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Direct Data Domain Algorithm in the Presence of Mutual Coupling

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***Abstract*-In a beamforming systems mutual coupling among elements can degrade performance of the system. In direct data domain algorithm this effect severely undermines the interference suppression capabilities. A new adaptive algorithm based on direct data domain in the presence of unknown mutual coupling effects is present. This algorithm can recover amplitude the desired signals, while simultaneoulsly calculate mutual coupling matrix and eliminate it. Numerical simulation shows that this algorithm can recover the desired signal accurately in the presence of mutual coupling.**

***IndexTerms*-mutual coupling,adaptive arrays**

1. Introduction

Adaptive array signal processing has been used in many fields such as radar, sonar and communication. The performance of an adaptive antenna array is strongly affected by the existence of the mutual coupling effect between antenna elements [1-6]. Many of the attempts on adaptive beamforming assume that the elements of the array are isotropic point sensors isolated from each other [8]. Therefore, to evaluate accurately the resulting system performance of practical antenna arrays, the electromagnetic influence among the elements must be carefully considered. Since most of the beamforming algorithms ignore the effects of Mutual Coupling(MC), especially in closely spaced antenna elements, the predicted system performances may not be accurate [1-6].

Recently Direct data domain least squares (D^3LS) algorithm [11] has been proposed to overcome the drawbacks of a statistical techniques such as MUSIC, no having to estimate a covariance and with one snapshot makes it possible to carry out an adaptive process in real time. This algorithm has ability to recover the desired signal while also automatically minimizes the interference power. but the performance of this algorithm affected by the mutual coupling effect[5]. Some authors compensates the effect of the mutual coupling with use of MOM analysis [6-7] or mutual impedance[8] or MCmatrix [10] calculation.

In this paper we will show a new algorithm that with help of properties of D^3LS Algorithm can estimate the mutual coupling coefficient and then eliminate it, without any calculation for MOM analysis or mutual impedance. This paper is organized as follows. In Section II we investigate effects of mutual coupling on the the performance of a direct data domain algorithm for the one-dimensional (1-D). In Section III we present new technique for compensate of mutual coupling effect. In Section IV, numerical simulations illustrate this proposed algorithm can accurately recover the desired signal in the presence of mutual coupling .

II.The Effects of Mutual Coupling

Sarkar and Sangruji presented a direct data domain technique to adaptively recover a desired signal arriving from a given look direction while simultaneously rejecting all other interference[2]. The technique is based on the fact that in the absence of mutual coupling, a far-field source presents a linear phase front at the ports of a linear array. Here, we demonstrate that the mutual coupling undermines the ability of this algorithm to maintain the gain of the array in the direction of the signal while simultaneously rejecting the interference. To do so, we compare the performance of the algorithm in the ideal case of mutual coupling with the case where mutual coupling is taken into account but not compensated for. We review the direct data domain adaptive [12].

A.*review of Direct Data Domasin Algorithm*

Consider an array of N uniformly spaced elements separated by a spacing of d shown in Fig.1. The array receives a signal S from an assumed direction θ and

M interference sources J_i from unknown directions. In the absence of mutual coupling, the voltage at the i th element due to the incident fields is:

$$X_n = e^{jknd\cos\theta}.\alpha_s + \sum_{m=1}^{M} e^{jknd\cos\theta_m}.j_m + n_n \qquad (1)$$

our objective is to estimate its complex amplitude while simultaneously rejecting all other interferences and noise.

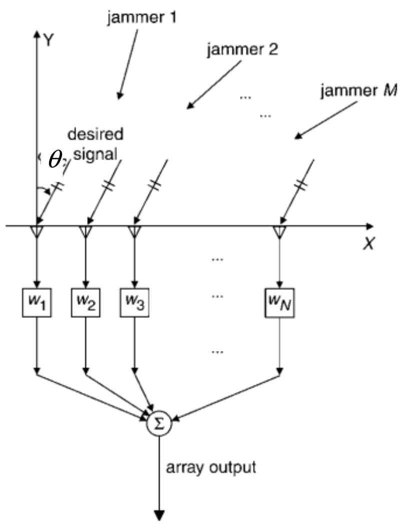

Figure 1. Linear uniform array

We make the narrowband assumption for all the signals including the interferers. The array 's output can be expressed as :

$$X = A.S + (A_J.J + N + ...) \qquad (2)$$

where X ,A ,S denote the received signal vector, steering matrix and desired signal. others are intereference and noise.

