A Fast Beam-Space Adaptive Null Beamforming

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1. Introduction

In recent years, as jamming techniques are becoming more complicated and advanced, we anticipate a practical application of an ANBF(Adaptive Null BeamForming) which can suppress multiple interference signals. In particular, because a DBF(Digital BeamForming) radar is fully flexible in handling signal processing in addition to being able to form multiple beams, an ANBF which forms nulls automatically in the direction of interference signals using an adaptive filter is regarded as a promising means to suppress interference signals. An adaptive sidelobe canceller is well known as one of ANBF[1], and it is classified into an Element-Space ANBF because an adaptive filter in this ANBF controls output signals of antenna elements directly. Generally, it causes computational load increase in the DBF radar that has a large number of antenna elements to let the number of adaptive weights be equal to the number of antenna elements, which makes implementation difficult. Therefore, when the number of weights is reduced to the number of interference signals, the suppression performance of interference signals greatly degrades in the Element-Space ANBF[2].

On the other hand, a Beam-Space ANBF has been proposed in which an adaptive filter controls received signals of auxiliary beams which have mutually different directivity[2],[3],[4]. Since correlation between input signals of the adaptive filter is small in this ANBF, it is said that the degradation of convergence speed is small compared with the Element-Space ANBF when the number of weights is reduced[3],[4]. However, there are only a few reports of evaluation results of such an ANBF by experiment.

In this paper, we carry out a performance evaluation of a Beam-Space ANBF by experiment and investigate relation between the suppression performance of interference signals and the number of weights. Especially, we examine a Beam-Space ANBF that forms auxiliary beams using FFT. This ANBF does not need a complicated pre-processing to predict the direction of interference signal. We also show the performance comparison with the Element-Space ANBF and confirm that the Beam-Space ANBF shows rapid convergence characteristic even if the number of weights is much smaller than that of antenna elements.

2. Beam-Space ANBF

In the Beam-Space ANBF, output signals of auxiliary beams with different directions are weighted by an adaptive filter. The auxiliary beamformer is adjusted so that each beam direction corresponds to one of the directions of interference signals. Accordingly, when the width of auxiliary beam is sufficiently narrow and the sidelobe level is low, the orthogonality between auxiliary beams is almost realized. Cross-correlation between input signals b_i of the adaptive filter becomes approximately zero as shown in the following equation,

$$E\left[b_k(n)b_m^*(n)\right] = \delta_{k,m} \qquad (1)$$

where $\delta_{k,m}$ denotes Kronecker's delta and the asterisk denotes the complex conjugate. Then the autocorrelation matrix becomes a diagonal matrix. In other words, it is said that the number of weights which is made equal to the total number of interference signals is enough for suppressing interference signals because the independence between input signals of the adaptive filter is secured in this ANBF.

Generally, the convergence speed of the adaptive algorithm is inversely proportional to the number of weights of the adaptive filter. Since the number of antenna elements becomes large to achieve a narrower main beam width and to improve the main beam gain, in the Beam-Space ANBF in which the number of weights is nearly equal to the number of interference signals, the convergence speed is improved compared with the Element-Space ANBF in which weights are controlled by the same adaptive algorithm[3]. Moreover, weights in the Beam-Space ANBF can be adjusted independently using modified RLS(Recursive Least Squares) algorithm by utilizing that the autocorrelation matrix completely becomes diagonal[5]. A similarity to RLS algorithm contributes to increase of its convergence speed.

The ANBF shown in Figure 1 is the Beam-Space ANBF using FFT(Fast Fourier Transform) network for the auxiliary beam formation intended for use as a Digital BeamForming(DBF) antenna using linear array antennas. We suppose the maximum number of interference signals, M, is known beforehand. FFT taken in output signals of antenna elements $(x_1, x_2, \ldots, x_L)$ forms L auxiliary beams. M beams need to be selected among L auxiliary beams instead of estimating the directions of interference signals. So utilizing the fact that beams corresponding to the directions of interference signals have larger power compared with desired signal power and noise power, M channels with largest power among L channels $(b_1, b_2, \ldots, b_L)$ are selected by a channel selector, and they are connected to input channels$(u_1, u_2, \ldots, u_M)$ of the adaptive filter.

3. Experimental Results

We have carried out radio experiment to confirm the suppression performance of interference signals for the Beam-Space ANBF shown by Figure 1. Figure 2 shows the basic configuration of experiment in the anechoic chamber. Major parameters of radio experiment are listed in Table 1. In this experiment, a desired signal is generated by distributing STALO (STable Local Oscillator) signal which occurs in receiver inside. Interference signals are generated by using two synthesizers. Signals received with antenna elements are amplified, phase detected, converted to video band signals in receiver and converted to digital signals by A/D converter. Finally, these digital signals are taken into a digital computer.

