Reducing the Mutual Coupling Effect in Adaptive Nulling Using a Re-Defined Mutual Impedance

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***Abstract*—The effect of mutual coupling in an adaptive antenna array for the nulling of interferences is investigated. The concept of mutual impedance is re-defined to take into account of the scattering effect due to the other antenna elements in the array. The re-defined mutual impedances are used to reduce the mutual coupling effect by calculating the open-circuit voltages from the measured voltages on the antenna terminals. Results show that by using the re-defined mutual impedances, substantial improvements in term of the depths and the accuracy of the nulls can be obtained over a previous method.**

***Index Terms*—Adaptive nulling, mutual coupling, mutual impedance, open-circuit voltage.**

I. INTRODUCTION

An important function of an adaptive array is to suppress interferences. This is achieved by steering the nulls of the radiation pattern toward the interferences. As with other functions of an adaptive array, adaptive nulling is significantly affected by the existence of the mutual coupling effect between the antenna elements. The mutual coupling effect will affect both the depths and the accuracy of the positionings of the nulls. Although the effect of mutual coupling on adaptive arrays has been widely aware of among researchers, most of the previous studies focused on other aspects [1]–[4], and few were found on adaptive nulling [5]. In [1], the authors studied the effect of mutual coupling on the signal-to-interference-plus-noise ratio (SINR) on adaptive arrays by deriving the open-circuit voltages from the measured voltages on the antenna terminals. The open-circuit voltage method is practicable and flexible in the sense that it requires the smallest number of assumptions. It is also fast and especially suitable for small to medium-sized adaptive arrays. However, as mentioned in [5], this method suffers from the drawback of not taking into account the scattering effect due to the presence of other antenna elements in the array. In this letter, we propose a method to improve the performance of the open-circuit voltage method. The problem with the open-circuit voltage method comes from the calculation of the mutual impedances used to obtained the open-circuit voltages from the measured voltages. In our method, the concept of mutual impedance is re-defined to taking into account the scattering effect due to the other antenna elements in the array. By using these re-defined mutual impedances, it is found that both the depths and the accuracy of the positionings of the nulls can be improved.

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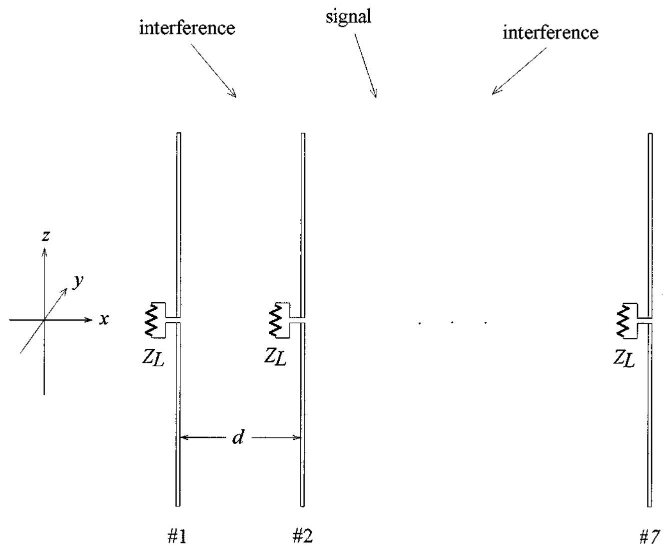

Fig. 1. Linear dipole antenna array for adaptive nulling.

