Design and Fabrication of an Electrically Small Meander Line Structure Antenna System for MIMO Applications

Prof. Abhilasha Mishra
Associate Professor,
E & C Engineering Department,
MIT, Aurangabad (India)
abbhilasha@gmail.com

Mr. Prakash S. Andhare
PG Student (Comm. Engg),
E & C Engineering Department,
MIT, Aurangabad (India)
piyuprakash18@gmail.com

Prof. Vidya H.Deshmukh
Assistant Professor,
E & C Engineering Department,
MIT, Aurangabad (India)
vidya_wangikar@yahoo.com

Abstract—A multiple-input multiple-output (MIMO) technique has been considered one of the most promising technologies to enhance the performance of wireless communication systems with high-speed transmission rates. A MIMO system utilizing several antenna components is more advantageous than a single-input single-output (SISO) system in terms of increasing channel capacity and reducing transmitting power. Conventional universal serial bus (USB) dongles are attractive for providing plug and- play functionality in mobile communication devices such as laptops. Future wireless USB dongles should be capable of accommodating higher data rates than the current systems owing to the advent of various multimedia services. Up to date, most MIMO antenna systems with more than two antennas are three-dimensional rather than planar. However, the basic problem with the MIMO systems is the requirement of electrically small antennas which usually have several constraints. Hence, these antennas are considered in our project work.

In this work the design, optimization, fabrication & testing of electrically small antennas suitable for MIMO (multiple input multiple output) applications are presented. When the transceiver uses more than one antenna, the antennas must be placed at least half of the carrier wavelength apart, in order to transmit/receive uncorrelated signals. Such antenna systems are required to fit within the hand-held (mobile) terminal which occupies a small size (typically not more than 60x100 mm^2). Since antenna integration and miniaturization are two major challenges in MIMO systems. We propose an electrically small antenna (ESA) that is based on the meander line antenna structure that operates in the 2.4-2.7 GHz ISM band. The proposed antenna has measured center frequency of 2.52 GHz with 240 MHz bandwidth. The proposed antenna is designed for USB based application with dimensions of 14.5X26.6 mm. The performance parameters of antenna are optimized to achieve an Omni directional radiation pattern with reasonably wide impedance bandwidth and high gain.

Keywords-Electrically *Small Antenna (ESA), Meander Line, VSWR, MIMO applications.*

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I. INTRODUCTION

A multiple-input multiple-output (MIMO) technique has been considered one of the most promising technologies to enhance the performance of wireless communication systems with high-speed transmission rates. A MIMO system utilizing several antenna components is more advantageous than a single-input single-output (SISO) system in terms of increasing channel capacity and reducing transmitting power. Conventional universal serial bus (USB) dongles are attractive for providing plug and- play functionality in mobile communication devices such as laptops. Future wireless USB dongles should be capable of accommodating higher data rates than the current systems owing to the advent of various multimedia services. Up to date, most MIMO antenna systems with more than two antennas are three-dimensional rather than planar. In practice, low-profile planar antennas are more preferred so that antenna radiators can easily integrated with other printed circuit board (PCB) components in USB dongles [1].

Multiple-input-multiple-output (MIMO) transmission is one of the promising antenna technologies used for wireless communications. Through spatial multiplexing, MIMO achieves high capacities. The only limitation is that, the transmitting and receiving antennas should be placed at least half the wave length of the carrier signal in order to transmit or receive uncorrelated signals. Apart from that, each of transmit or receive antenna requires a separate circuit which means, higher the no of antennas used higher the cost. It is indisputable that antenna plays a significant part in communication system. Therefore, an increasingly number of technicians begin to do some research and development of antenna. However, with rapid development of the communication industry, the requirement of antenna will be achieved with high quality. Nowadays, there are different kinds of antennas in the market such as dipole antenna, patch antenna, loop antenna, meander-line antenna and so on [2].

Antenna integration and miniaturization are two major challenges. The meander line antenna is a type of printed antenna that achieves miniaturization in size by embedding the wire structure on a dielectric substrate. In basic form meander line antenna is a combination of conventional wire and planer strip line. Benefits include configuration simplicity, easy integration to a wireless device, inexpensive and potential for low SAR features [3]. Meander line antenna is one type of the micro strip antennas. The meander line antenna was proposed by Rashed and Tai for reduce the resonant length [4].

Because recent years there are lot of changes in wireless communication technologies such as increase in data rate, MIMO system and at same time antenna size and weight is reduced. There are varieties of techniques to reduce the size of micro strip antennas: use of high permittivity substrates [5], shorting pins [6], and meander line. Inserting suitable slots in radiating patch is also a common technique in reducing the dimensions of patch antenna. The slots introduce parasitic capacitances which tend to reduce the resonant frequency of the antenna .For wireless communications applications such as USB Dongle, radio frequency identification tags, Bluetooth headset, Mobile phone Mean dear line antenna is convincing solution [7]. Meandering the patch increases the path over which the surface current flows and that eventually results in lowering of the resonant frequency than the straight wire antenna of same dimensions.