Radio experimental results of the Element-Space ANBF shcwn by Figure 3 and the Beam-Space ANBF shown by Figure 1 are as follows. We use LI(Learning Identification) algorithm [6] shown in the following equations as adaptive algorithm,

$$w_m(n+1) = w_m(n) + \mu e(n) u_m^*(n) / \phi(n) \ , \ (m = 1, 2, \cdots, M) \qquad (2)$$

$$\phi(n) = \sum_{m=1}^{M} |u_m(n)|^2 \qquad (3)$$

where $w_m(n)$ is the weight of the adaptive filter corresponding to input m and e(n) is the output signal of ANBF. Moreover, the step size μ is 0.05.

To compare the Beam-Space ANBF with the Element-Space ANBF on the same condition, we also select M received signals $(x_1, x_2, \ldots, x_M)$ as input signals of the adaptive filter in the Element-Space ANBF.

Figure 4 shows the convergence characteristic of these ANBFs. IMF(IMprovement Factor) denotes the performance evaluation parameter, which means the improvement ratio of desired signal to interference signal power ratio. Figure 4 shows the case that the number of interference signals is equal to that of weights, and dashed line denotes IMF of the Element-Space ANBF and solid line denotes IMF of the Beam-Space ANBF. Approximately 200 times' iteration of weight renewal is necessary for the Element-Space ANBF till IMF exceeds 15 dB. On the other hand, approximately 80 times' iteration is necessary for the Beam-Space ANBF, and improvement of the convergence speed by discrete Fourier transform can be confirmed. As for IMF of stationary state, the Beam-Space ANBF is superior to the Element-Space ANBF by approximately 10 dB, and we can identify that alignment error of the adaptive filter is small.

Figure 5 shows relation between the suppression performance of interference signals and the number of weights. In this figure, n =100 denotes IMF of transient states, and n =650 denotes IMF of stationary state. As shown in Figure 5, the suppression performance of interference signals for the Beam-Space ANBF is almost constant in transient and stationary states. On the other hand, the suppression performance of interference signals for the Element-Space ANBF is greatly influenced by the number of weights. When M is smaller than 5, we can confirm that the suppression performance of interference signals greatly deteriorates compared with the Beam-Space ANBF. Since the number of interference signals is small in this radio experiment, the range of the suppression performance of interference signals for the Beam-Space ANBF better than Element-Space ANBF is narrow in Figure 5. However, we have confirmed by computer simulations that such a range will become wider when more interference signals are received.

4. Conclusion

In this paper, we have carried out by experiment the performance evaluation of the Beam-Space ANBF which forms auxiliary beams using FFT.

We have confirmed that if the number of weights is more than that of interference signals, the suppression performance of interference signals for the Beam-Space ANBF is unrelated to the number of weights and that the degradation of suppression performance by reducing the number of weights is overcomed. Moreover, when the number of weights is smaller than that of antenna elements, we have confirmed the improvement of the convergence speed in the Beam-Space ANBF compared with the Element-Space ANBF and the effectiveness of a technique which makes input signals of the adaptive filter orthogonal using FFT.

References

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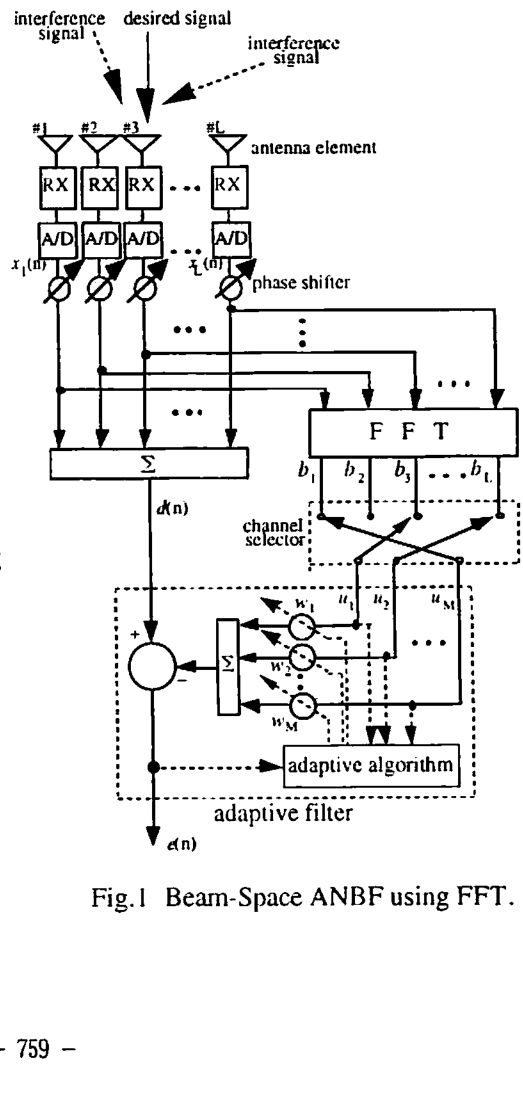

Fig.1 Beam-Space ANBF using FFT.

