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# Performance evaluation of the adaptive sidelobe canceller system with various auxiliary configurations

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In practical radar systems, the conventional adaptive sidelobe canceller (SLC) works very well as long as the input signal-to-interference-plus-noise (SINR) ratio is low or when the desired signal is known to be absent during certain time intervals. However, under high SINR, attenuation in the direction of the desired signal is inevitable. In this paper, the conventional sidelobe canceller is improved by replacing the separate auxiliary antennas by a number of existing elements of the main antenna array. This modification makes the proposed SLC different from the conventional one because the desired signal components of the main channel and auxiliary signals may be correlated. Such correlation may cause serious attenuation in the desired signal especially when the number of reused elements from both of the main array and auxiliary antenna is increased. The resulting malfunctioning of the desired signal cancellation is eliminated by adjusting the weights of the reused elements to produce a specific cancellation pattern. The required cancellation pattern should have two main features: first, it should have a level equal to that of the main array pattern at the interferer direction. Second, it should have a very low level or a null at the direction of the desired signal. The simulation results show that good performance for interference cancellation, maintaining a distortionless response for the desired signal, and low sidelobe level can be obtained by using the proposed technique. Besides the simplicity and low cost, the other advantage of the proposed SLC is that it can work effectively regardless of the strengths of the desired signal.

## 1. Introduction

A sidelobe canceller (SLC) is an adaptive antenna system that can suppress interfering signals incident on the sidelobes of the main antenna. Conventional SLC's that are employed in practical radar systems are effective only when the desired signal is very weak (relative to the interference signal) or when the desired signal is known to be absent during certain time intervals [1–3]. In applications where the desired signal may be of unknown strength and may always be present, then the problem of desired signal cancellation is inevitable [1,4]. The weights of the auxiliary antenna elements are usually chosen by minimizing the total output power. Choosing the weights to minimize output power can cause cancellation of the desired signal, since the desired signal also contributes to total output power. In fact, as the desired signal gets stronger it contributes to a larger fraction of the total output power and thus the percentage cancellation increases. Clearly, this is an undesirable effect. This limitation can be overcome through the application of linear constraints to the weight vector of the auxiliary antenna. This design criterion yields the well-known minimum variance distortionless response (MVDR) beamformer [5,6]. However, with the standard MVDR beamformer, desired signal cancellation also occurs in the presence of steering vector errors or in the case of smart interference in which the interference is correlated with desired signal [7–11]. Also, the performance of the MVDR beamformer is known to degrade substantially when the number of snapshots used for covariance matrix estimation is insufficient [12]. This often occurs in practical radar systems due to the requirement for fast tracking of the moving target.

Furthermore, in real-life applications of phased arrays, the accuracy of pointing an adaptive null toward an interfering signal is known to degrade substantially when the effect of mutual coupling between array elements is not taken into account [13] and/or due to the effect of frequency fluctuation [14]. Thus, there has been considerable interest in synthesizing array patterns with broad nulls [15–17] or extremely low sidelobes [18–20] to cope with these problems. It is also desirable to make the practical implementation of such phased arrays as simple as possible where the null steering in adaptive arrays is usually achieved by controlling

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the complex weights of all or most of the array elements. In [21] an alternative approach was proposed, where only the two side elements of the array are used for null steering.

This paper presents a new and less expensive sidelobe canceller technique that can solve the problem of the desired signal cancellation in the radar systems. The proposed technique involves reuse of few elements at the center of the original array, which together work as an auxiliary antenna and produce a cancellation pattern. Since no separate auxiliary antennas are needed, lower cost is inevitable. The amplitude and phase excitations of the reused elements are adjusted so that the main beam of the cancellation pattern, produced by them, coincides with sidelobe of the original array pattern. Then, a deep null or nulls toward the interfering signals can be generated by subtracting the cancellation pattern from the pattern of the original array. To get a good performance, the cancellation pattern should have near zero, or a very low level along the direction of desired signal to prevent the cancellation of desired signal in the adaptive part of the proposed technique. In this way, the desired signal and interference are separated completely, and this will preserve desired signal characteristics after the interference cancellation. The proposed technique supports the concept of partially adaptive arrays and it can be considered as a valuable alternative to the fully adaptive arrays that are very complex and expensive to implement [22].

This paper is organized as follows. Section 2 briefly describes the conventional sidelobe canceller technique and states its main disadvantages when it is applied in radar systems. In Section 3, the proposed adaptive sidelobe canceller technique is introduced. In Section 4, simulation results are provided to demonstrate the performance of the proposed technique and concluding remarks are given in Section 5.

