A bowtie-shaped MIMO dielectric resonator antenna for WLAN applications

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Abstract: A simple bowtie-shaped MIMO dielectric resonator antenna (DRA) resonating at 2.45 GHz with 75 MHz measured common bandwidth for both ports is presented in this paper for 2.40–2.48 GHz WIFI band applications. The MIMO characteristics are obtained by simultaneously exciting the TE²₁ modes by coaxial probe and TM₂₂¹ modes by coupled aperture feed in the DRA. Omni-directional radiation patterns are obtained in both principle planes, simulated and measured radiation patterns are found to be close to each other. Moreover, the proposed bowtie-shaped DRA is compact, exhibits high isolation (25 dB) and relatively low correlation (0.0156) suggesting its suitability for the MIMO applications.

Keywords: MIMO dielectric resonator antenna (DRA), bowtie dielectric resonator antenna, WLAN

Classification: Microwave and millimeter-wave devices, circuits, and modules

References

1 Introduction

Multi-input Multi-output (MIMO) technology is becoming attractive in recent wireless communication systems where high-quality data transmission at high speeds is required. The promising feature of MIMO technology is that it provides increased channel capacity without covering extra spectrum and utilizing additional radiation power [1]. MIMO antennas are generally implemented using printed microstrip technology [2]. At higher frequencies conductor losses in microstrip lines can become severe and the efficiency of the antenna reduces. To solve this problem dielectric resonant antenna (DRA) is preferred which employs a dielectric material as a radiator [3]. Due to the presence of a 3-D structure in DRA, it is easy to generate resonant modes required for different application with rather simplicity. The concept of a MIMO DRA was first demonstrated in [4] where it was shown that by using a cubic structure the antenna can achieve MIMO characteristics. In [5, 6, 7] singly-fed bowtie-shaped DRAs are presented exhibiting excellent radiation and bandwidth characteristics, however, these antennas are not targeted for MIMO applications and hence MIMO performance parameters are not reported in these works. In [8] a cylindrical DRA with dual polarization was designed by exciting the TE_{014} and TM_{014} modes in a single annular cylindrical DRA where two groups of 4 arc-shaped microstrip lines of various widths and lengths were used to excite the TE_{014} mode and a metal cap was placed on top of the probe to make the resonant frequency of TM_{014} modes and the TE_{014} mode equal. This antenna however has a bulky feeding mechanism and isolation up to 15 dB. In [9] a two-ports MIMO RDRA for 4G applications has been presented. Both the microstrip feeding lines excite TE_{011} mode in the DRA, which exhibits isolation up to 20 dB. In [10] a MIMO rectangular DRA for 4G (LTE) applications was designed. A
metallic strip was used for tuning the resonator frequency, which makes the feeding structure complicated. In [11] an L-shaped dual-band MIMO DRA for LTE applications is proposed. In which a cylindrical air-gap is created in the DRA to reduce the mutual coupling between ports. The antenna presents isolation about 17 dB. Antennas in [8, 9, 10, 11] either have complicated feeds or have complex structures, low isolation and may have fabrication issues.

In this letter, a simple bowtie-shaped MIMO DRA is proposed to operate at 2.45 GHz WiFi band applications. Two feeding techniques i.e. a coupled aperture for port1 and a coaxial probe for port2, are used to excite TM220 and TE210 modes respectively, in the proposed antenna. As compared to the antennas in [8, 9, 10, 11], the proposed bowtie-shaped DRA outperforms in terms of high isolation (25 dB), compact in size, and relatively low ECC (0.00156). Moreover, the proposed design relies on a simple structure and feeding mechanism that is easy to fabricate.

2 Antenna configuration and design

The geometry of the proposed bowtie-shaped DRA is illustrated in Fig. 1. The antenna comprises of a dielectric resonator, a supporting substrate, a ground plane and a microstrip feed line. The bowtie-shape of dielectric resonator is formed by carving out symmetrical notches from a rectangular DR which has dimensions’ length $a = 64$ mm, width $b = 46.3$ mm, and height $h = 23.6$ mm. A curve with depth $d = 4.9$ mm was carved out of the rectangular DR to form the bowtie-shaped DRA. A Taconic CER-10 DR material with $\varepsilon_r = 10$ and loss tangent = 0.0035 was employed for DRA fabrication.

The ground plane of $70$ mm $\times$ $50$ mm is supported by an FR4 substrate with a relative dielectric constant of 4.6 and a height equal to 0.8 mm. The ground plane is placed on the top layer of the substrate such that the dielectric resonator is in contact with the ground plane. The bottom layer of the substrate contains the microstrip feedline.

