Elimination of the Effects of Mutual Coupling in an Adaptive Nulling System with a Look Direction Constraint

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Introduction

Gupta and Ksienski [1] demonstrate that the mutual coupling between the elements of an adaptive array causes significant degradation in the signal-to-interference-plus-noise ratio (SINR). The mutual coupling also slows the response of the array. To compensate for the effect of mutual coupling, they obtain a simple matrix equation to relate the open circuit voltages and the actual voltages at the ports of the array. They suggest that the open circuit voltages are free of mutual coupling.

Gupta and Ksienski find the open circuit voltages using a model of a set of equispaced, identical, centrally fed dipoles. However, these voltages found at the ports of the array are the voltages in the presence of the other, open circuited, elements. This implies that the effect of mutual coupling is reduced, but not eliminated. The array may also be in the presence of near field scatterers which would cause large distortions in the measured signals. The formulation in [1] cannot be used for arrays in the presence of near field scatterers.

In this paper, we present an approach based on the method of moments (MOM) to model and eliminate the mutual coupling for signals arriving from a given direction of arrival (DOA). The MOM can model the mutual coupling and any near field scatterers that may be present. The technique is tested on a linear array with a signal being corrupted by jammers. Another test is the same array in the presence of a near field scatterer.

Elimination of Mutual Coupling

Consider a linear array of M thin, parallel (say z-directed), equispaced, identical wires. One can use the method of moments to analyze the response of such an array to an arbitrary incident field. In applying the MOM, simplifying assumptions as stated in [2] can be made. Using these assumptions, the integral equation to solve for the unknown currents is

$$E_z^{inc} = -\mu_0 \int_{axes} I(z') \frac{e^{-jkR}}{4\pi R} dz' + \frac{1}{\epsilon_0} \frac{\partial}{\partial z} \int_{axes} \frac{\partial I(z')}{\partial z'} \frac{e^{-jkR}}{4\pi R} dz' \tag{1}$$

This equation can be approximately solved by using piecewise sinusoid basis functions in conjunction with a Galerkin formulation. The integral equation is then reduced to the equation

$$[V_{MOM}] = [Z_{MOM}][I_{MOM}] \Rightarrow [I_{MOM}] = [Y_{MOM}][V_{MOM}] \tag{2}$$

$[Z_{MOM}]$ ($[Y_{MOM}]$) is the MOM impedance (admittance) matrix of order $N \times N$, where N is the total number of unknowns in the MOM solution (usually much larger than M). These matrices contain all the information about the mutual coupling between, and the loading on, the elements of the array and the interaction with any near field scatterers.

The voltages measured at the ports of the array is related to the currents at the ports by

$$[V_{meas}] = [Z_L][I_{port}] \tag{3}$$

where $[Z_L]$ is the diagonal load matrix. Because of the use of the subsectional basis, the entries of $[I_{port}]$ are just selected entries of $[I_{MOM}]$.

Using equations (2) and (3), one can write

$$[V_{meas}] = [Z_L][\widehat{Y_{MOM}}][V_{MOM}] \tag{4}$$

where $\widehat{Y_{MOM}}$ is a $M \times N$ matrix with only the rows of $[Y_{MOM}]$ that correspond to a port. Given the DOA of the signal (θ, ϕ) and the fact that the entries in $[V_{MOM}]$ are directly related to the incident field

$$V_{MOM}^{q+p;m} = V_{MOM}^{q;m} e^{\pm jkp\Delta z \cos\theta} \tag{5}$$

where, Δz is the subsection length, k the wavenumber, q the subsection number in wire $\#m$. If in the MOM model, wire $\#n$ is a scatterer and is at coordinates (x, y, z) with respect to one of the wires (say $\#m$) in the array,

$$V_{MOM}^{q;n} = V_{MOM}^{q;m} e^{\pm jk(z\cos\theta + x\sin\theta\cos\phi + y\sin\theta\sin\phi)} \tag{6}$$

