Capacity Reconfigurable Origami Enabled MIMO Antenna

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***Abstract*—In this work, a capacity reconfigurable Multiple-Input-Multiple-Output (MIMO) antenna is proposed. The goal is to allow the capacity of a MIMO communication channel to be adjusted in real time to varying data rate, gain, and space requirements. As a proof-of-concept, an eight element MIMO antenna is created using microstrip dipoles operating at 2.4 GHz. To reduce mutual coupling, the elements have their centers co-aligned and are orthogonally oriented with respect to one another. The antenna is implemented on a 3D printed modified scissor lift mechanism. This robust mechanism allows the channel capacity to be varied as a function of inter-element spacing. Based on the preliminary results using the proposed origami topology, the capacity can vary up to 50% while the gain can vary up to 10% by changing the inter-element spacing.**

I. Introduction

As the Internet of Things (IoT) continues to expand, with an expected 30 billion connected devices by 2020 [1], the next generation communication system (5G) requires higher bandwidth and spectral efficiency with reduced latency. These requirements are partially met by taking full advantage of MIMO systems. A MIMO system consists of N transmit and M receive antennas. In [2] it was demonstrated that channel capacity is a function of $min(N, M)$ assuming that the array elements have been sufficiently isolated (mutual coupling $\leq$ -10 dB) and signal propagation is occurring in a rich scattering environment.

To ensure sufficient element isolation, various diversity techniques have been developed. Among these techniques are spatial, polarization, pattern, and multimode diversity. In this work, both spatial and polarization diversity techniques are employed to achieve low mutual coupling.

It has been shown that inter-element spacing [3], element orientations [4], and topologies [5] impact channel capacity. Therefore, the ability to adapt in real time to channel conditions is necessary for maximizing channel capacity. Currently, there are four categories of reconfigurable antennas: frequency, radiation pattern, polarization, and any combination of the previous three categories. This work presents a proof-of-concept design of a capacity reconfigurable antenna, where the capacity is varied as a function of inter-element spacing.

To this end, an eight element MIMO array using microstrip fed dipoles is fabricated using an accordion origami structure as shown in Fig. 1. The accordion structure is selected because it allows for the inter-element spacing to be varied with minimal mutual coupling. Furthermore, the accordion structure allows itself to be implemented on a robust, modified scissor lift mechanism which was 3D printed and tested. This actuator allows all the elements to be identically and simultaneously folded using a single motor.

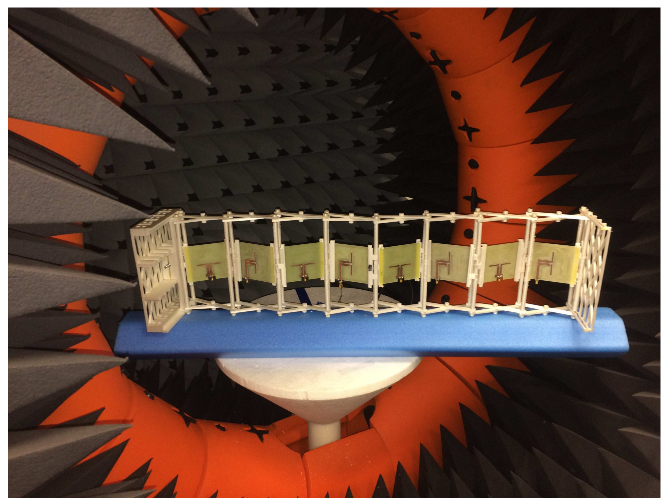

Fig. 1. Accordion struture implemented on modified 3D printed scissor lift

II. Antenna Design

A microstrip dipole array of eight elements, operating in the first mode, is selected for the proposed design. The centers of the elements are co-aligned and uniformly spaced by distance d. An accordion origami structure is used as a support for the elements allowing the distance d to be uniformly varied.

Maintaining high isolation between elements is critical for the success of a MIMO system. Mutual coupling of adjacent elements operating in the same mode and bandwidth can be reduced by orthogonally positioning the elements with respect to each other. To appropriately feed the orthogonal elements, a bent fed version of the dipole was designed as shown in Fig. 2 alongside its straight fed counterpart.

