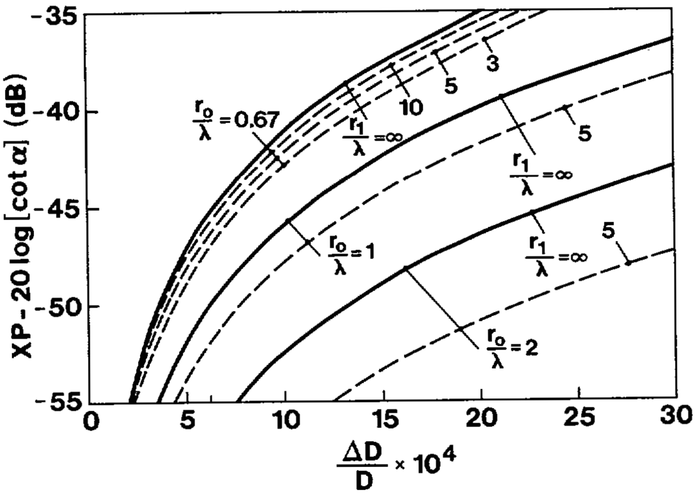

Fig. 2. Calculated normalized cross polarization versus ellipticity of the horn cross section.

tolerances are relaxed with increased operational frequencies, increased flare angle, and increased minimum radius and decreased length of the perturbed cross section.

Acknowledgment

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Signal Bandwidth Consideration of Mutual Coupling Effects on Adaptive Array Performance

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Abstract—**The effect of mutual coupling on the performance of a least mean square (LMS) adaptive array using dipole elements is analyzed in consideration of the signal bandwidth. The purpose here is to illustrate quantitatively the significance of the effect of mutual coupling. The results show that the effect in the broad-band signal cases is much greater than that in the narrow-band cases, particularly when few antenna elements are used.**

The mutual coupling between antenna elements usually contributes a significant effect to the performance of an adaptive array, especially when the interelement spacing is small. Some analyses have been presented on the studies of adaptive array performance with the effect of mutual coupling for least mean square (LMS) and Applebaum algorithms [1], for a power inversion adaptive array [2] and for some others [3], [4]. However, all of them were limited within the consideration of narrow-band signals. In this communication, we discuss the effect of mutual coupling on the performance of an LMS adaptive array [5], where the signals involved are broad band. The output signal-to-interference-plus-noise ratio (SINR) will be used as the parameter to evaluate the performance of the adaptive array.

It is known that wider band signals provide poorer output SINR performance of an adaptive array, because it is difficult for an array to match desired signals or to null interference signals over a wide spectral band [6]. In the presence of the effect of mutual coupling, particularly when few antenna elements are used, we will see that the performance of an array may be greatly affected. In some cases the performance is much improved and in some other cases it becomes much worse.

The frequency range of both desired and interference signals to be considered is from $f_0 - \Delta f/2$ to $+\Delta f/2$, i.e., of the bandwidth Δf with the center frequency f_0. The relative bandwidth is defined as $B = \Delta f/f_0$. Signals with different B of 0, 5, 10, and 20 percent are considered, respectively. Both desired and interference signals are assumed to arrive along the horizontal plane and constitute a Gaussian process with flat, bandlimited power spectral density over the above range. Only the case for which the desired signal arrives from the broadside direction is considered so that the limit in cancelling the interference signals is mainly taken into account. The thermal noise signals, being present at each element, are assumed to be statistically independent between elements, having a flat, bandlimited Gaussian spectral density over the above frequency range.

Dipoles of about half a wavelength are assumed as the antenna elements in the analysis. We take the radius of each dipole to be 0.005 λ_0 ($\lambda_0 = c/f_0$, c is the velocity of light) and the length of it is about 0.4675 λ_0 so that the dipole is resonant with respect to the center frequency f_0. Each dipole is terminated by a resistance which matches the dipole at the center frequency.

The method of moments [7] is used for the analysis of the effect of mutual coupling. The electric field density is used as the parameter of an incoming signal, and the output voltage vector of the antenna elements is calculated using the method of moments for each of the sampled frequencies, equal-spaced selected within the band range considered. The weight vector of the adaptive control loop is determined by the sum of the covariance matrices of the output voltage vector at the sampled frequencies.