Using equations (5) and (6), (4) can be written as

$$[V_{meas}] = [Z_L][Y''][V_{inc}] \tag{7}$$

Here, the $M \times N$ matrix $\widehat{Y_{MOM}}$ is reduced to a $M \times M$ matrix $[Y'']$ by incorporating the exponential factor given in (5) or (6) into $\widehat{Y_{MOM}}$. $[V_{inc}]$ is the matrix with the entries of $[V_{MOM}]$ that correspond to the ports of the array. Equation (7) can be used to solve for $[V_{inc}]$, which corresponds directly to the incident field. The voltages given in $[V_{inc}]$ are free of the effects of mutual coupling for signals arriving from the given DOA and can be used for signal recovery.

Numerical Examples

We test the above method of eliminating the mutual coupling, with two examples. In the first, a seven element array of $\lambda/2$ dipoles spaced $\lambda/2$ apart receives a signal of intensity $1.0V/m$ from direction $\phi = 45^o$ which is corrupted by three jammers. Two of the jammers arrive from $\phi = 60^o$ and 30^o with intensities $1.0V/m$ and $1.5V/m$ respectively. The third jammer arrives from $\phi = 75^o$ and its intensity is varied from $2.0V/m(6.0dB)$ to $2000V/m(66dB)$. The array is analyzed using seven unknowns per wire. The output of the signal recovery program is expected to remain constant as the intensity of the jammer changes. In both examples the signals and jammers arrive from $\theta = 90^o$ and the signal recovery algorithm of [3] is used.

Figure 1 shows the magnitude of the recovered signal if one used the measured voltages or the open circuit voltages. The jammer is not completely nulled in both cases and the output varies with the intensity of the jammer. Figure 2 shows the the recovered signal if one used the formulation described in this paper. Now, the jammer has been completely nulled.

In the second example, as a near field scatterer, a single, short circuited $\lambda/2$ wire is placed 2λ in front of the array. The environment is the same as that in the first example. Figure 3 shows the reconstruction of the signal after the mutual coupling has been eliminated. The jammer has been completely nulled even with the presence of a near field scatterer. As the jammer strength is increased, the reconstructed signal is nearly constant.

Conclusions

In this paper we present a MOM based method to eliminate the effects of mutual coupling in an adaptive array. The algorithm is easy to implement and yields accurate results for practical cases. The algorithm can also handle near field scatterers, a significant advance over earlier available techniques.

References

[1] I.J. Gupta and A.A. Ksienski. Effect of mutual coupling on the performance of adaptive arrays. *IEEE Transactions on Antennas and Propogation*, 31(5):785–791, September 1983.

[2] et.al. A.R. Djordjevic. *Analysis Of Wire Antennas and Scatterers: Software and User's Manual.* Artech House.

[3] T.K. Sarkar and N. Sangruji. An adaptive nulling system for a narrow-band signal with a look-direction constraint utilizing the conjugate gradient method. *IEEE Transactions on Antennas and Propogation*, 37(7):940–944, July 1989.