II. CONCEPT OF THE REDEFINED MUTUAL IMPEDANCE

Consider the linear dipole antenna array shown in Fig. 1. It consists of seven thin-wire dipole antennas of equal dimensions with a terminal load impedance Z_L at the centre of each dipole. The length of the dipoles is L and the radius is r with $r \ll \lambda$, where $r \ll \lambda$ is the free-space wavelength. The dipoles are equi-distantly spaced with the distance between adjacent dipoles equal to d. The array is aligned along the x-axis with antenna element #1 placed at the origin. The dipoles are oriented parallel to the z-axis. The signal environment consists of a signal of interest (SOI) and three interferences. We ignore the effect of noise in this study. The complex amplitude and the direction of arrival (DOA) of the SOI are known but those of the interferences are not. The SOI and all the interferences are assumed to be plane waves linearly polarized along the z-axis. The adaptive nulling of the antenna array is shown by the ability to steer three nulls (minima of the radiation pattern) to the interferences while maintaining a maximum of the radiation pattern toward the SOI. If we assumed that the antenna elements are ideal with no mutual couplings between them, then there are many methods available to achieve this aim. However, mutual couplings exist in real cases, and this will greatly reduce the array's ability to null the interferences and in some critical cases lead to a complete failure of the array. In [1], an open-circuit voltage method was proposed to calculate the open-circuit voltages from the measured voltages on the antenna terminal loads Z_L. By using the open-circuit voltages instead of the measured terminal voltages, the mutual couplings can be substantially reduced. This method was later used in several other occasions [2]–[4]. Although this method is practically realizable, it still suffers from the drawback of using the conventional concept of mutual impedance [6], which fails to account for the scattering effect of the other antenna elements in the array. The conventional mutual impedance accounts for the mutual couplings between two isolated antennas only. In view of this defect, we re-define the mutual impedance between two antenna elements by taking into account the scattering effect of all the other antenna elements in the array. This is done by calculating the mutual impedances between the two antenna elements in the same way as for the conventional mutual impedances, but the scattered fields due to the presence of all other antenna elements (open-circuited) in their respective positions are also taken into account in the calculation of the open-circuit voltage for the antenna element whose mutual impedance with the excited antenna element is being calculated. That is, if we calculate the mutual impedance between the mth and the nth antenna elements, we have [6]

$$V_{mn} = -\frac{1}{I_m(0)} \int_0^{\ell_m} E_{zmn}(z) I_m(z) dz \tag{1}$$

where V_{mn} is the open-circuit voltage induced on the terminals of the mth antenna due to an excitation current $I_n(z)$ flowing along the nth antenna, and $E_{zmn}(z)$ is the z component of the electric field induced on the mth antenna due to current $I_n(z)$. $I_m(z)$ is the current distribution on the mth antenna as if it were driven by a voltage at the terminals of the mth antenna. $I_m(0)$ is the value of $I_m(z)$ at the centre point of the mth antenna and ℓ_m is the length of the mth antenna. The difference introduced for the re-defined mutual impedance is that in the calculation of $E_{zmn}(z)$, we force the boundary condition not only on the mth and the nth antenna elements but also on all other antenna elements which are in an open-circuit state. The mutual impedance is then calculated by

$$Z_{mn} = \frac{V_{mn}}{I_n(0)} \tag{2}$$

where $I_n(0)$ is the value of $I_n(z)$ at the centre point of the nth antenna. This re-defined calculation procedure is done also for the calculation of the self-impedances. The result is that even the self-impedances of the antenna elements are slightly different because of the different positions of the elements in the array. By using the re-defined mutual impedances, the open-circuit voltages are calculated in the same way as in [1]. These open-circuit voltages are then fed into the adaptive nulling algorithm which generates the adaptive radiation patterns. Our calculation examples show that a substantial improvement in terms of the depths and the accuracy of nulls to suppress the interferences can be obtained over the open-circuit voltage method using the conventional definition of mutual impedance [1].

III. Numerical Results and Discussions

Improvements obtained by using the re-defined mutual impedances are demonstrated by computer simulations for the dipole array shown in Fig. 1 with $L = 0.5\lambda$, $r = \lambda/200$ and $Z_L = 50\ \Omega$. The moment method [7] is used to compute the re-defined mutual impedances and the measured voltages on the antenna terminals. The nulling adaptive algorithm used is the direct data domain technique [8]. Fig. 2 is the adaptive radiation patterns calculated by using the conventional and the re-defined mutual impedances. The distance between the antenna elements is $d = 0.5\lambda$ and the signal environment is given in Table I. We can see that three nulls are correctly generated at the directions of the interferences by using either the conventional or the re-defined mutual impedances. However, all the nulls are deeper when using the re-defined mutual impedances. The null at $\phi = 30^\circ$ generated by using the re-defined mutual impedances is about 12 dB deeper than that generated using the conventional mutual impedances. Note, also, that there is almost no difference with respect to the maximum generated by using either methods toward the SOI. In Fig. 3, the results are calculated for a more closely spaced array with $d = 0.4\lambda$ and the signal environment is shown in Table II.

