A PROPOSAL OF A HIGH-SPEED SCANNING ADAPTIVE SUPERRESOLUTION ARRAY

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Introduction

An adaptive superresolution array (SRA) [1] is used for finding signal source locations. However, it has been reported that the steering signal must be swept with time at a certain low scanning rate to obtain the superior superresolution array performance [2].

This paper describes the Howells-Applebaum (H-A) adaptive superresolution array. We assume that the steering signal in the H-A loop is scanned with time to observe signal sources.

First, we present a theoretical analysis of the steady-state performance of the scanned SRA. It will be shown that the superior SRA performance is obtained even at a high scanning rate if characteristics of filters in the H-A loop statisfy certain conditions. The SRA performance here means the location accuracy or angular resolution capability. Furthermore, we propose new configuration of filters with which we may obtain the better location accuracy and lower loop noise.

Analysis of SRA weight

We consider the SRA which is implemented by the Howells-Applebaum adaptive array. The array consists of a linear array having N-elements (where N is an odd number) and the H-A loop as shown Fig.1. The steering signal vector $\mathbf{S}^*(t)$ which is scanned with time in order to observe signal sources is given by

$$\mathbf{S}^*(t)=[e^{-jp\omega_s t},\ e^{-j(p-1)\omega_s t},\ \ldots,\ e^{jp\omega_s t}]^T \qquad (1)$$

where $p=(N-1)/2$, T denotes transpose and ω_s is an angular frequency of the scanning.

We assume the signal environment as follows. Signals are incident on the array. Independent thermal noise with equal power Pn is generated on each element antenna.

We compare the scanned SRA with an almost fixed SRA [2]. Here, the latter is the SRA whose steering signal vector is scanned very slowly. The steady-state weight vectors are given by respectively

$$\frac{1}{G}\mathbf{W}_O = (\mathbf{I}+\mathbf{M}G)^{-1}\mathbf{S}^*(t_O) \qquad \text{for an almost fixed SRA} \quad (2)$$

$$\frac{1}{G}\mathbf{W}(\omega)=\{\mathbf{I}+\mathbf{M}GH(\omega)\}^{-1}\mathbf{S}^*(\omega) \qquad \text{for a scanned SRA} \quad (3)$$

where $\mathbf{I}$ is identity matrix, G is a loop gain, $\mathbf{M}$ is a covariance matrix for input signals and $H(\omega)$ is a frequency characteristic of the LPF used in the H-A loop ($H(0)=1$). Eq.(2) represents the weight vector at a certain time t_O . $\mathbf{W}(\omega)$ and $\mathbf{S}^*(\omega)$ in eq.(3)

are Fourier Transforms of $\mathbf{W}(t)$ and $\mathbf{S}^*(t)$ respectively. Let $a_{mn}(G)$ be an (m,n)-th element of $(\mathbf{I}+\mathbf{M}G)^{-1}$, as a function of G. Then, m-th element of $(1/G)\mathbf{W}_o$ denoted by $\{(1/G)\mathbf{W}_o\}_m$ is given by

$$\{\frac{1}{G}\mathbf{W}_o\}_m = \sum_{n=1}^{N} a_{mn}(G)e^{-j(n-p-1)\omega_s t_o}. \quad (m=1,2,\cdot\cdot,N) \qquad (4)$$

The (m,n)-th element of $\{\mathbf{I}+\mathbf{M}GH(\omega)\}^{-1}$ is similarly expressed as $a_{mn}\{GH(\omega)\}$. Since $S_n^*(\omega)$ is $2\pi\delta(\omega-\overline{n-p-1}\omega_s)$, we have

$$\{\frac{1}{G}\mathbf{W}(\omega)\}_m = \sum_{n=1}^{N} a_{mn}\{GH(\omega)\}2\pi\delta(\omega-\overline{n-p-1}\omega_s). \qquad (5)$$

Therefore, the inverse Fourier Transform of eq.(5) is

$$\{\frac{1}{G}\mathbf{W}(t)\}_m = \sum_{n=1}^{N} a_{mn}\{GH(\overline{n-p-1}\omega_s)\}e^{j(n-p-1)\omega_s t}. \qquad (6)$$

It is seen from eq.(6) that the weight vector depends on $H(\ell\omega_s)(\ell=-p,\cdots,0,\cdots,p)$ for the scanned SRA. Namely, if $H(\ell\omega_s)=1$ the scanned SRA has the same weight vector as the almost fixed SRA. On the other hand, $H(\ell\omega_s)$ has a value other than unity at a high scanning rate if a first order lag element $L(\omega)$ is employed for $H(\omega)$ ($L(\omega)=1/(1+j\omega Tc)$, Tc denotes a time constant). Then, the weight vector in eq.(6) is different from eq.(4) and the SRA performance degradates.

