Network Theory Analysis of Coupled Antenna Diversity Performance *

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1 Introduction

In antenna diversity systems, mutual coupling impacts the element terminal impedance and radiation pattern characteristics, leading to altered diversity performance. Most studies of this effect only include the effect of the coupling on the pattern, [1], [2]. In this paper, we present a framework based on network theory that incorporates the impact of antenna termination [3], [4] in assessing the diversity performance of coupled systems.

2 Coupled Antenna Network Representation

We will use the scattering parameter (S-parameter) representation as the analysis framework for mutually-coupled antenna networks. Figure 1(a) illustrates a coupled receiving antenna system in which each element of the coupled array is characterized by a generator whose signal passes through a coupling matrix $\overline{\overline{S}}_c$ consisting of the blocks $\overline{\overline{S}}_{c,ij}$, $i, j \in [1, 2]$, where 1 and 2 refer to input and output ports respectively. The block $\overline{\overline{S}}_{c,22} = \overline{\overline{S}}_S$ represents the coupled S-parameter matrix measured at the antenna element input ports. Rather than trying to characterize the remaining blocks of $\overline{\overline{S}}_c$, we will simply represent the excitation signal at the antenna ports as $\overline{b}_S$ so that $\overline{a}_1 = \overline{\overline{S}}_S\overline{b}_1 + \overline{b}_S$. The N-port antenna in Figure 1(a) is attached to the M-port load network $\overline{\overline{S}}_L$ through a matching network with S-parameter matrix $\overline{\overline{S}}_M$ consisting of blocks $\overline{\overline{S}}_{ij}$, $i, j \in [1, 2]$.

The performance of antenna diversity systems depends upon the signal strength on each antenna branch as well as the signal correlation between branches. We use the covariance matrix for the voltages received on each branch to assess these metrics. For the network in Figure 1(a) with $Z_0 = 1$, the received voltages are given by

$$\overline{v}_L = (\overline{\overline{I}} + \overline{\overline{S}}_L)(\overline{\overline{I}} - \overline{\overline{S}}_{22}\overline{\overline{S}}_L)^{-1}\overline{\overline{S}}_{21}(\overline{\overline{I}} - \overline{\overline{S}}_S\overline{\overline{\Gamma}}_{\text{in}})^{-1}\overline{b}_S = \overline{\overline{Q}}\overline{b}_S \tag{1}$$

leading to the covariance matrix $\overline{\overline{R}}_L = \mathrm{E}\left\{\overline{v}_L\overline{v}_L^H\right\} = \overline{\overline{Q}}\,\overline{\overline{R}}_S\overline{\overline{Q}}^H$, where $\overline{\overline{R}}_S$ is the covariance of $\overline{b}_S$ and $\mathrm{E}\{\cdot\}$ represents an expectation. The quantities $\overline{b}_S$ and $\overline{\overline{R}}_S$ can be obtained from the element radiation patterns using an open-circuit network analysis.

3 Results

We will explore a receive array consisting of two z-oriented half-wave dipoles (0.01λ wire radius) separated by a distance d. The coupling is characterized using the finite-difference time-domain (FDTD) approach. Multipath arrivals are assumed confined to the horizontal plane and, unless otherwise specified, are uniformly distributed within this plane ($0 \le \phi < 2\pi$). Figure 1(b) plots the variation of the signal correlation coefficient magnitude (normalized off-diagonal element of the covariance matrix) as a function of antenna spacing for several different antenna terminations. The *Hermitian* match is an optimal match for power transfer such that $\overline{\overline{S}}_{11} = \overline{\overline{S}}_S^H$. This matching network can be chosen to also diagonalize the covariance matrix. As can be seen, for close spacing the correlation can be improved by proper matching.

Figure 2(a) shows the effective diversity order [3] computed at the 1% level as a function of spacing for the different termination conditions. We again see that for small antenna spacings, improved matching leads to improved diversity performance. This metric also reveals the expected result that although the matching network can diagonalize the covariance matrix, this diagonalization

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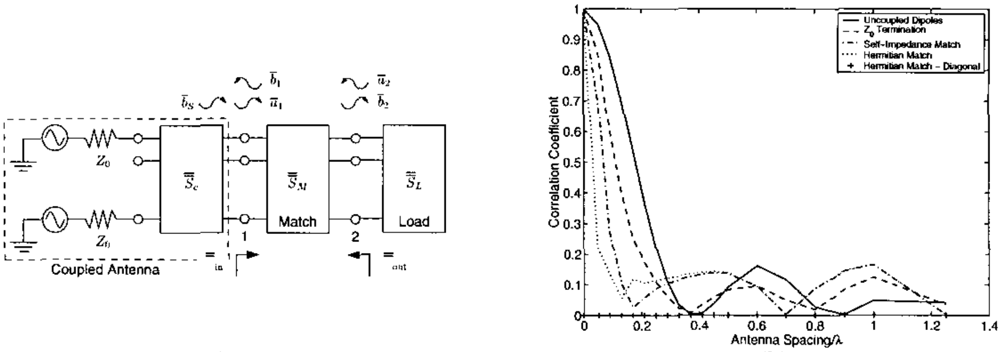
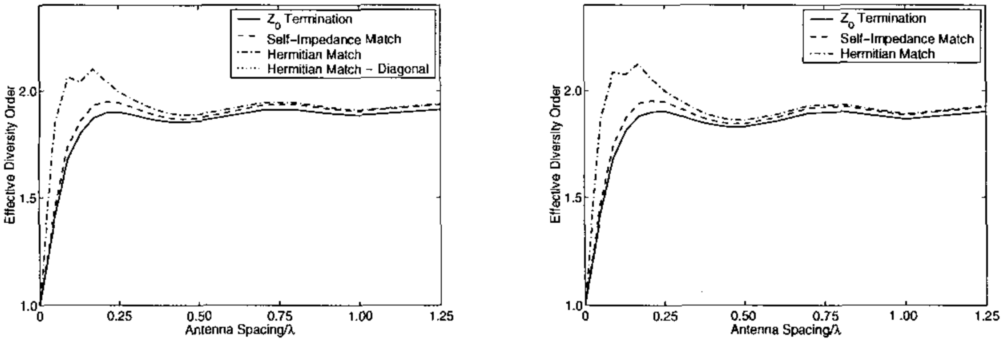
comes at the expense of unequal branch SNR and therefore does not facilitate additional diversity gain. For larger spacings, clearly the match becomes less important, as the curves for the different terminations tend to the same value. Finally, Figure 2(b) shows the diversity order as a function of spacing for when the channel is obtained using 5000 realizations of a statistical path-based channel model [5]. While there certainly are some slight differences between the results in Figures 2(a) and (b), the main conclusions obtained from this more practical example are the same as those drawn from the more simplistic, previous computation.



(a) (b)

Figure 1: (a) System model of a coupled diversity antenna array connected to a multiport matching circuit and individual loads. (b) Plot of branch signal correlation as a function of antenna spacing for two coupled dipole antennas terminated with various loads. The result for independent dipoles is shown for comparison.



(a) (b)

Figure 2: Plot of effective diversity order as a function of antenna spacing for two coupled dipole antennas terminated with various loads for (a) plane waves uniformly distributed in angle in the horizontal plane and (b) channels obtained from a statistical model.

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