

Four Element Antenna Array Working at 2.4/5.2 GHz for Wireless USB Dongle Applications

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Abstract—A four-element antenna array for a USB dongle multiple-input multiple-output (MIMO) antenna working in dual 2.4/5.2 GHz frequency bands is presented. For achieving reasonably low mutual coupling and good return loss characteristics of the antenna array, the positions of the antenna element are optimised within a compact low cost FR4 PCB board with dimensions of $25 \times 50 \times 0.8\text{mm}^3$. The array is evaluated as a MIMO antennas is presented, with analysis of the mutual coupling, correlation coefficient, total active reflection coefficient (TARC) and capacity loss. The proposed antenna meets the requirements for practical application within a wireless communications system.

I. INTRODUCTION

Digital devices developed in recent years are required to provide multiple services at all times and locations. Nevertheless, it is impossible to cover all the emerging new services such as high-quality multimedia broadcasting and wireless internet with a single device. To provide a simple plug-and-play function, the conventional universal serial bus (USB) was intended to make it fundamentally easier to connect and exchange information and data in most external devices, including personal computers (PCs), PDAs and laptops. To make this a wireless connection providing multiple services using a single terminal, a multiband antenna needs to be adopted. Recently, USB dongle antennas for WLAN [1-3] and UWB [4] applications have been reported. However, these antennas have not yet been demonstrated in the antenna arrays on MIMO USB dongle for multiband antenna.

The potential for MIMO antenna systems to improve reliability and enhance channel capacity in wireless mobile communications has generated great interest [5]. A major consideration in MIMO antenna design is to reduce correlation between the multiple elements, and in particular the mutual-coupling electromagnetic interactions that exist between multiple elements are significant, because at the receiver end this effect could largely determine the performance of the system. Lower mutual coupling can result in higher antenna efficiencies and lower correlation coefficients [6]. The effect of mutual coupling on antenna

diversity performance of the MIMO antenna array are studied in [6-12]. Authors in [2] have shown the effect of mutual coupling and correlation on the spatial diversity. Also, to evaluate the radiation performance, the total active reflection coefficient (TARC) is considered. The TARC provides a more meaningful and complete characterization measure of MIMO efficiency because it contains the effect of mutual coupling [7].

The purpose of the present work was to investigate the design of a practical MIMO antenna for the IEEE 802.11a and 802.11b/g bands (i.e. 802.11n as a MIMO realisation). The antenna design will be a challenging task due to the space constraints as well as the need to maintain good impedance and mutual coupling in MIMO USB dongle application.

II. ANTENNA DESIGN

The basic geometrical configuration and dimensions of the antenna arrays are shown in Figure 1. The design frequencies in this study are 2.4 GHz and 5.2 GHz, and the antenna arrays are mounted on a $0.2\lambda \times 0.4\lambda$ ground planes, evaluating λ at 2.45 GHz. The overall size has to be small, as it is for a USB dongle. The proposed closely-packed antenna arrays are etched on the low cost FR4 substrate with a PCB thickness of 0.8 mm and relative permittivity of 4.5. The L-shaped and S-shaped antenna at the top left hand side is represented as Antenna 1 (Figure 1a), where the L-shaped and S-shaped antennas are working at 5.2 and 2.4 GHz, respectively. The higher frequency section is driven and the other is parasitic. The inter-antenna spacing (centre-to-centre) is 0.08λ (10mm) between Antennas 1 and 2 and Antennas 3 and 4, and 0.12λ (15mm) between Antennas 1 and 3 and Antennas 2 and 4. The solid ground plane at the top and bottom of the PCB is reserved for the RF and digital circuitry which can be placed conveniently for practical use and allows the RF circuit to feed the antenna elements directly. The ground plane includes two slots with dimensions 0.2 by 1.7mm, and a number of vias as shown. These are included to increase the isolation between the antennas. The antenna arrays are ultimately connected to a USB connector in a practical implementation.