$$X = [x_1(t),...,x_N(t)]^T \qquad (3)$$

$$A = [1, e^{-j2\pi\frac{d}{\lambda}\cos\theta}, ..., e^{-j2\pi N\frac{d}{\lambda}\cos\theta}]^T \qquad (4)$$

For a conventional adaptive array system, we use of the K weights W_k, the relationship between K and N can be chosen as $K = (N + 1)/2$ [12]. Let us define

$$Z = e^{j2\pi\frac{d}{\lambda}\cos\theta} \qquad (5)$$

Then $X_k - Z^{1}X_{k-1}$ contains no components of the SOI. Therefore one can form a reduced rank matrix where the weighted sum of all its elements would be zero [9]. In order to make the matrix full rank, we fix the gain of the subarray by forming the weighted sum $\sum_{k=1}^{K} W_k Z^{k-1}$ along the DOA of the SOI to a prespecified value. gain of the subarray is $M+1$ along the direction of θ. Then we can write:

$$\begin{bmatrix} 1 & \cdots & Z^{K-1} \\ x_1 - Z^{-1}x_2 & \cdots & x_K - Z^{-1}x_{K+1} \\ \vdots & \vdots & \vdots \\ x_{K-1} - Z^{-1}x_K & \cdots & x_{N-1} - Z^{-1}x_N \end{bmatrix}_{K\times K} \times \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_K \end{bmatrix} = \begin{bmatrix} M+1 \\ 0 \\ \vdots \\ 0 \end{bmatrix}_{K\times 1} \qquad (6)$$

we can now estimate the SOI through using the following weighted sum:

$$y = \frac{1}{M+1}\sum_{k=1}^{K} W_k.X_k \qquad (7)$$

B.Numerical example

One example demonstrate the effect of MC on the described in sectionII-A. Here we using a seventeen element antenna array and spacing between two elements is $\lambda/2$. Array receive the desired signal with two jammers , signal to noise ratio is *10dB* and other parameters are listed in Table I.

TableI -Parameters for the desired signal and Interferer

	Magnitude	Phase	DOA
signal	1-10V/m	0	45°
Jammer1	100V/m	0	20°
Jammer2	100V/m	0	80°

The number of adaptive weights chosen for our simulation will be nine [12]. Jammers are 40 dB stronger than the SOI. We suppose all of signal and jammers arrive from the elevation $\theta = 90^o$. The magnitude of the incident signal is varied from *1*V/m to *10* V/m but jammers intensities are constant as given in Table I.

Fig.2 plotes the results of using the conventional D³LS. As can be seen, algorithm couldn't recover the signal accurately in presence of MC.

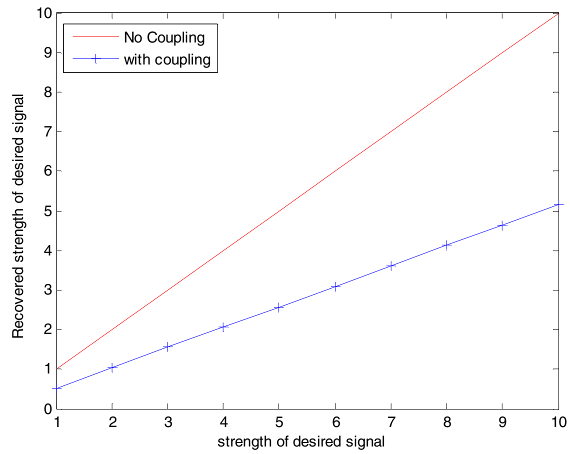

Fig2. Recovered strength of desired signal including mutul coupling an without mutual coupling

III. Mutual Coupling Compensation with Proposed Algorithm

If assume C denote the mutual coupling matrix of the Array, the output will be as:

$$X = C.A.S + (\text{noise and interferer} + \ldots) \qquad (8)$$

In this paper, we assume that one sensor is only affected by the coupling of the two sensor around it, which is shown in Fig.3.