The electrical small antenna defines as the largest dimension of the antenna is not more than one-tenth of a wavelength (λ/10) [8]. Electrically small antennas (ESA) are antennas that can be enclosed within a radian sphere, meaning that the relationship

$$K_a=1 \text{or } a=1/k, \qquad (1)$$

Where k=2π/λ and a is the largest diameter of the circle inclosing the complete antenna, has to be satisfied [9]. ESAs have high input reactance and low input resistance. Therefore, they have high Quality factor (Q) and low frequency bandwidth. In [10], an expression for the Q was derived and is given by,

$$Q = \frac{1}{K_a}^{3} \qquad (2)$$

Meander antenna is electrically small antenna .The design of meander line antenna is a set of horizontal and vertical lines. Combination of horizontal and vertical lines forms turns. Number of turns increases efficiency increases. In case of meander line if meander spacing is increase resonant frequency decreases. At the same meander separation increase resonant frequency decreases [11].

The meander line element consists of vertical and horizontal line so it formed a series of sets of right angled bends. The polarization of antenna depends on radiations from the bend. The spacing between two bends is very vital, where if the bends are too close to each other, then cross coupling will be more, which affects the polarization purity of the resultant radiation pattern. In other case the spacing is limited due to the available array grid space and also the polarization of the radiated field will vary with the spacing between the bends, and the spacing between the micro strip lines [12].

II. MEANDER LINE STRUCTURE AND DESIGN

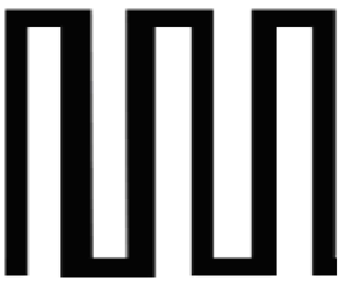

Fig.1 Meander Line Structure

A meander antenna is an extension of the basic folded antenna and frequencies much lower than resonances of a single element antenna of equal length. Radiation efficiency of meander line antenna is good as compare to conventional half and quarter wavelength antennas. Antenna size reduction factor β depends primarily on the number of meander elements per wavelength and spacing of element widths of the rectangular loops [13]. Planar meander line antenna with added quarter wave parasitic element at the both side of the meander can produce double beam radiation pattern at frequencies much lower than resonances of a single-element antenna of equal length [14]. A planar meander line monopole antenna element is the most suitable choice for the MIMO antenna system [15].

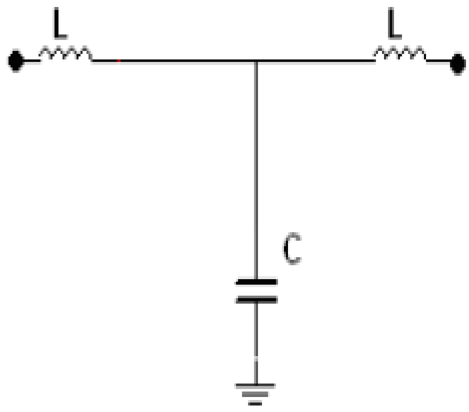

Fig.2 Lumped equivalent model of meander

The meander line antenna acts as a resonant LC circuit. The vertical elements act as the inductor, horizontal elements act as capacitor. The horizontal lines lie in the short length of the PCB while the vertical lines are placed along the long length of the PCB. The meander line configuration of the monopole allows reducing the occupied space of the antenna element to less than $0.1\lambda_0$ in each dimension.

The lumped inductance and capacitance are calculated as follows:

$$\text{Lumped inductance } L_A = \frac{Ll}{2} \qquad (3)$$

$$\text{Lumped capacitance } C_B = Cl \qquad (4)$$

Where L inductance per unit length is, C is capacitance per unit length and l is length of line segment [16].

Total length of antenna is given by

$$\lambda/10 = N \times S \qquad (5)$$

Where N number of turns, S is spacing between two meander lines

In this work, we design and fabricate a single input single output MLA with a center frequency around 2.52 GHz, bandwidth of at least 240 MHz and total size of an antenna 14.5X 26.6 mm. This paper presents an overview design printed meander antennas in the ISM band by providing a good initial geometrical configuration of the antenna. This article has-been divided into four sections. Section I describes introduction. Section II describes in detail of the meander line antenna structure and design. Section III describes in detail modeling of the meander line antenna. The results obtained from our proposed antenna are listed and discussed in Section IV. Finally concluding remarks are presented in Section V.

