Improvement of DOA Estimation Accuracy of UWB Signal by Using Sub-Band Processing

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1. Introduction

High resolution method for direction of arrival (DOA) estimation using array antenna is studied actively [1]. In almost previous studies, it is assumed that the antenna elements have the same directional patterns. However, it is very difficult to make many antenna elements they have just the same directional patterns. Furthermore, the directional patterns are distorted due to mutual coupling between the antenna elements. The estimation accuracy is decayed if the directional patterns are distorted intensively [2]. Generally, to avoid the effect of directional pattern distortion, antenna characteristics are calibrated before the estimation, however, it is difficult to cancel the effect of distortion when the arrival signal is very wideband because the directional patterns depend on the frequency.

In this paper, sub-band technique to decrease the effect of antenna pattern distortion is proposed. And following two methods using sub-band processing are proposed for improving the estimation accuracy: (A) Averaging the estimated DOA in respective sub-bands, (B) Averaging the MUSIC spectrums of respective sub-band. Moreover, effect of correlation between arrival waves is analyzed and discussed when plural waves are arriving. It is shown that method (B) has high tolerance for amplitude and phase distortion of the element pattern.

2. DOA Estimation by using Sub-Band Processing

Figure 1 shows the signal flow of proposed scheme. The scheme of respective method is as follows.

Method A）Sub-band DOA Averaging：

The signals received by the antenna elements are divided into *n* frequency sub-bands by using band-pass filters (BPF_1 ～ BPF_n). The MUSIC method [3] is applied to respective sub-band, and MUSIC spectrum in the respective sub-band is formed. DOA of the signal in the respective sub-band is estimated by detecting the angle of the peak of the spectrum. Examples of MUSIC spectrum in condition of Table 1 are drawn in Fig. 2(a). We can see that several peaks of MUSIC spectrum due to ambiguity of direction are observed. Moreover, the direction of unnecessary peaks are different each other because the element distance in

Table 1: Condition

Frequency	3～10GHz
Array	Linear,6-ele.
Element Space	5 cm
Arrival wave	1 wave
DOA	30 deg.
No. of sub-band	8

wavelength depends on the sub-band frequency. The DOA estimation accuracy of the UWB signal can be improved by averaging the estimated DOA in the respective sub-band.

Method B）Spectrum Averaging：

The signals received by the antennas are divided into *n* frequency sub-bands as the same as Method A. The MUSIC method is applied to respective sub-band, and then the MUSIC spectrums are averaged. Example of averaged MUSIC spectrum is shown in Fig. 2(b). The condition is the same with Fig. 2(a). By averaging the plural MUSIC spectrums, only one peak is remained and the others are disappeared.

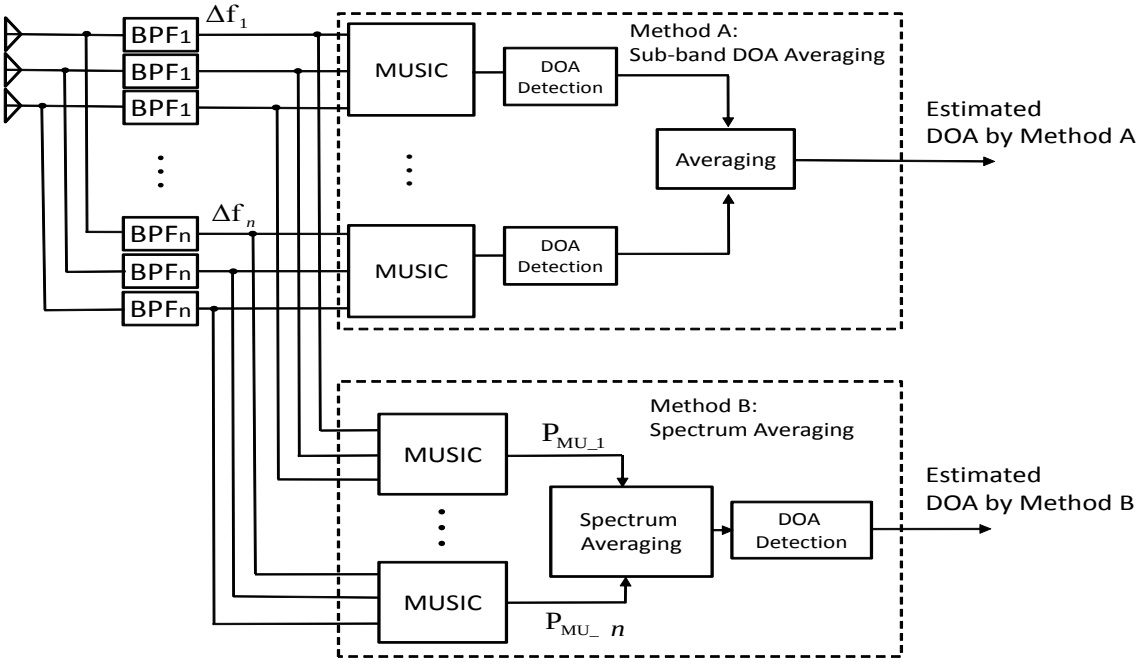
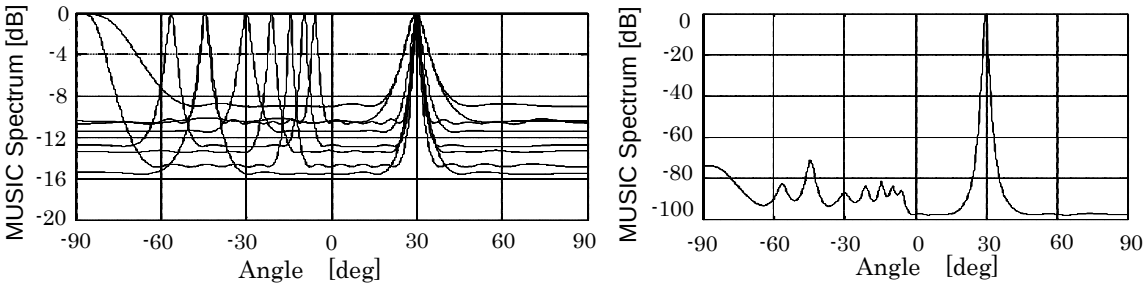