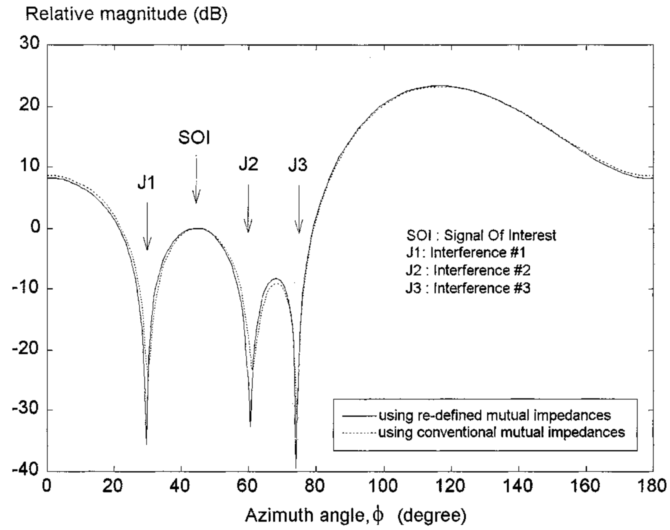

Fig. 2. Adaptive radiation patterns calculated by using the conventional and the re-defined mutual impedances for $L = 0.5\lambda$, $r = \lambda/200$, $Z_L = 50\ \Omega$, and $d = 0.5\lambda$. The signal environment is shown in Table I.

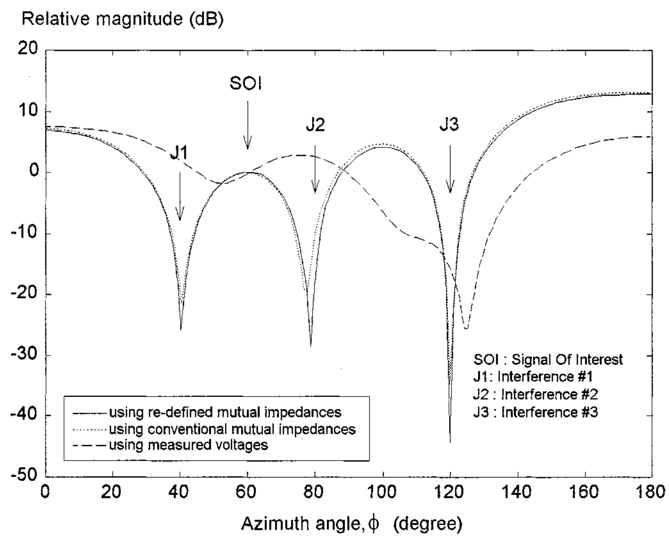

Fig. 3. Adaptive radiation patterns calculated by using the conventional and the re-defined mutual impedances for $L = 0.5\lambda$, $r = \lambda/200$, $Z_L = 50\ \Omega$, and $d = 0.4\lambda$. The signal environment is shown in Table II.

TABLE I
SIGNAL ENVIRONMENT FOR THE RESULTS IN FIG. 2

	Amplitude (V/m)	Azimuth ϕ (degree)	Elevation θ (degree)
Signal of interest	$1.0\hat{z}$	45	90
Interference #1	$1.0\hat{z}$	75	90
Interference #2	$1.5\hat{z}$	60	90
Interference #3	$2.0\hat{z}$	30	90

TABLE II
SIGNAL ENVIRONMENT FOR THE RESULTS IN FIG. 3

	Amplitude (V/m)	Azimuth ϕ (degree)	Elevation θ (degree)
Signal of interest	$1.0\hat{z}$	60	90
Interference #1	$3.0\hat{z}$	40	90
Interference #2	$1.5\hat{z}$	80	90
Interference #3	$5.0\hat{z}$	120	90

The adaptive radiation pattern generated using the measured voltages (with no reduction in the mutual coupling effect) on the antenna terminal loads is also shown. It can be seen that two nulls are correctly generated toward the interferences at $\phi = 40°$ and $\phi = 120°$ by using the conventional or the re-defined mutual impedances but the depths of the nulls are greater by using the re-defined mutual impedances. The null at $\phi = 80°$ generated by using the re-defined mutual impedances is about 9 dB deeper than that generated using the conventional mutual impedances. Moreover, the accuracy of this null is also increased as compared to that generated by using the conventional mutual impedances. On the other hand, we note that by using the measured voltages on the antenna terminals directly, the array fails to generate nulls for the interferences at $\phi = 40°$ and 80° while the null at $\phi = 120°$ is misplaced.

IV. CONCLUSION

In this letter, the concept of mutual impedance is re-defined to take into account of the scattering effect due to the presence of the other antenna elements in an adaptive antenna array. The re-defined mutual impedances are used to obtain the open-circuit voltages from the measured voltages on the antenna terminals. These open-circuit voltages are then used in the adaptive nulling of interferences. Simulation results reveal that by using the re-defined mutual impedances, substantial improvements in term of the depths and the accuracy of the nulls can be obtained.

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