III. MODELLING OF THE ANTENNA

A meander line antenna shrinks the electrical length of a regular monopole or dipole antenna by folding its length back and forth to create a structure with multiple turns. This method has advantages when antennas with low frequency of operation are of interest, since this will reduce the size of the antenna significantly. The size of the antenna will even get smaller because of the use of a dielectric substrate. Printed meander antennas usually have good radiation efficiency and close to Omni-directional radiation patterns.

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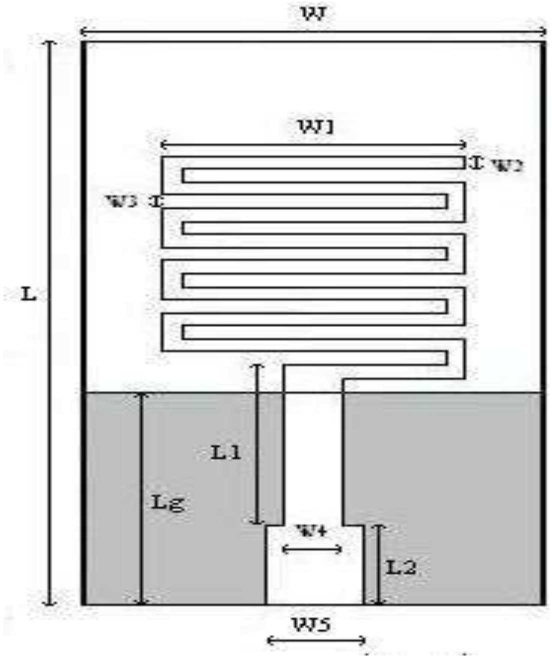

Fig.3. Geometry of the single Meander Line ESA.

The designed single Meander antenna structure is shown in Figure 1. Antenna dimensions were optimized using HFSS. The dimensions of the antenna are in mm and given by, L=26.6, W=14.5, Lg=11.32, W1=9.6, W2=0.62, W3=0.62, W4 =1.86, W5=3.1, L1= and L2=. The antenna was etched on an FR-4 substrate with 1.59 mm thickness, copper was used. A right angle PCB mount SMA connector was used as the feeding port for the antenna.

Table I shows the effect of No. of turns on different antenna parameter.

TABLE I
Effect of No. of Turns on Different Antenna Parameters

Sr. No.	NO. of turns	FR (GHZ)	R.L. (dB)	VSWR	BW (MHz)	Gain (dB)
1)	10 turns	2.34	-08.01	21.04	225	2.72
2)	09 turns	2.34	-17.38	1.38	225	5.42
3)	08turns	2.52	-39.1	1.02	240	7.22
4)	07 turns	2.79	-38.23	1.04	260	6.18
5)	06 turns	2.79	-54.01	1.04	261	6.15
6)	05 turns	2.80	-3.46	5.1	260	5.57

IV. RESULTS AND DISCUSSSION

Figure 4 shows the top views of the fabricated single MLA antenna. The radius of the sphere inclosing this antenna is 1.45 cm. Figure 5 shows the measured and simulated reflection coefficients. An HP 8514BNetwork Analyzer was used to conduct this measurement. The correlation between the two is very well observed. The simulated f_c was 2.52 GHz, while the measured one was 2.50 GHz. The simulated -10 dB bandwidth was 240 MHz while the measured one was 195 MH_z This shows a good match between the two, although some discrepancy is expected due to the presence of the GND plane. The MLA total size is 14.5 X 26.6 mm.