The feeding mechanism of the proposed antenna is as follows. To achieve MIMO characteristics, the DRA is fed by a combination of coupling aperture and a coaxial probe. The coupling aperture, with length $L_S = 18.92$ mm and width $W_S = 2.38$ mm, is cut in the ground plane of the substrate. The microstrip feed line present on the bottom layer of substrate excites the aperture which in turn excites the dielectric resonator. As a second feed, a coaxial probe is attached to one of the longer sides of DR. This is in contrary to placing the coaxial feed inside the DR as
can be found in conventional DRAs. This arrangement resulted in better values of isolation and ECC as will be presented in next section. Furthermore, the placement of coaxial probe on the side of DR also results in reduced air gap which is unavoidable if the probe is placed inside the DR.

The 50Ω microstrip line connected at port 1 excites the aperture which in turn excites the TM$_{22\delta}$ mode of the DRA. The port 2 is fed by a coaxial probe to excite the TE$_{021}$ mode of the DRA. By optimizing the depth “d” for carving out symmetrical notches from a rectangular DR, the resonant frequency of TM$_{22\delta}$ mode can be tuned to be the same as that of TE$_{021}$ mode so that both ports can excite the DRA on the same frequency i.e. at 2.45 GHz.

The photograph of fabricated prototype is shown in Fig. 2. The microstrip feeding line width (WF) = 1.88 mm, feeding line length (LF) = 45.39 mm, feeding stub length = 10.39 mm and the feeding coaxial probe has the length of 13.2 mm. The optimized dimensions for the prototype MIMO DRA were obtained after conducting a parametric study in a commercially available software package ANSYS HFSS which works on Finite Elements Method (FEM).

3 Parametric study

The model of proposed antenna was simulated in HFSS software and a parametric study was conducted in term of DR height (h$_{DR}$), substrate height (h$_{sub}$), probe height (h$_p$) and slot length (l$_s$) to calculate the effect of these important design parameters on antenna performance. Fig. 3 shows how resonant frequency is effected by the increase or decrease of aforesaid parameter’s values. From this parametric study, the optimize values have been chosen for the proposed design.

4 Experimental results

The simulated and measured input isolation and return loss of the proposed antenna are shown in Fig. 4. It can be noticed from the results in Fig. 4 that for a return loss better than −10 dB, the measured frequency band ranges 75 MHz (2.405–2.48 GHz) when port 1 is excited and 90 MHz (2.405–2.495 GHz) with port 2 is excited. The measured input isolation is found to be better than 25 dB, throughout the bandwidth, which is promising for MIMO applications. The simulated results generally agree well with the measured ones, however, a minor shift in resonant
frequency is observed that can be attributed to the unavoidable inaccuracy in DRA fabrication and SMA connector mismatches.

The simulated and measured far-field normalized radiation patterns, obtained in XZ and YZ principal planes, by exciting port 1 and port 2 are shown in Fig. 5. Radiation patterns show that the antenna works well as an omnidirectional MIMO radiator.
The performance of a MIMO antenna can be evaluated by analyzing the values of ECC (envelope correlation coefficient), diversity gain and total efficiency [12]. A lower value of ECC represents high channel capacity and increased antenna diversity. The value of ECC for the proposed MIMO antenna was computed using the scattering parameters as described in [12] and adopting the following formula.

\[
ECC = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)}
\]

The computed ECC value of the proposed MIMO antenna comes out to be 0.0156 which is much lower than the general criterion of low ECC i.e. \(ECC < 0.5\). The measured values of isolation, the average (ECC), the diversity gain, the total efficiency and antenna gain of the MIMO DRA for antenna isolation environment are shown in Table I.

<table>
<thead>
<tr>
<th>Input port</th>
<th>Antenna gain (dBi)</th>
<th>Total efficiency (%)</th>
<th>ECC at 2.45 GHz</th>
<th>Diversity Gain (dB)</th>
<th>Isolation (dB)</th>
</tr>
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<tr>
<td>1</td>
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5 Conclusions

A potentially simple and easy to fabricate bowtie-shaped MIMO DRA is presented in this letter for 2.45 GHz WIFI band applications. A dual feed mechanism has been employed to excite the \(\text{TE}_{321}\) and \(\text{TM}_{322}\) modes achieving MIMO characteristics. The S-parameters, radiation patterns, antenna gain, ECC and efficiency of the proposed structure were computed and compared with the measured practically. The measurement and simulation results agree well with each other. The performance of the proposed DRA is also compared with several recently reported DRAs. The results show that our designed bowtie-shaped MIMO DR system is compact, exhibits high isolation and relatively low ECC as compared to reference antennas and is a strong candidate for MIMO terminal applications.