Characterization of Pattern Reconfigurable Antenna Arrays for MIMO Systems

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***Abstract*—In this paper, we focus on the characterization of a pattern reconfigurable antenna design for mobile terminals and application in next generation technologies. We use a simple and efficient approach to measure and analyze the envelope correlation of the antenna diversity system. Specifically, we provide an analysis of the effects of mutual coupling and input match on the diversity performance of the antenna system using its scattering parameters. This evaluation is performed for a two antenna element array with multiple radiation patterns.**

***Index Terms*—Reconfigurable Antennas, Antenna Arrays, and Spatial Correlation**

I. Introduction

Tremendous progress has been made in the research of adaptive antenna systems such as reconfigurable antennas with numerous designs that are reconfigurable in frequency, pattern, polarization, or a combination of these parameters [1]. Pattern reconfigurable antennas are of special interest due to their ability to dynamically change their radiation properties to the wireless channel characteristics. These antennas are able to generate uncorrelated radiation patterns which can produce uncorrelated channel realizations in a multipath rich wireless channel for a given frequency [2]. As a result, "two co-located antennas with different patterns see differently weighted multipath components so that they interfere differently resulting in better reception"; this improves link reliability [3], and channel capacity [4].

However, the potential benefits of these adaptive antennas may not be obtainable due to degraded antenna system performance. The performance of a multi-antenna system in a rich multipath environment is often described by the antenna diversity and spatial correlation. Spatial correlation –a correlation between the signal's spatial direction and the average received signal gain – degrades the performance of multi-antenna systems and limits the number of antennas that can compactly be fit on a device [5]. For this reason, the correlation coefficient, which describes the independence of the incoming signals is a parameter of interest in the development phase of the antenna system. In this work, we study these antenna performance characteristics to understand and evaluate their effects on the pattern diversity of the relevant reconfigurable antenna.

Previous works in [2] and [6] focused on either exploiting pattern diversity or polarization diversity without considering antenna efficiency. The work in [6] proposes an omnidirectional monopole antenna for WiMAX applications while the work in [2] proposes a circular patch antenna. Our work in [7] presents the reference design of the reconfigurable Alford loop antenna architecture and studies the parameters of the antenna array structure in simulation whereas the work in this paper uses a fabricated prototype of the design. The main contribution of this work is the analysis of the effects of mutual coupling and input match on the diversity performance of the Alford loop antenna array using measured scattering parameters. We exploit the effects of antenna geometry and mutual coupling between radiating elements of the array to generate different radiation patterns for pattern diversity.

In Section II, we present the motivation and the antenna design specifications of the reconfigurable antenna, and then, the methodology for evaluating the antenna diversity performance in Section III. In Section IV, we analyze the measurement results; and finally, give a brief conclusion in Section V.

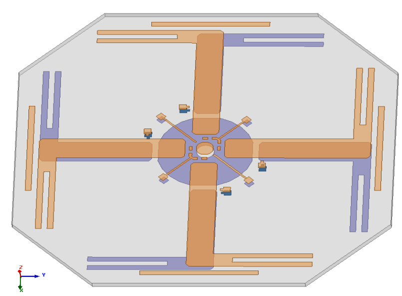

Fig. 1. A Reconfigurable Alford Antenna

II. Reconfigurable Alford Loop Antenna

A. Motivation

The main motivation for the reconfigurable Alford Loop antenna design is antenna efficiency and the need to combine omnidirectional and directional radiation patterns [7]. Inefficiency issues are particularly important in the design of pattern reconfigurable antennas due to its uneven effect on the transmission capability of the antenna in different radiation states. The work in [3] has demonstrated how some of the antenna radiation patterns may have lower radiation efficiency than others at a particular frequency. Reduced radiation efficiency means lower power is radiated the antenna in certain states; this effect increases the pattern spatial correlation which

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conversely, reduces the pattern diversity gain and capacity [8]. The reconfigurable Alford Loop design shown in Fig. 1 attempts to address these radiation efficiency problems. Its design generates the different radiation patterns through the excitation of fixed dipole arms rather than changing lengths of the dipole antennas. This design minimizes the inefficiency caused by resonant frequency offsets resulting from changing electrical lengths/properties of the antenna when it is operating in different states.