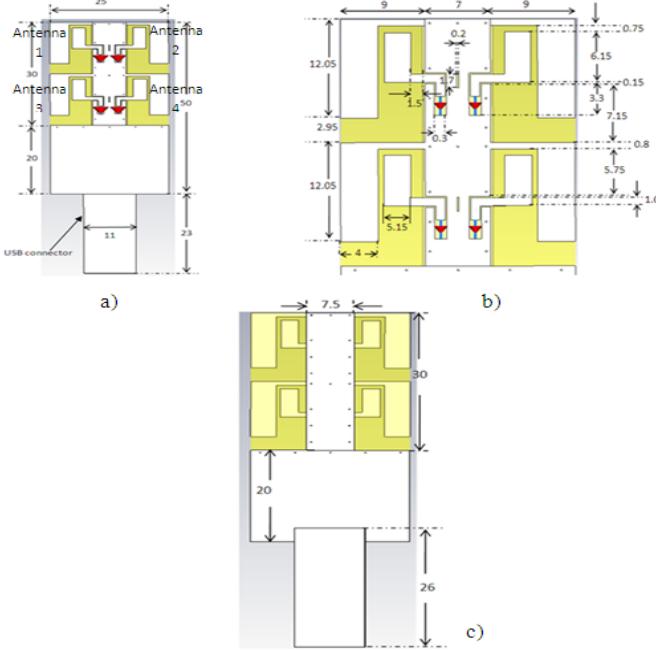


Fig.1: Antennas geometries and dimensions: a) 2-D schematic of antenna, top view, b) antenna details, c) 2-D schematic, bottom view.

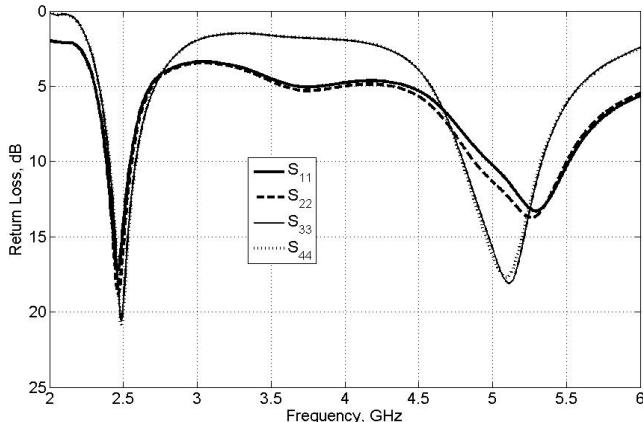


Fig.2: Simulated return loss of the proposed antenna array.

III. PRELIMINARY CONCEPTS OF MIMO

In this section, the equations to describe the characteristics of the MIMO antenna will be addressed. For diversity and MIMO application, the correlation coefficient between the two antenna patterns is one of the paramount factors in evaluating this antenna, since it is directly connected with the loss of spectral efficiency and degradation of performance of a MIMO system. In general, the envelope correlation coefficient of an antenna array can be computed by using either the far-field radiation pattern [13] or scattering parameters from the antenna system [14]. Due to the complication of the 3D far field measurement and calculation, the S-parameters method of computing the correlation coefficient of the two antennas is used. According to [15], the envelope correlation coefficient, ρ_e of a $N \times N$ antenna system can be determined using the following equation:

$$\rho_e(i, j, N) = \frac{\left| \sum_{n=1}^N S_{i,n}^* S_{n,j} \right|^2}{\prod_{k=i, j} \left[1 - \sum_{n=1}^N S_{k,n}^* S_{n,k} \right]} \quad (1)$$

In addition, to evaluate the radiation performance, the total active reflection coefficient (TARC) is considered. The TARC provides a more meaningful and complete characterization measure of MIMO efficiency because it contains the effect of mutual coupling. Authors in [7] defined TARC (Γ) as the ratio of the square root of total reflected power divided by the square root of total incident power and can be computed using following equation:

$$\Gamma_a^t = \sqrt{\sum_{i=1}^N |b_i|^2} / \sqrt{\sum_{i=1}^N |a_i|^2} \quad (2)$$

where a_i is incident signal and b_i is reflected signal. This is readily calculated from the S – parameters of the multiport antenna.