Figure 1: Signal flow of proposed DOA estimation methods



(a) MUSUC spectrum in respective sub-band (b) Averaged spectrum

Figure 2: Examples of MUSIC spectrum

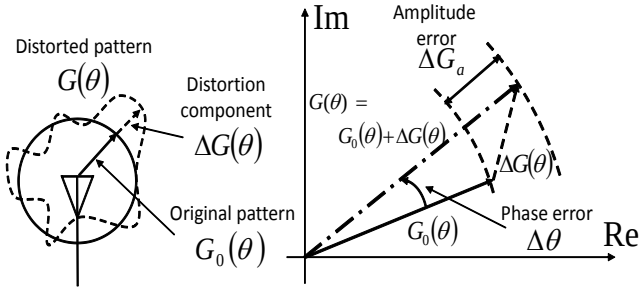
3. Model of Directional Pattern Distortion

The effect of distortion of element pattern is evaluated through computer simulation in the following section. The model of directional pattern of antenna elements is indicated in Fig. 3. In the Fig. 3(a), $G_0(\theta)$ and $\Delta G(\theta)$ is the original directional pattern and error component

due to the distortion, respectively. Figure 3(b) shows the complex expression of distorted pattern. Here, ΔG_a and $\Delta\theta$ is defined as "Amplitude error" and "Phase error," respectively. In this paper, it is assumed that "Amplitude error" and "Phase error" follows log-normal distribution and normal distribution, respectively. Namely, each parameter is determined by following equations.