B. Antenna Design

The antenna design is first modeled using the electromagnetic software simulator HFSS on an FR-4 dielectric substrate with relative permittivity, ϵ_r, of 4.4. The eight metallic elements (four at the top layer and four at the bottom layer) are connected to the feedline though an array of PIN diodes as switches. Each of these elements can be selectively connected or disconnected to the feed to generate different radiation patterns. When adjacent microstrip elements are excited through connection to a voltage on the feedline, a directional pattern is generated. The energy toward the disabled branches undergoes reflections that focuses the beam in the direction of the excited pair. Similarly, when all the branches are connected to the feedline, an omnidirectional pattern is generated from the uniform current distribution on the antenna surface. Therefore, one element is capable of generating at least eight different antenna patterns.

III. Methodology for Evaluation of Diversity Performance

A. Method

Traditionally, the evaluation of the diversity and antenna pattern correlation performance of an antenna system requires the measurement of the radiation patterns of the system. This can be a cumbersome process regardless of whether it is done numerically or experimentally. However, the work in [9], proposed and evaluated a simple technique to evaluate the correlation of an antenna diversity system. This approach has the advantage showing the explicit influence of mutual coupling and input match without necessitating the measurement of the radiation patterns of the antenna system. In this work, Blanch et al. derived a formulation to compute the correlation based on the Scattering-parameter characterization of the antenna system. This formulation is included in (1) below for reference. Through experimental measurements, their work also demonstrated that this formulation provided a criteria for minimizing the envelop correlation in antenna design. This approach of computing the envelope correlation from the S-parameter description of the antenna system generates the same results as the technique that derives it from radiation pattern measurements of the antenna system as in [10]. The experimental analysis our work therefore employs the methodology in [9] based on (1) due to its simplicity and efficiency.

$$\rho_e = \frac{|S_{11} * S_{12} + S_{21} * S_{22}|^2}{(1 - (|S_{11}|^2 + |S_{21}|^2))(1 - (|S_{22}|^2 + |S_{12}|^2))} \quad (1)$$

where ρ_e is the correlation coefficient, S_{11} and S_{22} are the input and output port reflection coefficients, respectively, and S_{12} and S_{21} are the reverse and forward voltage gains, respectively.

B. Antenna Characterization Setup

For this work, the reconfigurable Alford antenna design was first fine tuned to resonate at the WiMAX frequency band 2.5 –3 GHz. The scattering parameters of the prototypes and the effects of mutual coupling between the elements of an antenna array of two reconfigurable Alford elements are analyzed. This characterization enabled us to derive a relationship with the pattern correlation between the Alford array elements as discussed in the prior section. This analysis helps us to draw inferences on how the antenna array characteristics affect the performance of a MIMO system that employs this array.

Fig. 2 shows the setup of the antenna array of two elements. The close proximity ($\lambda/4$) of the two elements have deliberately been selected so that there is strong mutual coupling between them. This coupling is effectively leveraged to generate different radiation patterns for each array's geometry. The antenna branches 1 and 2 of antenna element one and branches 2 and 3 of antenna element two are enabled or connected to the feedline –element one is in mode 1 and element 2 is in mode 2. The second configuration is obtained when branches 1 and 4 of antenna element one and 3 and 4 of antenna element two are enabled to generate the directional pattern. In this configuration, antenna element one is in mode 4 and element two is in mode 3, respectively. Note, the element is in mode 5 when branches 1 and 3 are activated, and in mode 6 when branches 2 and 4 are enabled. When all of the branches of the element are active, the antenna element is said to be in mode 7.