Theoretically, increasing the number of antennas of the MIMO system can improve the channel capacity. However, the presence of uncorrelated Rayleigh-fading MIMO channels will induce loss of channel capacity. This loss can be computed from the correlation matrices given in [16]. In the case of high SNR, the capacity loss is given as follows:

$$C_{loss} = -\log_2 \det(\psi^R) \quad (4)$$

where ψ^R is the receiving antenna correlation matrix

$$\psi^R = \begin{pmatrix} \rho_{1,1} & \cdots & \rho_{1,N} \\ \vdots & \ddots & \vdots \\ \rho_{N,1} & \cdots & \rho_{N,N} \end{pmatrix} \quad (5)$$

IV. RESULTS AND DISCUSSION

Figure 2 shows the simulated return losses for the antenna array. At the lower resonant frequency band, the antenna's impedance bandwidth operates over the frequency interval 2.38 to 2.52 GHz, for return loss better than 10 dB, which corresponds to 5.71% relative bandwidth with respect to the centre frequency of 2.45 GHz. At the higher resonant band, the antenna is capable of operating in the frequency band from 5.15 to 5.35 GHz at better than 10 dB return loss. This provides adequate coverage for IEEE 802.11a and 802.11b/g standards. Fig.3 depicts the mutual coupling performance of the antenna array. As can be seen, six combinations of the mutual coupling values, i.e. S_{21} , S_{23} , S_{24} , S_{31} , S_{32} and S_{34} , are given. It is found that the mutual couplings for this design are better than -10dB over the entire operating frequency band at 2.4/5.2. It is clearly seen that the spacing between the antenna elements plays an important role in obtaining good isolation. The simulated radiation characteristic of this

antenna was also investigated. It was found that the average gain of this antenna is around 1.2 dBi and 2.3 dBi over the band at 2.4 and 5.2 centre frequencies respectively. The simulated radiation patterns also show its high consistency and stability over the required operating bands.

Table 1 Simulated results at 2.4 GHz and 5.2 GHz

Antenna Pair	Correlation Coefficient, ρ		TARC, F_a^t (dB)		Capacity Loss, (bits/s/Hz)	
	2.4 GHz	5.2 GHz	2.4 GHz	5.2 GHz	2.4 GHz	5.2 GHz
1, 2	0.009	0.059	-12.56	-17.25	0.98	0.70
1, 3	0.046	0.025	-7.69	-13.79	1.04	0.56
1, 4	0.002	0.011	-14.8	-12.21	0.22	0.32
2, 3	0.002	0.011	-13.6	-10.09	0.19	0.32

In order to understand the MIMO characteristics of the proposed antenna, Table 1 presents a comprehensive description of the diversity performance between all antenna pairs. It is seen that the simulated correlation coefficient in the frequency band of interest is always less than 0.5, which is sufficient to fulfill the diversity requirements for MIMO systems [14]. Table 1 also shows the significant impact of isolation on the TARC and capacity loss results.

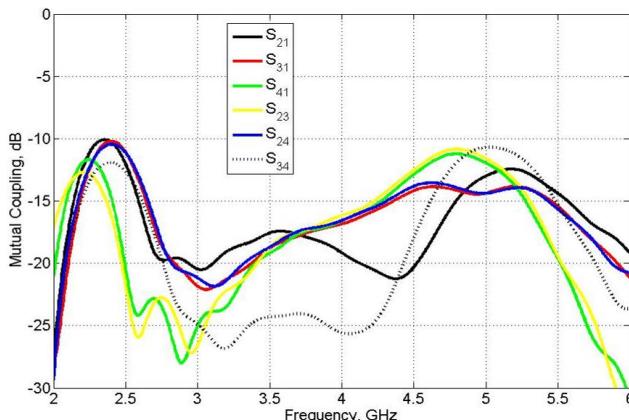


Fig.3: Simulated mutual coupling of the proposed antenna array

V. CONCLUSIONS

A very compact design for a 2.4 GHz and 5.2 GHz 802.11n MIMO antenna array, housed in a USB dongle, was derived and characterised. The design showed good performance, with adequate inter-antenna isolation. It can be effectively prototyped on a thin profile FR4 substrate at low cost and is thus particularly suitable for compact USB applications. The array may be etched on a reasonable ground size of only 25×50 mm ($0.2\lambda \times 0.4\lambda$ at 2.45 GHz) to work over the 2.4 GHz and 5.2 GHz frequency bands. The diversity performance of the MIMO antenna system was analysed using CST Microwave Studio and MATLAB

software and this showed that the proposed antenna could meet the requirements for practical application in wireless communication systems.

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