$$G(\theta) = \left| 10^{\frac{\Delta G_a}{20}} \right| \quad (1)$$

$$\angle G(\theta) = \Delta\theta * (\pi / 180) \text{ [rad]} \quad (2)$$



(a) Directional pattern (b) Complex expression

Figure 3: Model of directional patterns

4. Improvement of DOA Estimation Accuracy

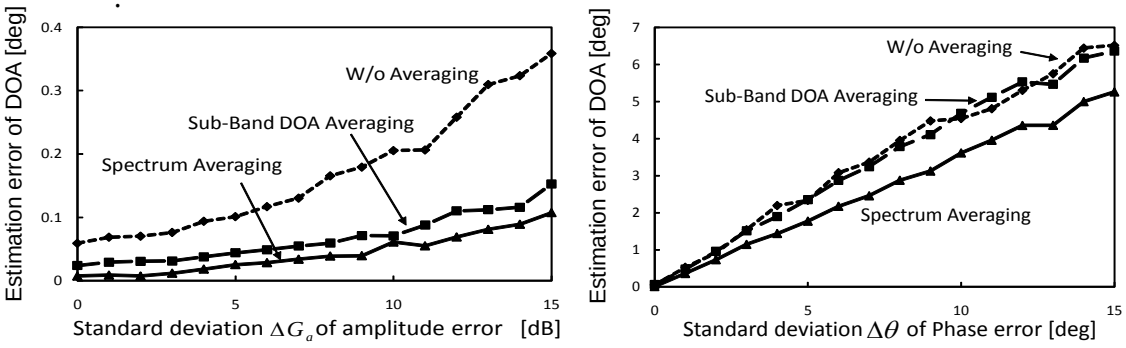
4.1 Effect of Amplitude and Phase error

Figure 4(a) shows the effect of amplitude error of antenna element pattern on DOA estimation accuracy. The conditions of the simulations are indicated in Table 2. Here, phase error is set at 0 degree. We can see in the figure that the estimation error by proposed sub-band processing is reduced compared with the original MUSIC method.

Table 2: Simulation Condition

No. of Element	6-ele.
Element Space	0.5 λ@3GHz
Arrival wave	1 wave
DOA	30 deg.
SNR	20 dB
No. of sub-band	8
No. of trial	100

The effect of phase error of element pattern on estimation accuracy is shown in Fig. 4(b). Here, the amplitude error is set at 0. In Fig. 4(b), the estimation accuracy is improved by "Spectrum Averaging Method", however, "Sub-band DOA Averaging Method" is ineffectual compared with original MUSIC method.



(a) Effect of amplitude error (b) Effect of phase error

Figure 4: Effect of element distortion on estimation accuracy

4.2 Effect of Correlation between arrival waves on estimation accuracy

In multipath environment, plural arrival wave might have correlation. Thus, the effect of correlation between arrival waves is evaluated. Examples of MUSIC spectrum in condition of Table 3 are drawn in Fig. 5. Here, the correlation coefficient between signals is fixed at 1. The result is shown in Fig. 6. We can see that the accuracy of "Sub-band DOA Averaging Method" and "Spectrum Averaging Method" are improved compared with that of original MUSIC method. And It is found that the estimation accuracy is improved as the number of sub-band is increased.

Table 3: Simulation Condition

No. of Element	6-ele.
Element Space	0.5 λ@3GHz
Arrival wave	4 waves
DOA	-30,0,30,60 deg.
Correlation	1
Amplitude error	15 dB
Phase error	3 deg
SNR	20 dB
No. of trial	100

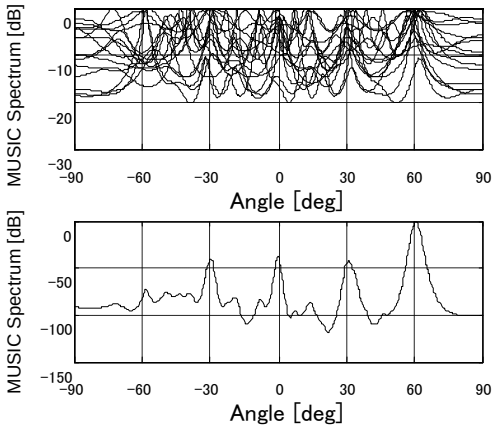


Figure 5: Spectrum of plural arrival waves

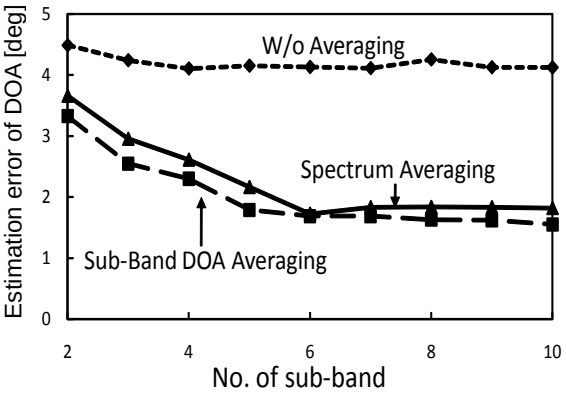


Figure 6: Effect of sub-band number

5. Conclusion

In this paper, two techniques to reduce the effect of antenna pattern distortion and correlation between arrivals were proposed and evaluated. As a result, it was clarified that "Spectrum Averaging Method" had excellent tolerance for element pattern distortion and correlation between arrival waves.

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References:

[1] "Special issue on adaptive signal processing technology in antennas," IEICE Trans. Commun., E78, 11, pp.1433-1517, Nov. 1995.

[2] N. Ishiura, T. Hori and M. Fujimoto, "Equivalent SNR Expression for Location Error of Elements on MUSIC Algorithm," Proc. Int. Symp. ISAP 2004, vol. 1, pp. 33-36, Oct. 2004.

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