IV. Performance Results

Figs. 3(a) and 3(b) plot the pattern correlation between the antenna array patterns for different array configurations at different frequencies. They illustrate the performance in both linear and non-linear scales.

The trends of the correlation curves for the states of the reconfigurable Alford (configurations 1 –8) indicate that on the correlation of the array patterns is $<$0.006 or -22 dB. This is very low compared to the correlation values of the conventional antenna array that uses omnidirectional antennas. In the latter case, the maximum value is as high as 0.5 or -3 dB which indicates that the patterns generated by this antenna array is highly correlated. This high pattern correlation is directly related to the spatial MIMO spatial channel correlation and is known to reduce channel capacity [4] and [8]. In contrast, the consistently lower spatial correlation of the pattern configurations of the reconfigurable Alford array can be used to maximize channel capacity through adaptation. The proper choice of the transceiver array configuration for a particular multipath environment can be made based on the available channel information.

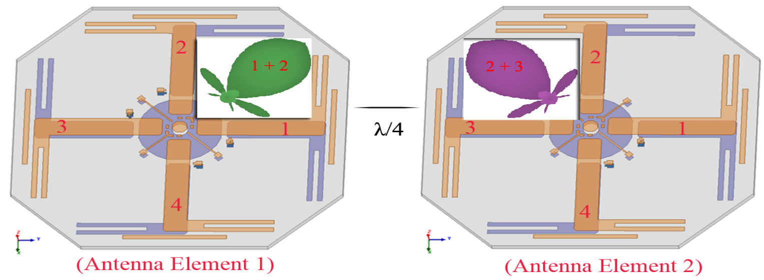
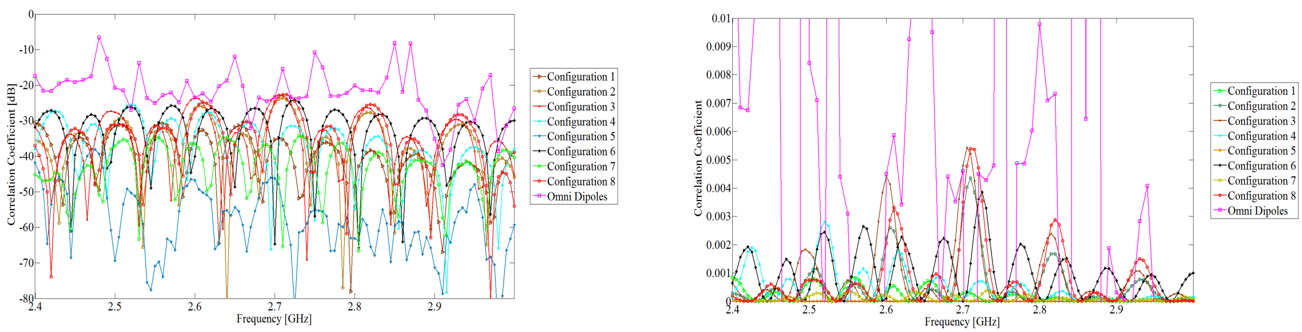


Fig. 2. Measurement Setup for the S-parameters (a) Configuration 1 (b) Configuration 2



(a)

(b)

Fig. 3. Envelope Correlation for two Collinear Quarter-wave Alfords at different Frequencies for different Configurations (a) decibel (dB) scale (b) Linear scale

V. Conclusion

In this work, we evaluated the antenna diversity performance of an antenna array with multiple radiation patterns. We used a simple but efficient methodology to demonstrate that improved diversity performance of the antenna system can be realized when the pattern correlation is minimized. Through field experimental measurements, we illustrated that the pattern correlation of the presented antenna design is consistently low for all the different modes of operation. This makes it a great candidate for use in portable mobile terminals to improve system capacity. The main contribution of our work is the analysis of the effects of mutual coupling and input match on the diversity performance of the Alford loop antenna array using measured scattering parameters.

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