Reconfigurable Single-Feed Antennas for Diversity Wireless Communications

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1. Introduction

Antenna arrays are used in wireless communications to combat multipath fading by exploiting the spatial diversity of the multipath channel. Often only two antenna elements are used, since larger arrays require a complex feed structure and possibly more power amplifiers (PAs) and low-noise amplifiers (LNAs). An alternative to a more standard antenna array with one or multiple corporate feeds is a single-feed electronically reconfigurable antenna combined with an oversampling receiver. Such an antenna can exploit the diversity offered by a multipath channel by radiation pattern switching. In this paper, we present a reconfigurable One Port Multiply Excited (OPOMEX) antenna array along with simulations of the resulting diversity gain. We show that this approach offers more than 14dB of diversity gain at a probability of error of 10^{-4}. This improvement is less than that of a standard dipole array of equivalent aperture size, but the OPOMEX antenna contains a single simple feed and would require a single LNA in reception.

A brief description of the reconfigurable OPOMEX antenna is given in the following section. Section 3 discusses the capacitor values chosen and the corresponding Finite Difference Time Domain (FDTD) simulation results for this antenna. The simulated antenna patterns are used in Section 4 to evaluate the probability of error for an oversampling receiver. The paper concludes with a discussion of the tradeoffs involved in using the reconfigurable OPOMEX antenna to exploit spatial diversity in a wireless communication system.

2. One Port Multiply Excited Antenna

A printed 10-element OPOMEX array [1] is chosen as the example for this paper. The idea behind this type of antenna array is the following. The thick and thin strips form a half-wavelength long transmission line. Therefore, the generator voltage appears at all points that are multiples of $\lambda/2$ from the feed point. The thick and thin lines are physically switched every half wavelength to unbalance the guided-mode currents, allowing for radiation. This mode of operation is fundamentally the same as in coaxial collinear (CoCo) antennas [2]. The antenna is shown in Fig.1, with relevant dimensions.

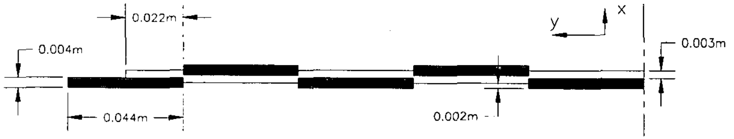

Figure 1: Left half of 10-element planar OPOMEX antenna geometry [1]. Antenna is skew symmetric about the vertical centerline.

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In order to make the OPOMEX antenna reconfigurable, variable capacitors are added in shunt at the "virtual" feed points as shown in Fig. 2. Adding the capacitors affects both the impedance and radiation pattern of the antenna. In our design, we attempt to minimize the change in input impedance and maximize the change in radiation pattern as the capacitance values are varied. The ultimate goal of varying the capacitance at each virtual feed is to generate a linearly independent set of radiation patterns that exploit the spatial diversity of the multipath channel. The capacitors can be implemented with varactor diodes by adding bias lines to the design

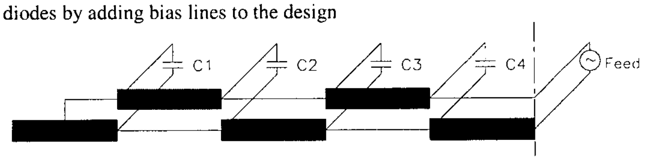

Figure 2: Geometry of the left half of the 10-element reconfigurable OPOMEX antenna. Capacitors are placed at each of the virtual ports and are labeled as C1-C8 (left-to-right).

3. FDTD Simulation Results

The OPOMEX antenna is simulated as printed on a 480mm x 50mm substrate with a thickness of 0.5 mm and a relative permittivity of 2.17. FDTD simulations indicate that this base antenna is near resonant at 2.85 GHz with an input impedance of 476 + j67 Ω. The electric field radiation pattern in the yz-plane is shown in Fig. 3.

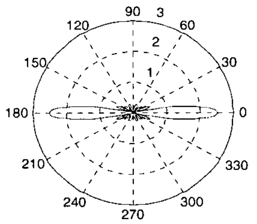

Figure 3: 10-element OPOMEX E_θ normalized radiation pattern in the yz-plane.

FDTD is also used to simulate the capacitively loaded antenna. The operating frequency is chosen again to be 2.85 GHz. The variable capacitors are modeled as lumped capacitors whose values are changed for different simulations. The three sets of capacitor values considered are listed in Table 1 along with the corresponding input impedances. The radiation patterns in the yz-plane for these configurations are shown in Fig. 4. The capacitor configurations are not chosen to optimize the patterns, but rather to maintain the input impedance value

C1	C2	C3	C4	C5	C6	C7	C8	R_{in} [Ω]	X_{in} [Ω]
0.1	0.2	0.1	0.4	0.1	0.3	0.1	0.1	6.8	-62
0.4	0.3	0.2	0.1	0.1	0.2	0.3	0.4	7.3	-70
0.8	0.4	0.2	0.1	0.1	0.2	0.4	0.8	6.5	-65

Table 1: Reconfigurable OPOMEX capacitor configurations and respective input impedances. All capacitor values are in picofarads.