Fig.2 illustrates the typical SRA performance for a single signal with the input SNR=20dB located at 7.5° off broadside. Where $Ts=2\pi/\omega_s$, g=GPn. The better SRA performance is obtained for $Tc/Ts=10^{-1}$ or $H(\ell\omega_s)=1$. However, when $Tc/Ts=10^{-3}$ or 10^{-2}, the SRA performance degradation is observed. Namely, the angle for the maximum output SNR is different from the signal location and the output SNR decreases.

In order to obtain the better scanned SRA performance, $H(\omega)$ must satisfy the following condition.

$$H(\omega) = 1 \quad (\omega=-p\omega_s,\cdots, 0,\cdots, p\omega_s) \qquad (7)$$

When $L(\omega)$ is used for $H(\omega)$, the condition is satisfied when $\omega_s Tc \ll 1$. Namely, Tc must be very short when the scanning rate is high. The control loop noise, however, increases since the LPF has a high cut-off frequency ($2\pi/Tc$).

Filter configuration

In order to obtain the better SRA performance and decrease the loop noise, the LPF must satisfy eq.(7) and have a narrow pass-bandwidth. Namely, it is desired that the LPF has comb filter characteristics given by

$$H(\omega) = \begin{cases} 1 \text{ for } \omega=-p\omega_s,\cdots, 0,\cdots, p\omega_s \\ 0 \text{ else where.} \end{cases} \qquad (8)$$

Now, we present the configuration of the LPF. The LPF in the H-A loop consists of a first order lag element $L(\omega)$ and a transversal filter $F(\omega)$ as shown in Fig.3. $F(\omega)$ which is shown in Fig.4 is expressed as

$$F(\omega) = \sum_{m=0}^{M} Cm\ e^{-j2\pi m\omega/\omega_S} \qquad (9)$$

where

$$Cm = \frac{\sin(2\pi m\omega/\omega_S)}{\pi m} + \frac{1}{(M+1)}\{1 - \sum_{n=0}^{M} \frac{\sin(2\pi n\omega/\omega_S)}{\pi n}\} \qquad (10)$$

Cm is determined in such a way that the mean square of $F(\omega)-K(\omega)$ has the least value under the constraint $F(\ell\omega_S)=1$.

$$K(\omega) = \begin{cases} 1 & \text{for } |\omega| \leq \Delta\omega \\ 0 & \text{for } |\omega| > \Delta\omega \end{cases} \quad \text{in } |\omega| \leq \omega_S/2 \qquad (11)$$

The amplifier characteristics of $F(\omega)$ are shown in Fig.5. Since $F(\omega)$ is a periodic function with period ω_S, it is easily seen that eq.(7) is satisfied. On the other hand, $L(\omega)$ is used to limit the periodicity of $F(\omega)$ to a finite range.

By using the noise-bandwidth Bn defined as follows [3]

$$Bn = \int_0^\infty |H(\omega)|^2\, df\ , \qquad (12)$$

comparison may be made between the conventional first order lag element and the filter proposed in this paper for the loop noise. If noise-bandwidths of $L(\omega)$ and $F(\omega)*L(\omega)$ are represented by Bo and Bn respectively, we have

$$Bn/Bo = \sum_{m=0}^{M} Cm^2 \qquad (13)$$

For example, when $\omega_S Tc \leq 10^{-3}$, $M \leq 4$ and $\Delta\omega/\omega_S < 0.1$, it is seen from eq.(10) and (13) that Bn/Bo is almost $1/(1+M)$.

It is seen from these results that the better SRA performance is obtained and the loop noise decreases if we employ the filter configuration which is proposed in this paper.

Reference

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[2] M.Ueno, K.Kawabata and T.Morooka:"Scanning Limitation in Adaptive Superresolution Array", IEEE Trans., AP-32, No.3, pp.213-218 (Mar. 1984).

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[4] M.Ohmiya, Y.Ogawa and K.Itoh:"A Study on a Howells-Applebaum Adaptive Array", I.E.C.E. Technical Report, AP84-33 (Jun. 1984).

