Digital Beamforming Equipment by Time Division Multiplex Receiving for the Direction Finder

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1. Introduction

Eigen-decomposition methods are attracted attention for direction-of-arrival (DOA) estimation. It is necessary for these methods to detect number of incident wavefronts and to divide the eigen-space into signal subspace and noise subspace. Generally, when the co-variant matrix estimated by finite snapshots is eigen-decomposed, eigenvalues corresponding to noise are not the same. Therefore, we cannot judge the number by means of the distribution among the eigenvalues. In these cases, signal detection by Akaike Information Criteria(AIC) or Minimum Description Length(MDL) based on information theoretic criteria is useful[1]. However, when spatial smoothing method for coherent signal classification is introduced, these detection methods become useless since steering vectors among the subarrays are not the same because of the mutual coupling[2]. It is not necessary for Capon to detect the number. But, it is said that accuracy and resolution of Capon are not as good as those of eigen-decomposition methods. Whereas, it is proposed for improvement of signal detection to exclude the mutual coupling effects from the covariant matrix by multiplying the compensation matrix[3]. Although these studies have been evaluated by computer simulation, it is necessary to evaluate them in actual propagation environment.

We have developed a Digital BeamForming (DBF) receiver for direction finding to evaluate these algorithm in indoor and urban mobile radio. In this equipment, 8 channel signals received by 8 elements array antenna are sequentially input to one receiver by Time Division Multiplex (TDM) receiving in order to simplify the hardware. First Fourier Transform (FFT) is applied for demodulation. Antenna aperture is an equi-spaced linear array and composed of 8 stripline dipoles with back reflector. In this paper, we present about design, calibration, trial-manufacturing, and evaluation tests in the anechoic chamber.

2. Design

2.1 TDM Receiver

It is necessary for DOA estimation to sample signals received by array antenna and to calculate the sample co-variant matrix. Generally, there are many receivers in the equipment since a receiver corresponds to an antenna element. We have adopted TDM receiving as shown to Fig.1 in order to simplify the hardware. It is not necessary to calibrate gain and transmission delay among receivers, since there only is one receiver in it. However, it must be assumed that the propagation environment is invariable during TDM receiving. Sample receiving signals of each antenna element are transformed to frequency domain by FFT. Then, the amplitude and phase are extracted from the discrete FFT spectrum

2.2 Calibration

As cables connecting each antenna element to a receiver cannot be made identical at all, signal phase must be calibrated by value measured by the network analyzer. Initial phase of each signal is not the same as shown to Fig.2 since starting time for receiving is different. Therefore, signal for an antenna as the reference is received every time before receiving another channel in order to decide initial phase of each interval. Then, phase of TDM receiving signal is aligned by the initial phase.

3. Trial Manufacturing

The schematic diagram and specification are shown to Fig.3 and Table1, respectively. 8PST transfer switch is used for TDM receiving. Timing signal for switching is generated by hardware based on sampling clock of AD converter. It is available to change TDM receiving interval arbitrarily. AD converter is equipped on PCI board as shown to Fig.6. It can memorize TDM receiving signals, temporarily. PC demodulates the sample receiving signals and estimates DOA.

Antenna aperture and RF section are shown to Fig.4 and 5, respectively. Antenna aperture is composed of 8 stripline dipoles with back reflector. Central frequency is 2.45GHz. In order to evaluate various array antennas, the aperture and receiver are manufactured separately and connected by coaxial cables. It is possible to be cheaply manufactured because of simple composition. The expense to make this equipment was about 1,000,000 yen including PC and operation system.

4. Evaluation Tests

The aperture and DBF receiver were set on the positioner in the anechoic chamber. Stability of receiving amplitude and phase for each antenna element has been evaluated using CW signal transmitted by an antenna from boresight of the aperture. Fig.7 shows the phase stability. It is considered that calibration is working right from the fact that phase deviations among snapshots are less than 2˚.