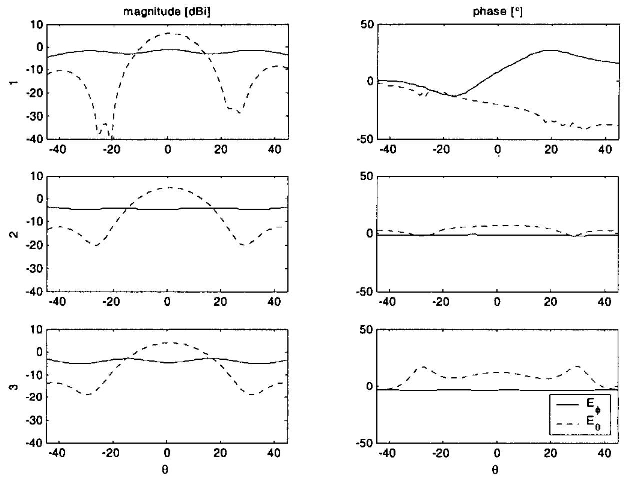

Figure 4: Normalized radiation patterns in the yz-plane of the loaded 10-element OPOMEX antenna for three different capacitive loadings.

4. Communication System Performance

Multiple samples per symbol, or oversampling, is commonly used in digital communication receivers. Analogous to [3], we switch through the reconfigurable OPOMEX radiation patterns at the receiver during a single symbol duration and coherently combine the received signals associated with each pattern to form a symbol estimate. Coherent combining of different patterns gives rise to spatial diversity gains.

In order to simulate a mulitpath channel, we assume Rayleigh fading from thirty independent complex normal gaussian scatterers linearly distributed in the yz-plane spanning an angular interval of 90° centered about the z-axis. Furthermore, we assume the channel coefficient for each pattern is known at the receiver so the optimal maximal ratio combining receiver (MRC) is applicable [4]. The channel coefficient for each pattern is determined by the magnitude and phase of the radiation pattern and the scatter geometry. The probability of error versus signal to noise ratio (SNR) in this case is a known function of the eigenvalues of the channel coefficient correlation matrix [3]. Fig. 5 compares the probability of error for a 10-element OPOMEX antenna using different numbers of receive patterns and that of an array of $\lambda/2$ dipoles with equal aperture and similar levels of diversity.

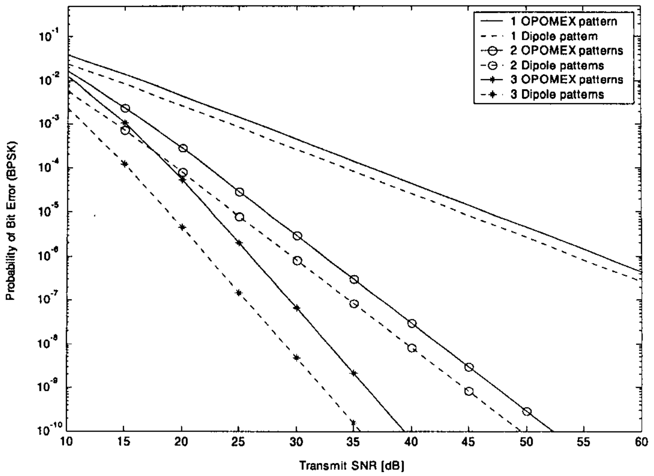

Figure 5: BPSK probability of error versus SNR. Results for the 10-element OPOMEX antenna compared with those calculated assuming a $\lambda/2$ dipole array.

5. Discussion

Fig. 5 clearly demonstrates that the reconfigurable OPOMEX antenna exploits spatial diversity for improved error performance. At a bit error rate of 10^{-4}, the two pattern OPOMEX antenna requires approximately 14dB less transmit power than the single pattern antenna. Although the array of dipoles requires about 4dB less transmit power, the slope of the comparable error curves is the same. This suggests the reconfigurable antenna is exploiting the same level of diversity, but has less net gain than the dipole array. Note that the reciprocity principle indicates the performance is identical if the antennas are used to obtain transmit diversity by transmitting the same symbol on multiple patterns or array elements. In contrast to an antenna array, the electronically reconfigurable OPOMEX antenna can exploit spatial diversity using only a single feed (which is not a lossy dispersive corporate feed) and a single low noise or power amplifier.

References

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