PATTERN RECONFIGURABLE CIRCULAR PATCH ANTENNA FOR MIMO COMMUNICATIONS

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Abstract

This paper presents a reconfigurable two-port circular patch antenna that improves the performance of a MIMO wireless communications system through pattern diversity. Different modes of the circular patch antenna can be excited by varying its radius with PIN diode switches. Based on this antenna architecture a practical algorithm that exploits the wireless channel spatial selectivity to select the antenna radiation pattern is proposed by means of an electromagnetic clustered channel model. Results show an improvement in throughput while reducing the physical size of the antenna array on the communication device.

INTRODUCTION

Recent advances in Multiple Input Multiple Output (MIMO) systems have shown that multi element reconfigurable antennas can improve the throughput and the robustness of the wireless communication link [1-3].

In this paper we present a two port pattern reconfigurable circular patch antenna (RCPA) that can be varied in radius through PIN diode switches. The antenna exploits the principle of pattern diversity in order to provide: (i) increased data rate compared to common non reconfigurable antennas, (ii) reduced space occupation by the antenna on the communication device and (iii) a reduced number of radio-frequency chains needed at the receiver/transmitter.

In order to exploit the gain offered by such antenna, we propose a practical antenna configuration algorithm that uses spatial correlation information from a single antenna configuration to select the antenna radiation pattern to be used at the receiver. Unlike previous work [2], the proposed algorithm, can exploit the gain offered by a reconfigurable MIMO system without any extra power consumption with respect to a MIMO system equipped with conventional antennas. We present this configuration selection approach studying the performance of the RCPA in a 2 × 2 MIMO system by means of a realistic electromagnetic clustered channel model.

RECONFIGURABLE CIRCULAR PATCH ANTENNA

The RCPA, first introduced by the authors in [3], consists of PIN diodes, located radially on the antenna structure, that can be turned on and off to achieve a circular patch with two different radii. A detailed schematic of the RCPA is shown in Figure 1. The antenna is built on a FR4 substrate of dielectric constant equal to 4.4 and each antenna acts as a two element array. There are two ports on the antenna structure,

separated by 25º, such that they are well isolated and the radiation patterns excited simultaneously at the two ports are spatially orthogonal to each other. The distance of the two ports from the center of the patch is strategically selected in order to have both ports matched at a frequency of 2.484 GHz for both antenna configurations. Four pads symmetrically located around the circular patch, are used to provide a ground for the biasing current of the PIN diodes. Toggling the switches located radially on the antenna it is possible to vary the current distribution on the patch and excite different TM electromagnetic modes, each corresponding to a particular shape of radiation pattern. The antenna design depicted in Figure 1 allows selecting among two different configurations: TM_{13} and TM_{14}. When all the switches are off, mode TM_{13} is excited at both ports of the antenna, while when all the switches are on, mode TM_{14} is excited.

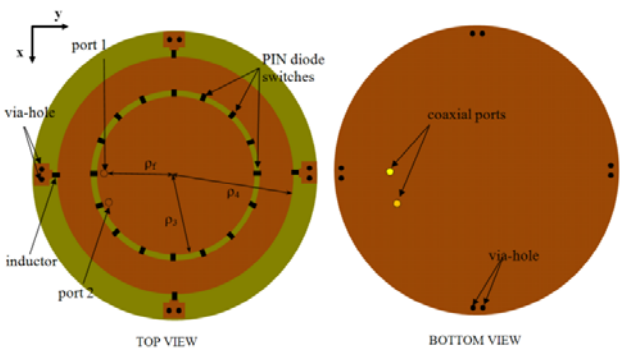

Figure 1: RCPA antenna design (top and bottom view).

Figure 2 show the scattering parameters measured at the two input ports of the RCPA. We note that the return loss is below -10 dB and that the isolation between the two ports is less than -20 dB for both configurations in the band of interest. The large isolation between the two ports allows for the generation of orthogonal radiation patterns, using a single antenna structure as a two element array. Figure 3 reports the measured radiation patterns in the azimuth plane for the two antenna configurations. We observe that the radiation patterns excited at the two ports of the antenna are orthogonal to one another: where there is a maximum in radiation at port 1, there is a null in radiation at port 2. The maximum directivity is 7 dB for configuration TM_{13} and 9 dB for configuration TM_{14}.