We first show the characteristics of the dipole elements used. Fig. 1 shows the output voltage magnitude of each dipole element in an array in the absence of mutual coupling, which is the same for that of a single element. Fig. 2 shows the output voltage magnitudes of both elements in a two-element array ($N = 2$) in the presence of mutual coupling. The coordinate system of the array is shown in Fig. 3. The normalized input electric field strength is $E \cdot \lambda_0 = 20$ dBV for all frequencies. By comparing Figs. 1 and 2, we see that the output voltage magnitude is changed considerably by the mutual coupling,

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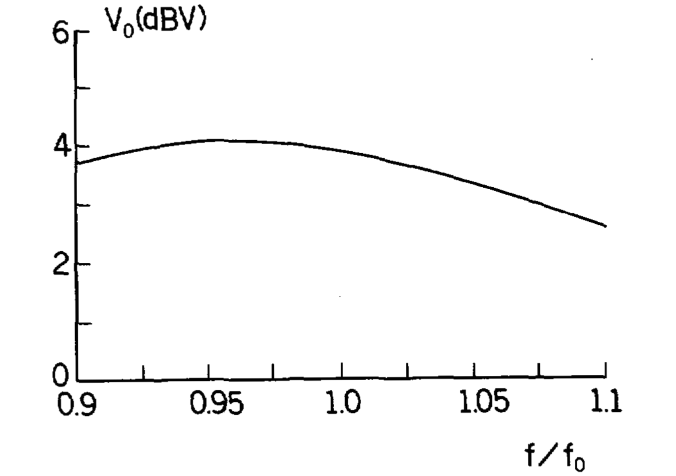

Fig. 1. Characteristics of dipole element in the absence of mutual coupling.

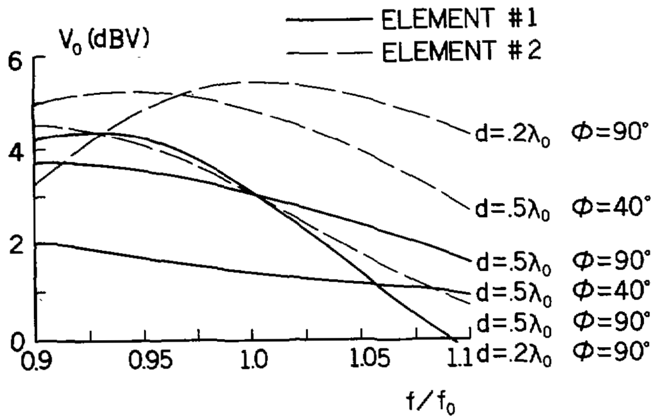

Fig. 2. Characteristics of dipole element in the presence of mutual coupling (N = 2).

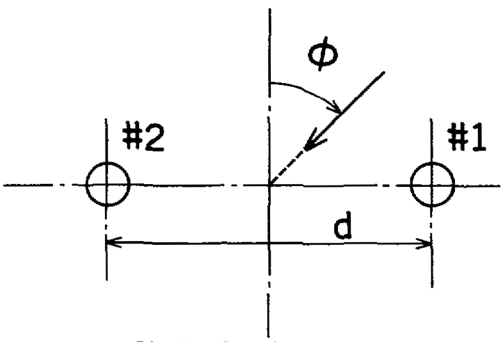

Fig. 3. Coordinate system.

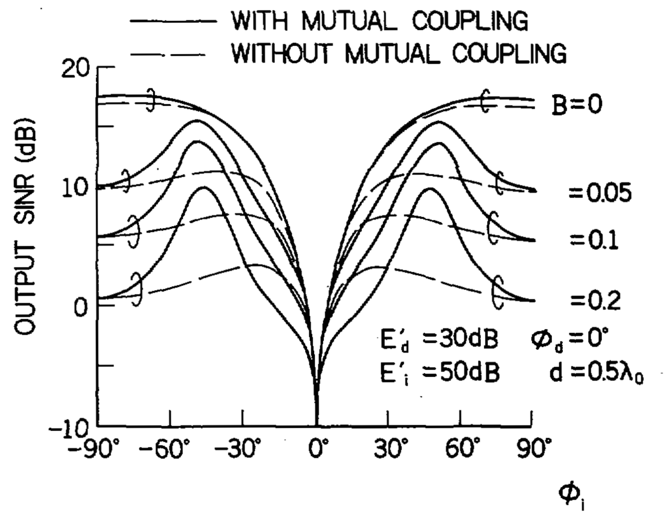

Fig. 4. Output SINR versus signal arrival direction (N = 2).

