Advances in Sidelobe Cancellation Including Mutual Coupling

(Invited Paper)

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***Abstract*—An interference cancellation algorithm with mainlobe maintenance is presented under the framework of generalized sidelobe canceller. The preservation of the pattern mainlobe is obtained by the mainlobe subspace. The mainlobe subspace assumed for the main beam is modified by the embedded element patterns using fast full wave simulation techniques. Simulation results show the effectiveness of the sidelobe canceller.**

I. Introduction

Whenever antenna array weights are adjusted to form nulls in interference directions, especially when the interfers appear near the mainlobe, a distortion appears in the mainlobe. Especially for high dynamic-range radio-telecopes, such as the Square Kilometer Array (SKA), minute beamshape distortions can be unacceptable [1]. The generalized sidelobe canceller (GSC) has been widely used in array pattern synthesis and nulling, given its effectiveness and simplicity for achieving multiple linear constraints under the quiescent beam pattern [2],[3].

As is known, mutual coupling will affect both the depth and the accuracy of the position of the nulls. Incorporating the mutual coupling into the array nulling should be very useful. That can be done by replacing the steering vector by the embedded element pattern (EEP) [4].

In this paper, a sidelobe cancellation method is proposed in which the mainlobe gain is preserved by multiplying the blocking matrix which is orthogonal to the mainlobe space. Besides, the subspace is set separately by co- and cross polarization patterns, both of which reflect the effect of mutual coupling.

The remainder of this paper is organized as follows. In Section 2, the quiescent pattern nulling algorithm is summarized. The problem of polarization antenna pattern nulling with EEP is formulated. In Section 3, simulation examples are used to illustrate the techniques for the subspace based sidelobe cancellation. The conclusions are addressed in Section 4.

II. Problem formulation

A. Traditional GSC quiescient pattern nulling

Consider an N-element irregular planar array, whose radiation pattern $F(\theta,\phi)$, steering to direction (θ_0,ϕ_0) with excitation vector w, is given by

$$F(\theta,\phi)=\sum_{n=1}^{N} f_n(\theta_0,\phi_0)w_n e^{-jk(ux_n+vy_n)}=Ew \quad (1)$$

where k is the wave number, (x_n,y_n) is the position and $f_n(\theta_0,\phi_0)$ is the EEP of each antenna element. $E=f_n(\theta_0,\phi_0)e^{-jk(ux_n+vy_n)}$ ($u = sin\theta cos\phi$, $v = sin\theta sin\phi$) can be seen as the the new "steering vector", which includes the effect of mutual coupling.

Assuming the weight of the quiescent pattern (pattern before nulling) is w_q, the solution of the quiescent pattern nulling under the framework of GSC [2] is

$$\hat{w}=w_q-G^H(GG^H)^{-1}Gw_q \quad (2)$$

where G is the "steering vector" matrix to the desired nulling directions. The matrix $G^H(GG^H)^{-1}G$ operating on w_q is a projection matrix mapping $\hat{w}$ into the null space of G, by which nulls are substrated on the quiescent pattern.

B. Sidelobe cancellation considering the mutual coupling

We aim to maintain a mainlobe gain identical to that of the quiescent pattern while suppressing the sidelobe interference. The blocking matrix B orthogonal to the mainlobe space is constructed to alleviate the mainlobe distortion. In the following, we propose to ensure that each steering vector that appears in G also has a zero in a number of directions within the mainlobe. The weight vector $\hat{w}$ will be computed as

$$\hat{w}=w_q-BG^H(GG^H)^{-1}Gw_q \quad (3)$$

The solution of $\hat{w}$ involves determining the null space and the mainlobe space. E can consist of co- and cross components as practical antennas generally have both the co- and cross polarization patterns. The covariance matrix of the mainlobe region and the null region are constructed respectively according to the co- and cross patterns [5]

$$R_\Theta^{co}=\sum_{i=1}^{Q}E_i^{co}(E_i^{co})^H, R_\Theta^{cro}=\sum_{i=1}^{Q}E_i^{cro}(E_i^{cro})^H \quad (4)$$