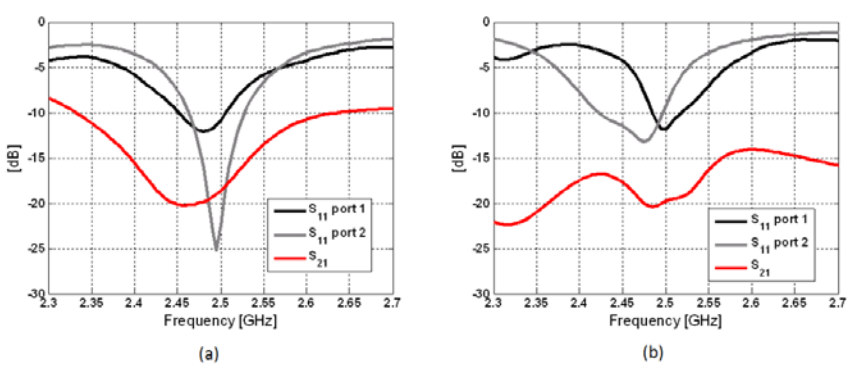

Figure 2: Measured scattering parameters of the RCPA in configuration (a) TM_{13} and (b) TM_{14}.

In Figure 4, we show the cumulative distribution functions of the ergodic channel capacity obtained from channel measurements for the RCPA and for non reconfigurable circular patch operating in configuration TM_{13} and TM_{14} for a system signal to noise ratio (SNR) of 10 dB. The ergodic channel capacity CDF is obtained from a measurement campaign conducted with the RCPA mounted on two channel sounders that implement the 802.11n communication standard. The results show an achievable

capacity improvement, with 50% probability, of 15% and 52% with respect to a system employing circular patch antennas in configuration TM_{13} and TM_{14} respectively.

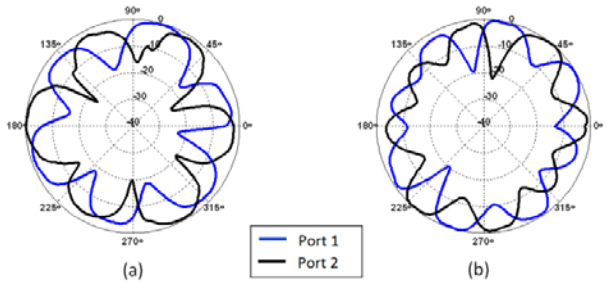

Figure 3: Measured radiation patterns (in dB) of the RCPA in the azimuth plane, at a frequency of 2.484 GHz, for configuration (a) TM_{13} and (b) TM_{14}.

RCPA CONFIGURATION SELECTION

In this section we present a selection algorithm to be used for selecting the RCPA configuration at the receiver without the need for estimating the wireless channel for each configuration of the reconfigurable multi element antenna. We describe the wireless channel according to the electromagnetic cluster channel model presented in [4]. According to this model, we can define the spatial correlation between the *k*-th and *m*-th pattern configuration excited at the *j*-th and *l*-th ports of multi element antennas as [1]:

$$r_{j,k,l,m} = \sqrt{\left(1-\left|S_{11_j}\right|^2\right)\eta_{j,k}\left(1-\left|S_{11_l}\right|^2\right)\eta_{l,m}} \times \frac{\int_{4\pi} P(\Omega)\boldsymbol{E}_{j,k}(\Omega)\boldsymbol{E}^*_{j,k}(\Omega)d\Omega}{\int_{4\pi} P(\Omega)|\boldsymbol{E}_{ref}(\Omega)|^2 d\Omega} \qquad (1)$$