Then, 2 coherent signals generated by dividing CW signal into 2 using a divider were transmitted from different angle. (See Fig.8) In order to measure coherent signals, spatial smoothing was applied to the co-variant matrix before DOA estimation by MUSIC. MUSIC spectrum is shown to Fig.9. 2 apparent peaks corresponding to the DOAs are appeared.

5. Conclusion

A DBF receiver using TDM receiving concept was demonstrated. Receiving signals are demodulated in frequency domain by FFT. Calibration method for TDM receiving was proposed. It became clear that the calibration method is available through evaluation tests of a trial manufacturing model. The phase stability was less than 2˚. We installed MUSIC algorithm with spatial smoothing on the model, and experimented in the anechoic chamber. We were able to estimate DOAs of two coherent wavefronts. In the future, we are to install Capon and compensation algorithm of covariance matrix for AIC and MDL on it, and are to evaluate these algorithm in the mobile radio environment.

References

[1]S.Haykin, ”Advances in Spectrum Analysis and Array Processing Vol.3,” Prentice Hall, 1995.

[2] M.Wax and T.Kailath, ”Detection Signals by Information Theoretic Criteria,” IEEE Trans. Acoustic, Speech, and Signal Processing, Vol.ASSP-33, No.2, pp.387-392, 1985.

[3]A.Kato and Y.Kuwahara, ”A Compensation Technique of the Mutual Coupling Effect on DOA Estimation,” Proc. of the 2001 IEICE General Conference, pp.56, 2001.