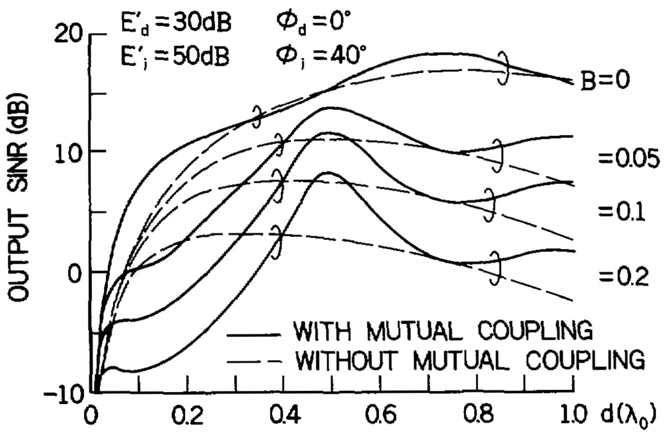

Fig. 5. Output SINR versus interelement spacing (N = 2).

and the effect closely depends upon the interelement spacing and the signal direction-of-arrival.

Figs. 4 and 5 show the steady state output SINR performance of a two-element LMS adaptive array with the variation of the direction-of-arrival of the interference ϕ_i and with the interelement spacing d, respectively, where we mention again that the desired signal is assumed to arrive from the broadside direction ($\phi_d = 0°$). It is assumed that one desired and one interference signal are arriving. Furthermore, in the figures, for the continuous wave (CW) signal ($B = 0$) case, $E' = E \cdot \lambda_0/\sigma$, where E is the incident electric field intensity and σ is the equivalent noise voltage. For a broad-band case, the signals have their respective power spectrum remaining at the same total power as that of the CW one.

Obviously, from Figs. 4 and 5, the effect of mutual coupling on the output SINR tends to become more significant as the signal bandwidth widens. Moreover, the output SINR with the mutual coupling effect is more oscillatory compared with that in the absence of the mutual coupling effect. When the relative bandwidth is about 5 percent or more, the output SINR with the mutual coupling effect changes similarly for different bandwidths and notable peak values appear there.

We can see that all the curves of B = 5, 10, and 20 percent are very similar in their form. A great improvement in the output SINR is seen in Fig. 4 for the signals with each of all the three bandwidths when the interelement spacing is half a wavelength at the center frequency and ϕ_i is about 50°. For B = 20 percent, the improvement is about 8 dB. The reason of the improvement in the output SINR is that the effect of mutual coupling at this condition compensates the propagation phase difference of different frequencies over the concerning range. The relative output voltage of the two elements, including the magnitude ratio and the phase difference, is shown in Fig. 6. We see that the phase difference is smaller in the presence of mutual coupling, in spite of a small difference caused in the magnitude ratio by the mutual coupling.

On the other hand, the performance of output SINR becomes much worse in Fig. 5 for all values of B = 5, 10, and 20 percent and with interelement spacing near 0.2 λ_0, and $\phi_d = 0°$ and $\phi_i = 40°$. Again the answer is clear from the relative output voltage of the elements. It is seen in Fig. 7 that both the magnitude ratio and the phase difference vary very much over the frequency range in this case. The magnitude

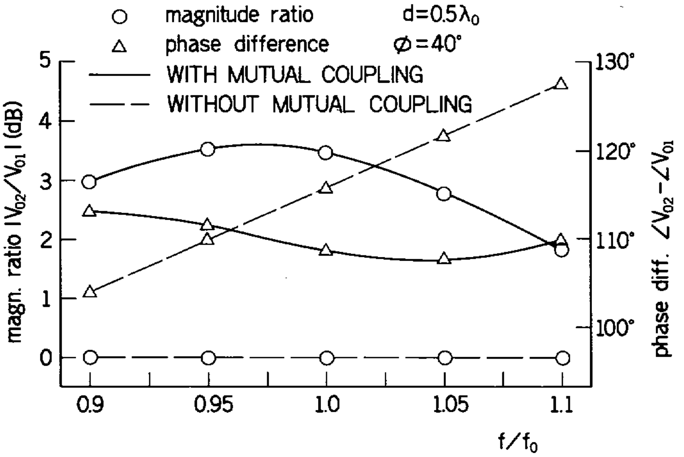

Fig. 6. Relative output voltage ($N = 2$, $d = 0.5\,\lambda_0$, $\phi = 40°$).