## 2. Conventional sidelobe canceller

Fig. 1 shows a conventional adaptive SLC system that consists of a main channel and one or more auxiliary channels. The main channel can be either a single high gain antenna (such as dish antenna) or an N-element phased array antenna. It has a highly directional response, which is pointed toward the desired signal. The interfering signals are assumed to enter through the sidelobes of the main antenna pattern while the auxiliary channel(s) also receive the interfering signals. Similarly, the auxiliary channel can be either a single antenna or a phased array antenna involving a number of receiving elements, $M$. The goal is to choose the auxiliary antenna weights $\boldsymbol{W}_a = [w_1, \quad w_2, \ldots, \quad w_M]^T$ in order to cancel the main channel interference component. This implies that the radiation pattern of the main antenna in the directions of interfering signals and that of the auxiliary antenna(s) must be at the same level and in antiphase. The overall system then has a response of zero at the direction of interference signal. In general, requiring zero response to all interference signals is either not possible or can result in significant white noise gain [4]. Thus, the weights are usually chosen by minimizing the expected value of the total output power given by:

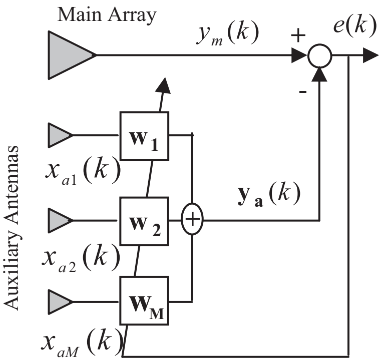

**Fig. 1.** Structure of the conventional adaptive SLC technique.

$$\min_{\mathbf{w_a}} \quad E\left\{\left|y_m - \mathbf{w_a^H x_a}\right|^2\right\} \tag{1}$$

where $y_m$ is the output signal of the main antenna and $\boldsymbol{X}_a = [x_{a1}, \quad x_{a2}, \ldots, \quad x_{aM}]^T$ are output signals of the auxiliary antennas. The optimum weights solution is given by [4]:

$$\mathbf{w_a} = \mathbf{R}_a^{-1}\mathbf{r}_{ma} \tag{2}$$

$$\mathbf{r}_{ma} = E\{\mathbf{x}_a y_m^*\} \quad \text{and} \quad \mathbf{R}_a = E\{\mathbf{x}_a \mathbf{x}_a^H\} \tag{3}$$

where $*$ represents complex conjugate and the superscript H represents Hermitian transpose. As the signal to interference-plus-noise ratio (SINR) gets better more desired signal leaks through the auxiliary channels. As a result, the output signals of the auxiliary antenna ($\boldsymbol{X}_a$) will contain a significant amount of desired signal. Choosing proper weight values ($\boldsymbol{W}_a$) to minimize output power may lead to cancellation of the desired signal. Therefore, cancellation of the desired signal in this technique is inevitable. In order to overcome this important problem and modify this technique to be more effective and less expensive in practical radar systems, a new adaptive SLC is presented in the following section.

## 3. The proposed sidelobe canceller

The proposed structure of the new SLC is shown in Fig. 2. This technique involves two steps: the first step is to generate a cancellation pattern using a number of the central elements of the main array, and the second step is to place a null(s) in the resulting array pattern by subtracting the cancellation pattern from the main array pattern. Optimal values of the auxiliary weights are obtained by using adaptive interference cancellation method [23]. The details of each step are shown as follows:

### 3.1. Original main array

For a simple description of the idea, the elements will be considered as scalar isotropic receivers. The element pattern and polarization can then be easily accounted for in the case of a practical design. For uniform inter-element spacing $d$, the far zone field pattern is given by:

$$AF_{Main}(\theta) = \sum_{n=1}^{N} a_n e^{jkd(n-1)\sin(\theta)+\beta} \tag{4}$$

where $N$ is the total number of array elements, $a_n$ is the amplitude excitation of the $n$th element, $k = \frac{2\pi}{\lambda}$ is the wave number, $\theta$ is the angular position of the field point, and $\beta$ is the phase difference between adjacent element excitations. Also for simplicity of presentation, the excitation is assumed uniform across the array; that is $a_n = 1$ and $\beta = 0$. In such case, the expression for array factor can be summed in closed form as [24]:

$$AF_{Main}(\theta) = \frac{\sin\left[\left(\frac{N}{2}\right)\ \mathrm{kdsin}\ (\theta)\right]}{\sin\left[\left(\frac{1}{2}\right)\ \mathrm{kdsin}\ (\theta)\right]} \tag{5}$$

### 3.2. Auxiliary array

Let the auxiliary array under investigation is composed of $M$ elements of the primary array that are symmetrically located at the center of the main array as shown in Fig. 2. Let the complex