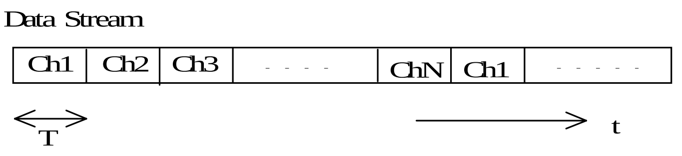

Fig.1 Time Division Receiving

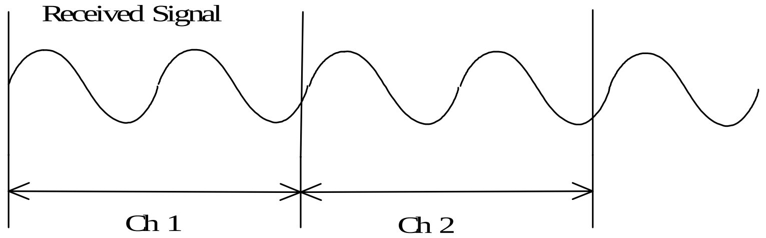

Fig.2 Initial Phase Error

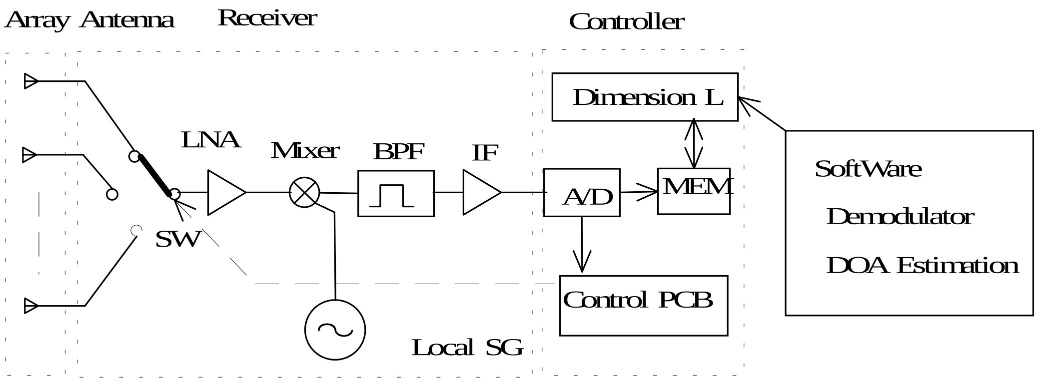

Fig.3 Schematic Diagram of the Direction Finder

Fig.4 Dipole Array Antenna with Reflector

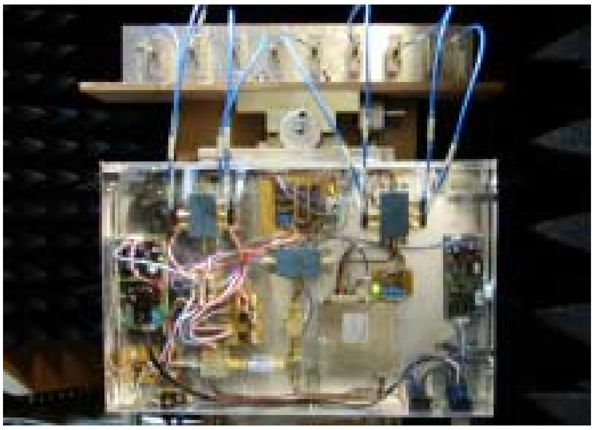

Fig.5 DBF Receiver

Table.1 Specification

Items	Parameters
Receiving Channel	8
Receiving Interval/channel	0.1024ms
Local Frequency(GHz)	2.2-2.5GHz
Step of Receiving Frequency	5MHz
Stability	8ppm
IF Frequency	1MHz
IF Output Level	0-5V
Sampling Frequency	40MHz
ADC Bit Number	8
InterFace	RS422
Operation System	
Data Sampling and Contorol	Visual C++
DOA Estimation	MATLAB

Fig.6 ADC

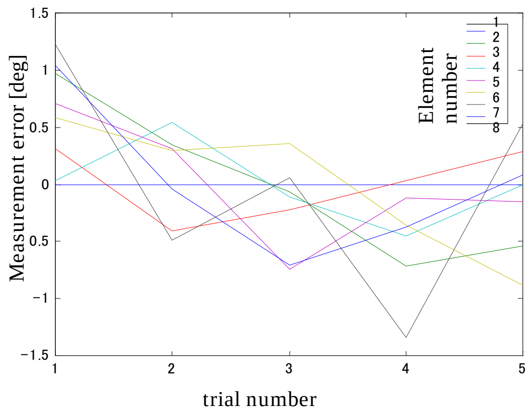

Fig.7 Phase Error of Each Channel

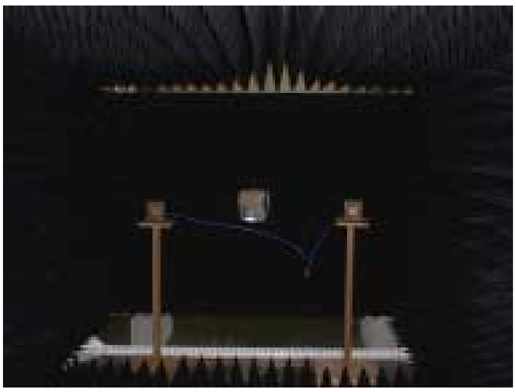

Fig.8 Transmitting Antennas
in the Anechoic Chamber

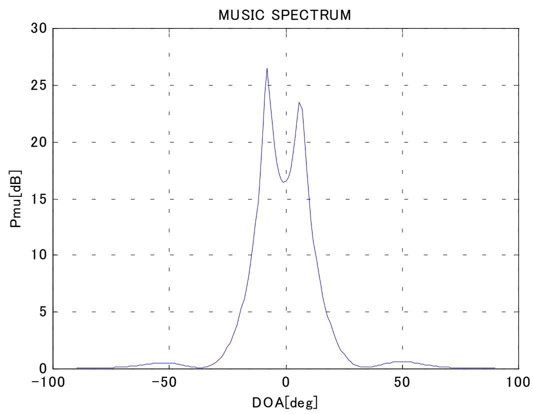

Fig.9 MUSIC Spectrum