A Novel MIMO Antenna Design Using Characteristic Modes

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Abstract — A novel design of Multi-Input Multi-Output (MIMO) antenna is presented. Pattern and polarization diversity is created using Characteristic Modes (CM) theorem and reduces the envelope correlation and isolation between the ports. So a printed structure consists of two circular patches is proposed for MIMO application. This structure is fed by two slotted coupled feeds configuration. The proposed antenna has been simulated in Ansoft HFSS software and simulation results are presented.

Keywords-component: Multiple Input Multiple Output (MIMO) Antenna, Pattern Diversity, Polarization Diversity, Characteristic Modes.

I. INTRODUCTION

Recently, there is a great interest in using multiple-input multiple-output (MIMO) systems in the wireless communication, because of their ability to increase the channel’s capacity and reduction of multipath fading. There is extensive literature on MIMO antennas such as planar inverted F antennas (PIFA) [1] and a tri-band printed monopole antenna for WLAN and WiMAX MIMO Systems [2].

However, among the literatures which present MIMO antennas, there is not sufficient attention to physical insight of design procedure. Recently, Theory of Characteristic Modes [3] has received considerable attention due to its ability to provide physical insight from radiating behavior of the antenna [4].

In this paper a novel approach to design MIMO antenna using physical insight of characteristic modes theorem is presented. The proposed antenna provides a high isolated ports and low envelope correlation due to producing pattern and polarization diversity. The full wave package Ansoft HFSS is used to simulate the proposed antenna.

II. CHARACTERISTIC MODES THEOREM

By the method explained in [3] and [5] Characteristic Modes or Characteristic Currents can be obtained by the eigenfunctions of the following particular eigenvalue matrix equation:

\[
[X]J_n = \lambda_n[R]J_n
\]

where \(\lambda_n\) is eigenvalues, \(J_n\) is \(n^{th}\) eigenvector or Characteristic Current, and \([X]\) and \([R]\) are the real and imaginary parts of the Generalized Impedance Matrix \([Z]\), which is produced in traditional Method of Moment (MoM) analysis of a structure [6]. In fact Eq. (1) is derived from a particular weighted eigenvalue operator equation. A complete description of the mathematical operations has been presented in [3] and [5].

One of the most important things which should be taken into consideration in Eq. (1) is how eigenvalues \(\lambda_n\) respond to alteration in frequency. \(\lambda_n\)’s variation range is from \(-\infty\) to \(+\infty\), and \(\lambda_n\)’s of smallest magnitude are more important from radiation and scattering problems point of view. Equation (20) of [3] shows that the modes with positive \(\lambda\), predominantly store magnetic energy, whereas those with negative \(\lambda\), mainly store electric energy. The mode having \(\lambda = 0\) is called the resonant mode. At a specific frequency the eigenvalue of a particular mode becomes zero and the mode resonate.

Another representation of \(\lambda_n\) is \(\alpha_n\) which is called Characteristic Angle [7] and is easier to deal with. The formulation is as follows:

\[
\alpha_n = \frac{180^\circ}{\tan^{-1}(\lambda_n)}
\]

Obviously, here, a mode is at resonance when Characteristic Angle \(\alpha_n\) is 180°. Furthermore, due to [8] angles ranging from 135° to 225° represent the mode bandwidth.

We realized in our studies that to study the modal behavior of a conducting body, the first seven modes would
suffice, since modes of higher order experience low amplitude and intense oscillation.

III. ANTENNA DESIGN

First, the characteristic modes of a circular patch have been studied using a suitable MoM code. Fig. 1 shows characteristic angles of the 7 first modes. It is seen that characteristic angles of two modes J1 and J2 are same at every frequency and at 2.8 GHz are about 180 degree. So, these two modes radiate in 2.8 GHz efficiently.

Because of the orthogonal property of CM’s far field patterns [3], by exciting the modes J1 and J2 pattern diversity is obtained.

On the other hand as seen in Fig. 2 the normalized current distribution for the modes J1 and J2 are orthogonal to each other. So, these two modes can provide polarization diversity.

Therefore, due to created pattern and polarization diversity, by exciting the modes J1 and J2 a MIMO structure with low mutual coupling and envelope correlation is obtained.

For exciting the modes J1 and J2, two circular patches with two slotted coupled feeds configuration are used. Fig. 3 shows the proposed configuration. As it seen, a square ring shape slot is created in ground plane under each of the patches and coupled the current from the feed lines on the bottom of substrate to the patches. In this way the current distribution due to port1 and port2 is similar to characteristic currents of the modes J1 and J2 respectively. So, these two modes are radiated by exciting the ports.

Two layer substrate of Rogers RT/duroid 5880 with permittivity of 2.2 are used and each substrate thickness is $h = 1.6$ mm. The dimensions of this antenna are as follows: $a = 30$, $L_s = 40$, $w_s = 3.105$, $L_f = 65$ and $w_f = 4.95$ mm.

IV. RESULTS

The proposed structure has been simulated in Ansoft HFSS software. Fig. 4 shows the reflection coefficient and isolation of the designed antenna. It can be seen the proposed MIMO antenna operates at 2.87GHz and the isolation between the ports is less than -23 dB.

The envelope correlation can be computed from s-parameters using the following formula [9]:

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

(3)

![Figure 1. Characteristic angle variation with frequency for the 7 first characteristic modes.](image)

![Figure 2. The normalized current distribution for 7 first characteristic modes of the circular patch.](image)
Figure 3. Dimensions of the proposed structure. (Space of two circular patches is about $\lambda_g/5$).

Figure 4. Reflection coefficient and isolation of the designed antenna.

Fig. 5 shows envelope correlation of the proposed MIMO antenna. As can be seen, the envelope correlation of this structure is less than 0.004.

The radiation efficiency of the antenna in the resonance frequency is higher than 96% and the peak gain is about 2.27dB.

V. CONCLUSION

A novel design of MIMO antenna using Characteristic Modes Theorem was presented. The envelope correlation and isolation between the ports have been reduced using pattern and polarization diversity. The proposed MIMO antenna operates at 2.87GHz with higher than 96% radiation efficiency. The antenna provides less than -23 dB isolation and envelope correlation of lower than 0.004, between the ports.

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REFERENCES