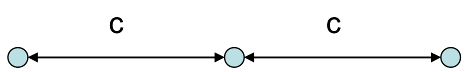

Fig3. Map of mutual coupling

Tthe MC matrix can be expressed as:

$$C = \begin{bmatrix} 1 & c & 0 & \ldots & 0 \\ c & 1 & c & \ldots & 0 \\ \vdots & \ddots & \ddots & & \vdots \\ 0 & \cdots & c & 1 & c \\ 0 & \cdots & 0 & c & 1 \end{bmatrix}_{N\times N} \qquad (9)$$

If we form the $X_k - Z^{1}X_{k-1}$,for the case of presence of mutual coupling we have

$$\begin{aligned} X_1 - z^{-1}X_2 &= -\alpha_s c z^{-1} + (\text{noise and interferer}) \\ X_2 - z^{-1}X_3 &= 0 + (\text{ noise and interferer}) \\ &\ldots \qquad\qquad\qquad\qquad\qquad\qquad (10) \\ X_{N-2} - z^{-1}X_{N-1} &= 0 + (\text{ noise and interferer}) \\ X_{N-1} - z^{-1} X_N &= \alpha_s c z^{N-1} + (\text{ noise and interferer}) \end{aligned}$$

We can observe the mutual coupling don't have more effect on the matrix of (6), so in order to eliminate the effect of the mutual coupling we only must estimate coupling coefficient (c) and then make the $\widetilde{C}$ matrix . From 10 we can write:

$$c = \frac{X_1 - z^{-1}X_2}{-\alpha_s . z^{-1}} \qquad (11)$$

$$c = \frac{X_{N-1} - z^{-1}X_N}{\alpha_s . z^{N-1}} \qquad (12)$$

So for estimate the c, we can calculate and give average from (11) and (12).

$$c = \tfrac{1}{2} . \frac{(z^{1-N}X_{N-1} - z^{-N}X_N) + (X_2 - z\ X_1)}{\alpha_s} \qquad (13)$$

Because we don't know the α_s, at the first we suppose amplitude of the desired signal ($\widetilde{\alpha}_s$) is 1 and then calculate:

$$\widetilde{c} = \tfrac{1}{2} . \frac{(z^{1-N}X_{N-1} - z^{-N}X_N) + (X_2 - z\ X_1)}{1} \qquad (14)$$

With this first estimation we calculate MC matrix and after inversing and multiplying at receiving signals we recover the signal as $\widetilde{\alpha}_s$, after the algorithm estimates amplitude of the desired signal, this new amplitude estimation uses for new estimation of $\widetilde{c}$.

$$\widetilde{c} = \tfrac{1}{2} . \frac{(z^{1-N}X_{N-1} - z^{-N}X_N) + (X_2 - z\ X_1)}{\widetilde{\alpha}_s} \qquad (15)$$

And with repeat of the algorithm mutual coupling matrix and amplitude of the desired signal determined:

$$\widetilde{\alpha}_s = \frac{1}{M+1} \sum_{k=2}^{K} W_k \widetilde{C}^{-1} \widetilde{X}_k \qquad (16)$$

IV.*Numerical Examples*

In this section the capability of mutual coupling compensation for proposed algorithm with an example will be test. scenario is the same as the example used to demonstrate the effect of MC in sectionII-B. Fig.4 show the result of using the new proposed algorithm .

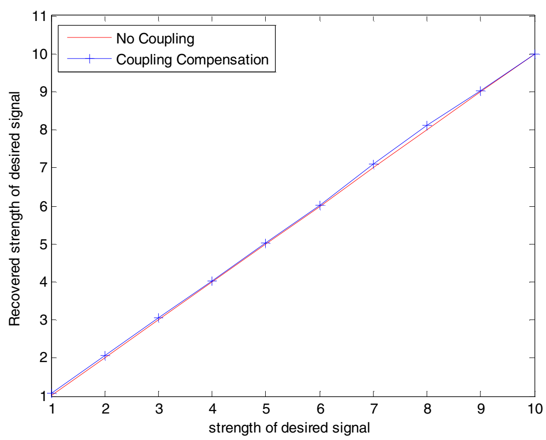

Fig4. Recovered strength of desired signal under different incident strengths of desired signal using proposed algorithm

5. Conclusion

In this paper we investigate the effect of mutual coupling between the elements on the performance of D^3LS algorithm. We had shown the mutual coupling causes the adaptive algorithm to fail. Without using the MOM method and impedance matrix calculation and only using a first and end elements on array we could estimate the mutual coupling coefficient and then we could eliminate mutual coupling with inverse matrix and recovered the desired signal accurately.

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