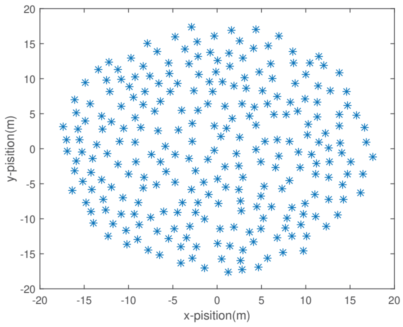

Fig. 1. Position of 256 SKALA antennas.

where the (co,cro) superscripts stand for the co- and cross components of the radiation pattern, Q is the number of steering vectors in the null space or the mainlobe space.

For the null and the mainlobe region computing the eigenvalue decomposition of matrix R_{Θ}^{co} and R_{Θ}^{cro} , and spliting the eigenspace by selecting the eigenvalue under a threshold. The solution of $\hat{w}$ becomes

$$\hat{w} = w_q - V_m^{\perp} V_n^{\parallel} w_q \quad (5)$$

where $V_m^{\perp}$ is the subspace orthogonal to both co- and cross patterns of the mainlobe space, which approximates the blocking matrix B. And $V_n^{\parallel}$ is the subspace parallel to both the co- and cross patterns of the null space.

III. Simulation Results

In this section, numerical results of interference nulling is analyzed. In practice, SKA Log periodic antenna (SKALA) providing 2 orthogonal polarization is used in the simulation [6]. The array is made of 256 SKALA antennas (see Fig. 1), randomly distributed over a circle of 35 meter in diameter with minimum distance of $1.35m$. The array is simulated at 110 MHz, HARP [7] is exploited to simulate the station and to calculate all the EEPs. The response vector of generalized pattern greater than or equal to $-6\ dB$ is selected as the mainlobe space.

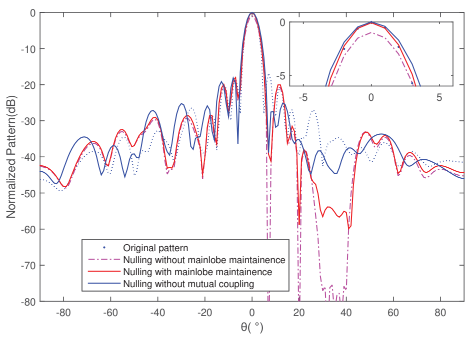

Fig. 2. Normalized pattern in $\phi = 90°$ cut.

The interferences are assumed at the same plane $\phi = 90°$ with $\theta = 7°, 20°$ and cover a region of θ in $[30°, 40°]$; ϕ in $[70°, 90°]$. Fig. 2 displays the original radiation pattern and patterns after nulling in the $\phi = 90°$ plane of the array. The mainlobe subspace and the nulling subspace is selected by the corresponding eigenvalue greater than 10^{-1} and 10^{-3}. It is clear that mutual coupling effects the depth and position of the nulling. After multiplation by the blocking matrix, the mainlobe distortion in the steering direction is reduced from $0.983\ dB$ to $0.075\ dB$. Fig.3 shows the radiation pattern considering the mainlobe preservation.

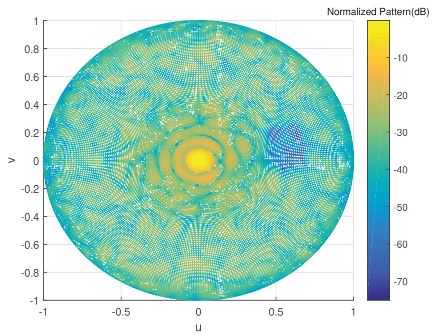

Fig. 3. Radiation pattern after nulling with the mainlobe preservation.

IV. Conclusion

The sidelobe cancellation method can be used in polarization antenna array nulling considering mutual coupling. The null subspace and the mainlobe subspace can be determined by using the eigenvalue of the array covariance matrix. Besides, with the blocking matrix, the pattern mainlobe gain is maintained as that of the quiescent pattern. However, the null depth deteriorates under the mainlobe maintainance, further research will focus on the trade off between the null-depth and the pattern distortion.

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