where S_{11} is the voltage reflection coefficient at the antenna input ports, η is the antenna radiation efficiency, $P(\Omega)$ is the power angular spectrum (PAS) of the scattered electric field over the solid angle $\Omega = (\varphi, \theta)$, $\boldsymbol{E}(\Omega)$ is the electric field of each array element and $\boldsymbol{E}_{ref}(\Omega)$ is the electric field of a reference antenna configuration that is used as normalization factor for the spatial correlation coefficient. As in [4] we assume a power angular spectrum that is Laplacian distributed. In Figure 5(a) the averaged channel capacity achievable for all the configurations of the RCPA, used at the only receiver, is reported as a function of the angle spread (AS) of the PAS, for a SNR = 10 dB. The ergodic channel capacity values are averaged over all azimuthal angles of the incoming PAS. We observe that the achievable averaged channel capacity varies as a function of the PAS angle spread. In particular each antenna configuration outperforms the others for a certain range of angle spread. It is therefore possible to select the RCPA configuration at the receiver based on PAS angle spread knowledge. In order to discriminate between different channel scenarios, characterized by different AS, we can use, as reported in [5], the reciprocal

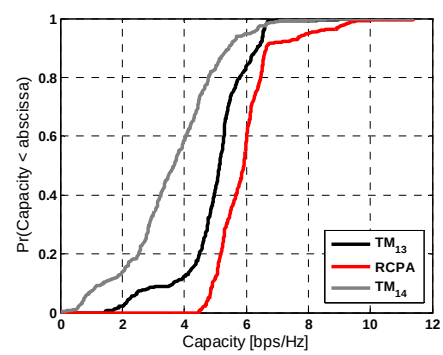

Figure 2: CDF of the measured channel capacity for the RCPA and for circular patch antennas operating in mode TM_{13} and TM_{14}. SNR=10 dB.

condition number of the transmit/receive correlation matrices, D_λ, defined as the ratio between the maximum and the minimum eigenvalues of the transmit/receive correlation matrices. In Figure 5(b) the values of D_λ are reported as a function of AS for configuration TM_{13} of the RCPA. For each value of AS, there is a corresponding value of D_λ. We can therefore map the values of AS that define a switching point between two configurations with those of the reciprocal condition number. According to this channel parameterization, the wireless channel scenario can be identified determining the spatial correlation matrix at the receiver for a single reference antenna configuration of the RCPA (e.g. TM_{13}). Knowing the channel characteristics it is then possible to select the antenna configuration that achieves on average the highest capacity, using the pre-computed results presented in Figure 5(a).

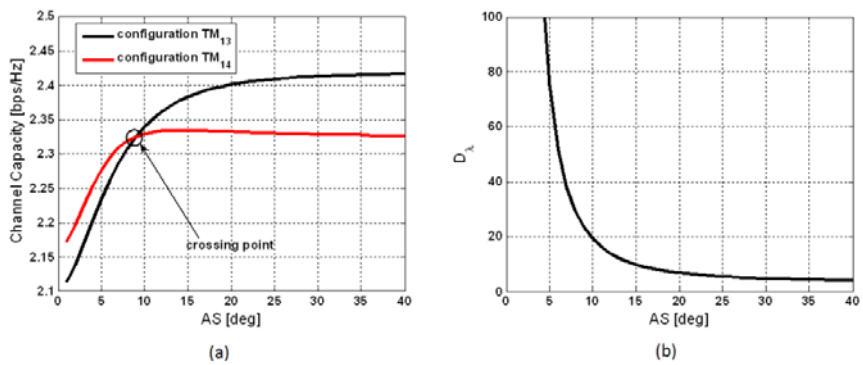

Figure 3: (a) Channel capacity curves for the RCPA configurations in function of the angle spread (AS) for a 2×2 MIMO system employing the RCPA at the receiver, SNR = 10 dB; (b) reciprocal condition number, D_λ, in function of the angle spread for the antenna configuration TM_{13} at the receiver.

CONCLUSIONS

A two port reconfigurable circular patch antenna that can be used as a building block of MIMO transceivers has been proposed. This antenna can be reconfigured in pattern for improving the throughput of the link while decreasing the antenna space occupation on the communication device. A selection algorithm to be used for selecting the RCPA configuration at the receiver without the need for estimating the wireless channel for each configuration of the reconfigurable multi element antenna has also been presented. Simulated results showed that this antenna selection approach is an effective technique suitable for efficiently using pattern reconfigurable antennas in MIMO systems.

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