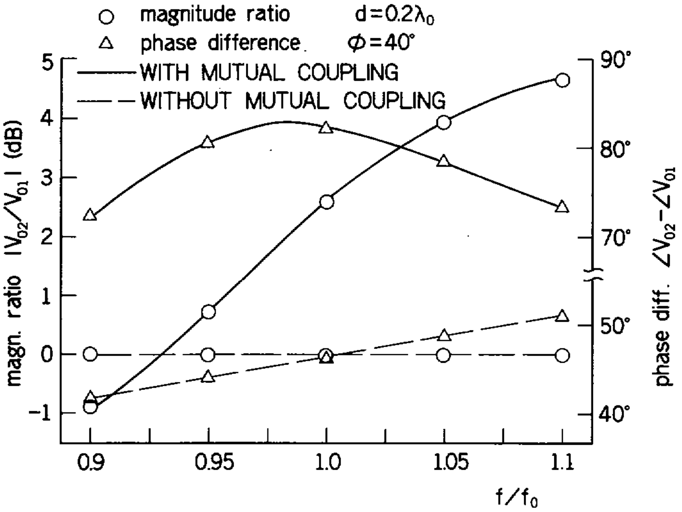

Fig. 7. Relative output voltage ($N = 2$, $d = 0.2\,\lambda_0$, $\phi = 40°$).

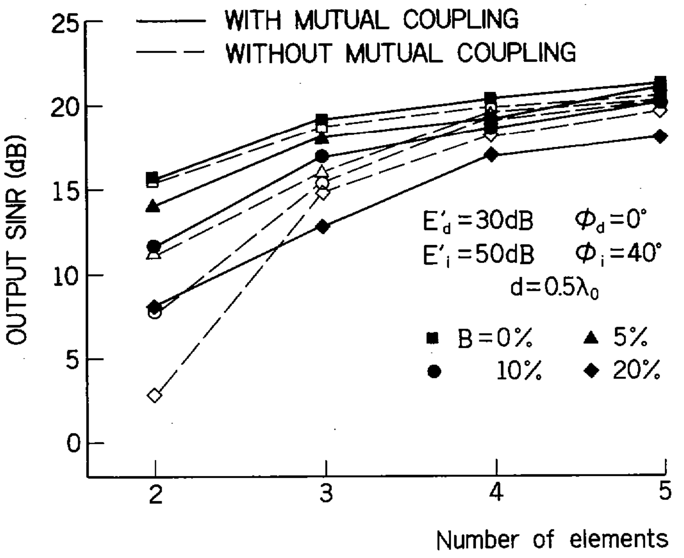

Fig. 8. Output SINR versus the number of antenna elements.

ratio, particularly, is near 20 dB over it. Obviously, only the interference power with a very narrow band is able to be cancelled by a two-element array.

Fig. 8 shows, in both cases with and without the consideration of the mutual coupling effect, the variation of the output SINR for the signals of different bandwidth as the number of antenna elements increases. We see that both the effects of the mutual coupling and the signal bandwidth generally become smaller when more antenna elements are used, provided that the signal bandwidth is not so narrow. This tendency is different with respect to that in the narrow-band signal case.

If we note in Fig. 8 the small difference between the output SINR for different signal bandwidth when a number (4–5) of antenna elements are used, another important fact can be seen, namely that an interference signal with wide bandwidth can be effectively suppressed by applying an adaptive array with a higher number of antenna elements instead of using tapped-delay line processing. The reason is simply that an array of multi-elements can produce nulls at different spatial directions, or equivalently, at different frequencies under the condition discussed namely that there only exists one interference signal of a wide bandwidth.

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Axial Ratio of an Antenna Illuminated by an Imperfectly Circularly Polarized Source

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***Abstract*—A method for determining the axial ratio of an antenna illuminated by an imperfectly circularly polarized source is described. This method requires measurements of the right- and left-handed amplitude components and their relative phases for both the receiving and transmitting (or source) antennas. From these measured data and, of course, the theory of power transfer between the source and receiving**

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