III. Capacity Calculation

To compute the channel capacity, (1) is used as provided by Janaswamy in [6].

$$C = \log_2 \left(det \left[I_M + \frac{\rho}{N} \times \frac{\boldsymbol{Z}_R \boldsymbol{\Psi}^R \boldsymbol{Z}_R^\dagger \boldsymbol{H}^u \boldsymbol{Z}_T^\dagger \boldsymbol{\Psi}^T \boldsymbol{Z}_T \boldsymbol{H}^{u\dagger}}{|C_T C_R|^2} \right] \right) \quad (1)$$

C represents the mean channel capacity in bits/s/Hz over 300 channel realizations, $\rho = P_o/(L_0 P_n)$ where P_o is the average input power to the transmit array, L_0 is the mean path loss, and P_n is the mean noise power per element. In this paper, is assumed that ρ is 10 dB without loss of generality. $\boldsymbol{H}_{ij}^u$ is an uncorrelated complex Gaussian process with zero mean and unit variance and † represents Hermitian conjugate. $\boldsymbol{Z}_T = \boldsymbol{Z}^T(\boldsymbol{Z^T} + \boldsymbol{Z_S})^{-1}$ and $\boldsymbol{Z}_R = \boldsymbol{Z}_L(\boldsymbol{Z^R} + \boldsymbol{Z_L})^{-1}$ where $\boldsymbol{Z}^T$ and $\boldsymbol{Z}^R$ represent the antenna impedance matrices at the transmitter and receiver sides, respectively. $\boldsymbol{Z}_S$ is a diagonal matrix composed of the N source impedances and $\boldsymbol{Z}_L$ is a matrix composed of the M receiver impedances. Note that it is assumed that $Z_{sn} = Z_{nn}^{T*}$ and $Z_{lm} = Z_{mm}^{R*}$ where the superscript $*$ represents complex conjugation. C_T and C_R are also functions of the impedance matrices as $C_T = Z_{11}^T/(Z_{11}^T + Z_{11}^{T*})$ and $C_R = Z_{11}^{R*}/(Z_{11}^R + Z_{11}^{R*})$.

In this paper, it is assumed that the same array is used as both a transmitter and a receiver, therefore $\boldsymbol{Z}^T = \boldsymbol{Z}^R$. Furthermore, $\boldsymbol{\Psi}^T$ and $\boldsymbol{\Psi}^R$ represent the spatial correlation matrices at the transmitting and receiving sides. $\Psi_{\rm ij} = J_0(k_0 d_{ij})$ (see [7]) where $d_{ij} = |i - j|d$ and d is defined as the inter-element spacing.

IV. Results

The eight dipole element array is fabricated on FR4 with relative electric permittivity of 4.4 and thickness 1.5 mm. All the elements are designed to resonate at 2.4 GHz following the design philosophy of [8]. The element's resonant frequency and bandwidth are functions of ψ.

As the antenna moves to a collapsed state (increasing ψ), the inter-element spacing is decreased and the mutual coupling is affected. All the elements have mutual coupling below -10 dB for all the ψ angles. The corresponding results are omitted here due to the space limitation and they will be presented in the conference.

The mean capacity and gain reconfigurability of this antenna are shown in Fig. 3. As the antenna is collapsed, the mean capacity and gain increase until $\psi = 50^0$, after which they begin to fall. This indicates that $\psi = 50^o$ is an optimal point for the assumed channel realization. More results will be presented in the conference.

V. Conclusion

This work has demonstrated how a capacity reconfigurable MIMO antenna is capable of optimizing its gain and capacity to a given channel realization. Furthermore, it has shown that such an antenna is realistically implementable. Exploitation of this reconfigurability allows the communication system to sustain high data rates more reliably by maximizing channel capacity given real time data rate, gain, and space requirements.

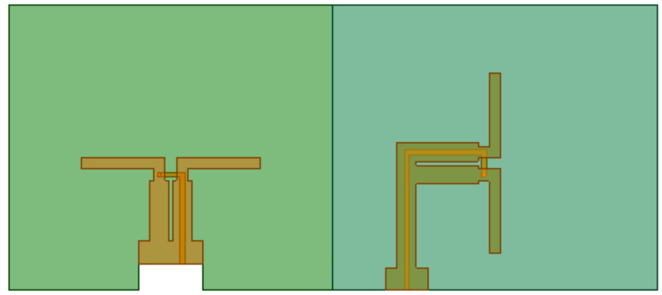

Fig. 2. Straight and bent fed elements

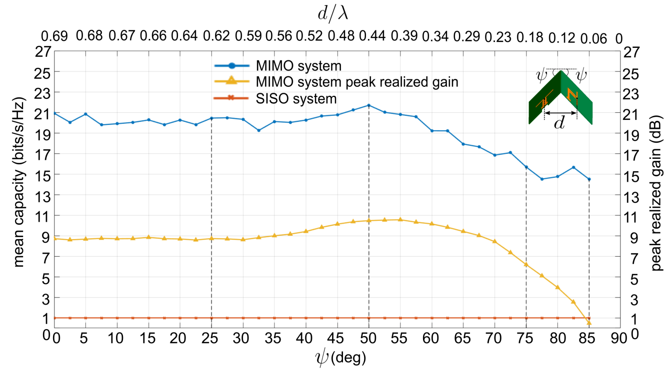

Fig. 3. Capacity as a function of fold angle and inter-element spacing

Acknowledgement

This work is supported by the Air Force Office of Scientific Research (AFOSR).

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