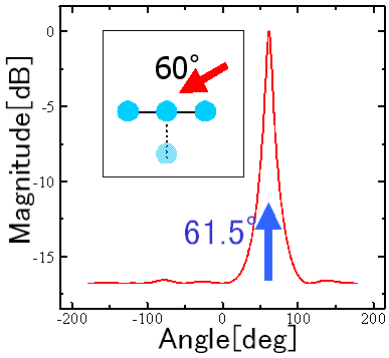


Fig. 9 Spectrum (DOA =60 deg)

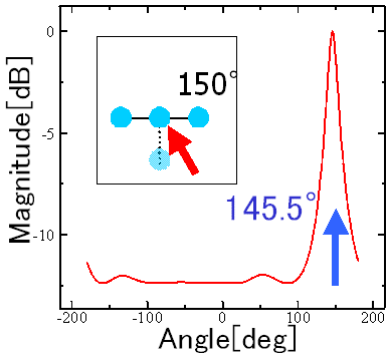


Fig. 10 Spectrum (DOA =150 deg)

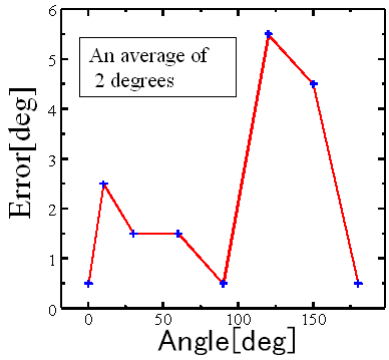


Fig. 11 Estimation error

## CONCLUSION

In this paper, we proposed a system to estimate DOA and electric power by the 'T' character-type array antenna for investigating electric wave propagation environment. The DOA can be estimated using the virtual uniform rectangular array created from the original 'T' character-type array. The performance of the proposed system was confirmed through some simulation and experiments. The future works would be the DOA estimation for the case of two or more arrival waves, and DOA and electric power estimation in the open air.

## REFERENCES

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[2] K.Mori, Y.Inoue, K.Ichige, H.Arai, "Experiments of DOA Estimation by DBF Array Antenna at 2.6GHz", *IEICE Trans. Commun.*, vol.E84-B, no.7, pp1871-1875, July 2001.