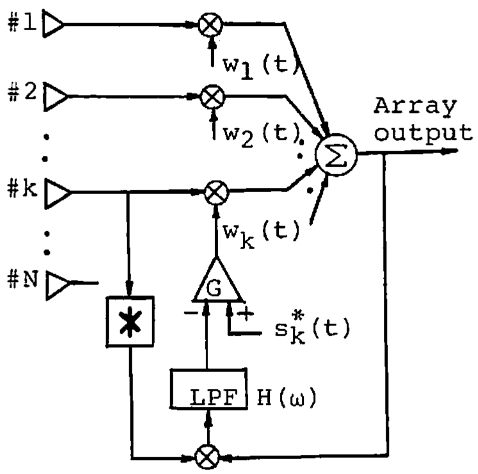

Fig.1-Howells-Applebaum adaptive super-resolution array.

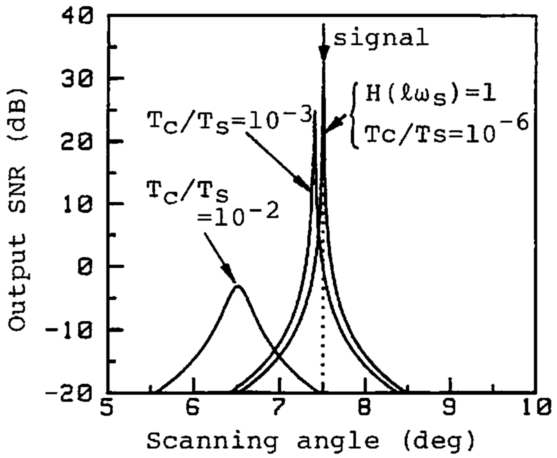

Fig.2-Scanning effects. N=17, Input SNR=20dB, g=10. An inner-element spacing is a half wave length.

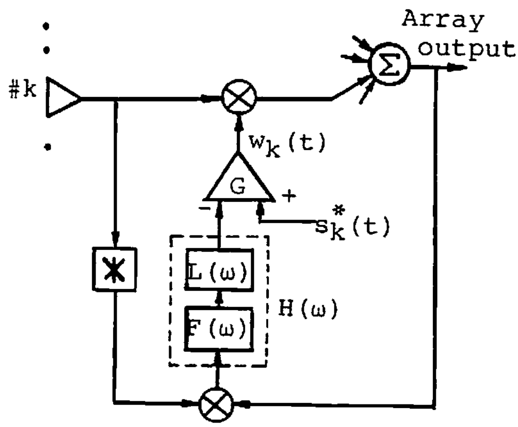

Fig.3- New configuration of the LPF H(ω).

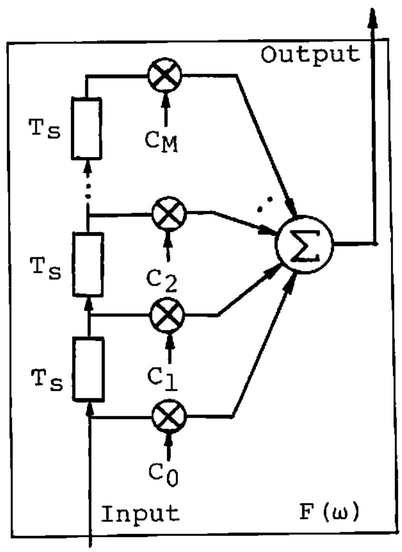

Fig.4-Block diagram of transversal filter.

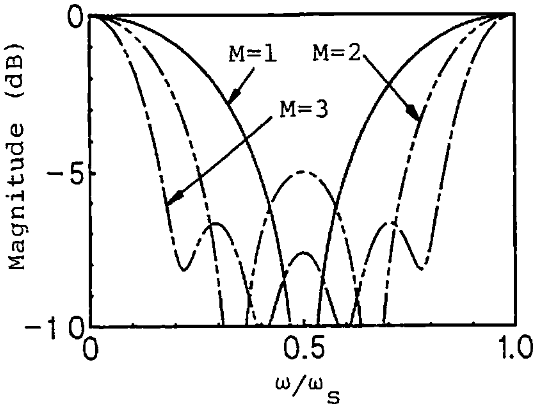

Fig.5-Amplitude characteristics of F(ω). $\Delta\omega/\omega_s=0.1$.