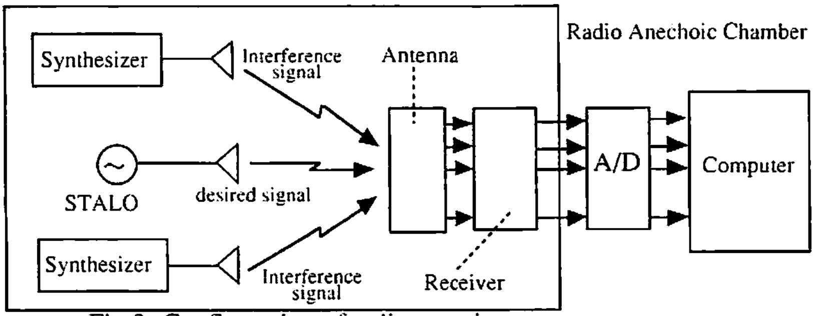

Fig.2 Configuration of radio experiment.

Table 1 Parameters of radio experiment.

Receiving antenna	16 element linear array
Distance between adjacent auxiliary antennas	Half of wave length
Desired signal frequency	9.7 [GHz]
Desired signal incident angle	0.0 [deg]
Desired signal to noise power ratio	15 [dB]
Number of interference signals	2
Interference signal frequency	9.701 [GHz], 9.699 [GHz]
Interference signal incident angle	+18 [deg], -18 [deg]
Interference signal to noise power ratio	30 [dB]
Receiver band width	5 [MHz]
A/D sampling frequency	5 [MHz]
A/D bit number	8

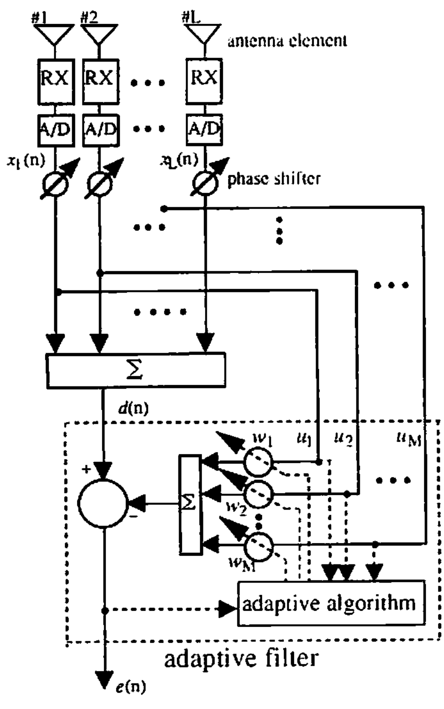

Fig.3 Element-Space ANBF.

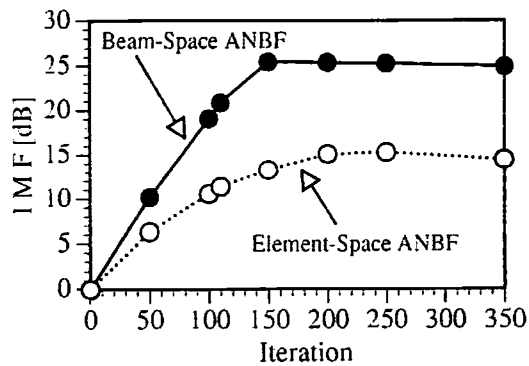

Fig.4 Comparison of convergence speed.

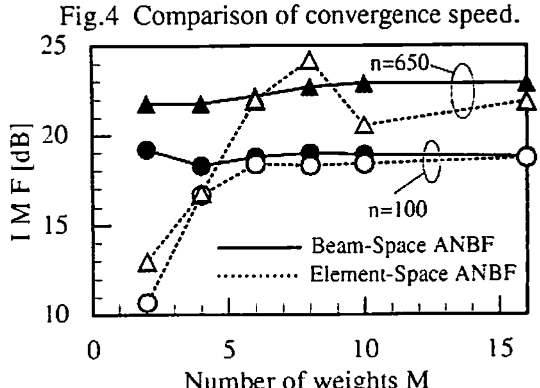

Fig.5 Relation between the number of weights and IMF.