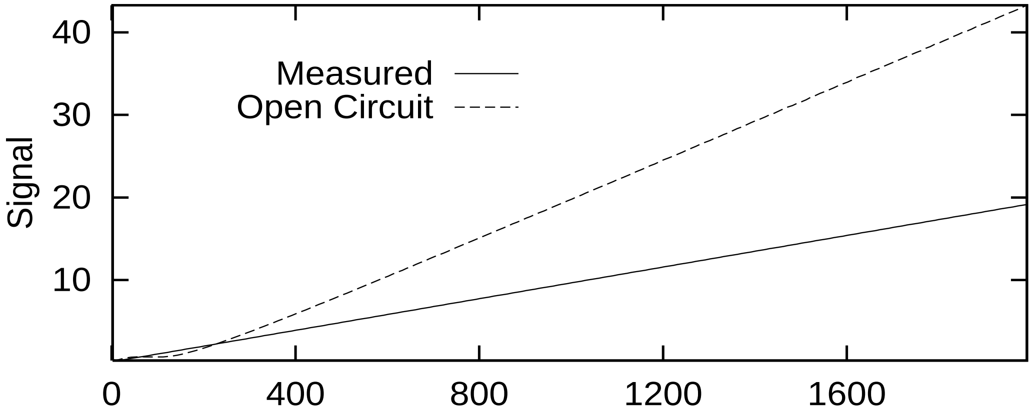

Figure 1. Signal Reconstruction Using Measured or Open Circuit Voltages

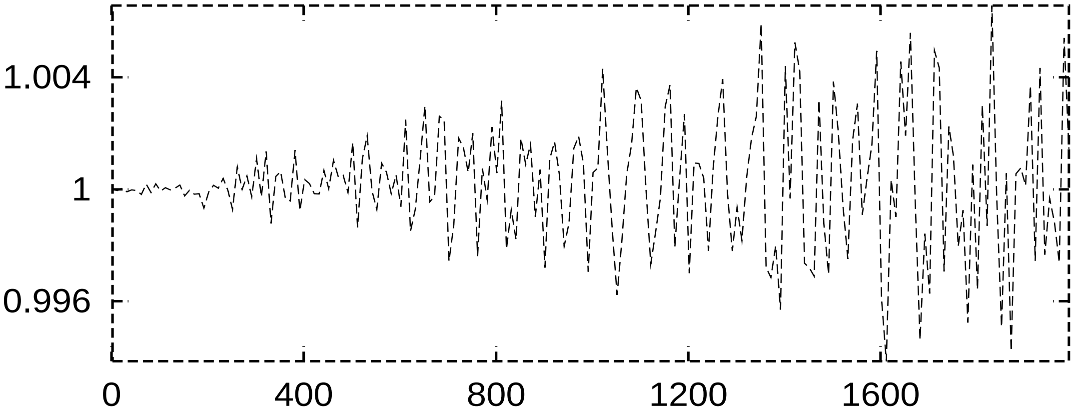

Figure 2. Signal Reconstruction After Elimination of Mutual Coupling

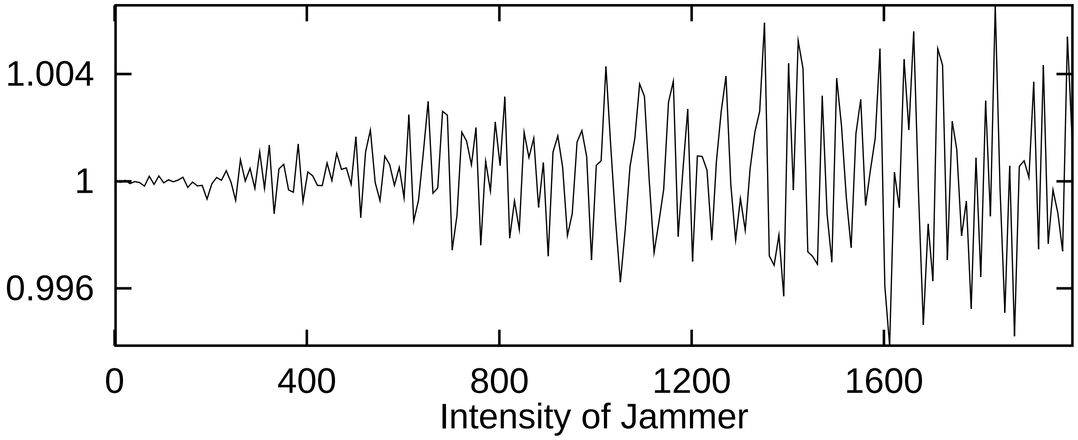

Figure 3. Signal Reconstruction in the Presence of a Near Field Scatterer