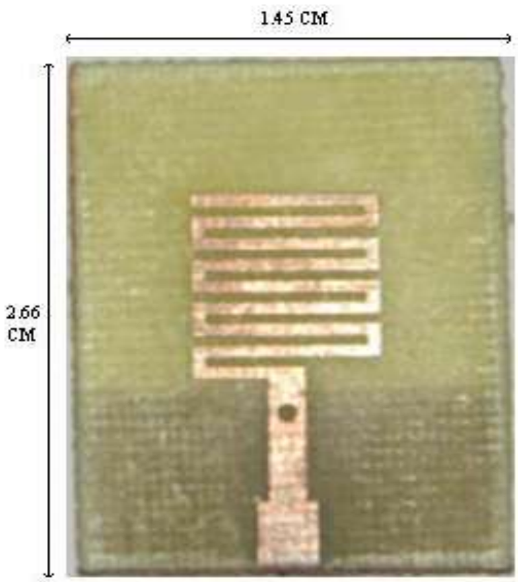

Fig.4 Photo of the fabricated antenna

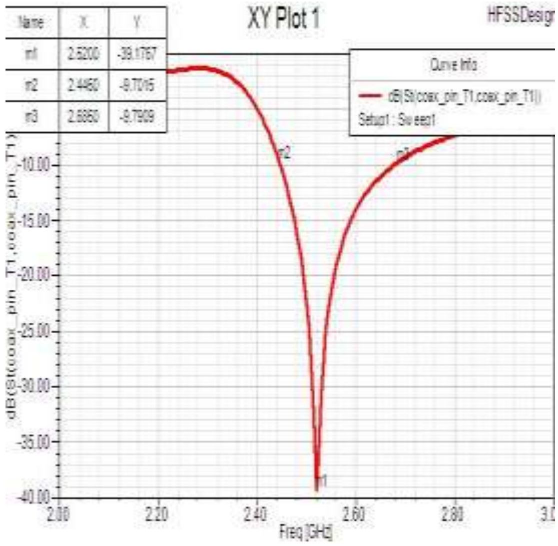

Fig.5 Simulated return loss for proposed MLA antenna

This section presents the simulated results of modified MLA. HFSS has been used to simulate the antenna for several performance parameters such as impedance bandwidth, radiation patterns and VSWR. The parametric study of the antennas reveals the band behavior. The antenna is designed to operate on 2.5 GHz ISM band. Fig. 3illustrates the S11 of MLA; where it shows a return loss of -39.1 dB for the operation on 2.5 GHz. The impedance bandwidth calculated at -10 dB scale for this band is 240 MHz Figure 6 shows the simulated and measured VSWR for proposed MLA antenna. In small antennas, the ground plane plays a major part in radiation. As a consequence of the change in ground plane size, shift in the resonant frequencies has been noticed.

ISSN: 2321-8169
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The current distribution on the ground plane and its effect on the resonant frequencies were also observed during simulation. The measured radiation patterns for the single element MLA antenna are shown in figure 7.

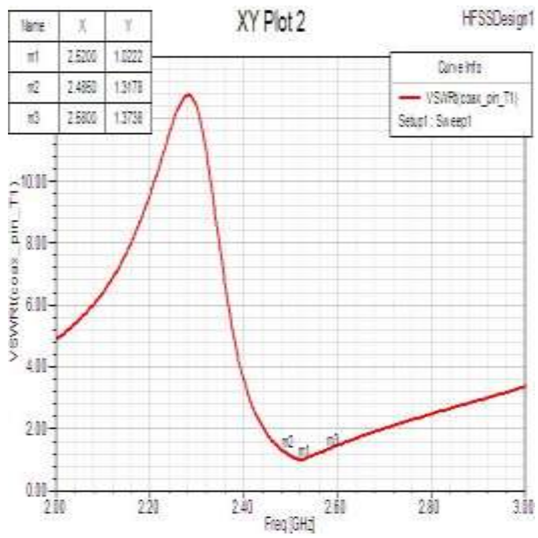

Fig.6 Simulated VSWR for proposed MLA antenna

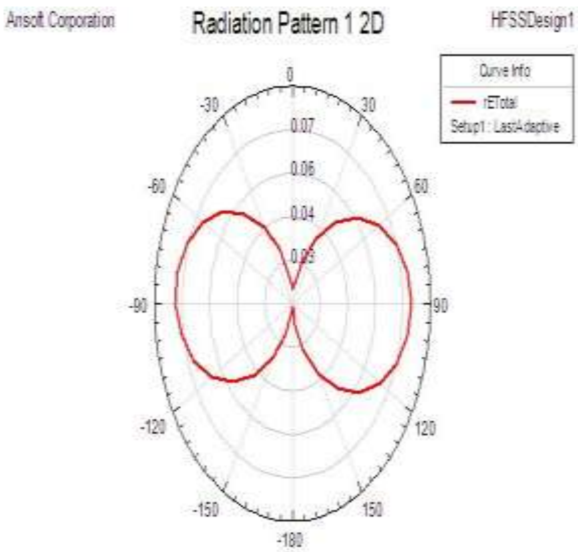

Fig.7 Radiation Pattern of Proposed antenna

V. CONCLUSIONS

A compact electrically small antenna (ESA) design and fabrication that is based on the meander antenna is presented. The antenna is intended for the use in the 2.4-2.7 GHz of the USB applications. Simulation and measurement results are compared. The single antenna has a measured center frequency of 2.52 GHz, bandwidth of 240 MHz, Return loss -39.17 is obtained. and total size of antenna is 14.5X26.6 mm.

The practical challenge is achieving an efficient match over a desired operating bandwidth. In some applications, particularly where the antenna is very small, it is acceptable and perhaps necessary to add loss to the antenna structure so as to increase the usable operating bandwidth. The addition of loss to enhance bandwidth is often necessary where manufacturing tolerances with high *Q* antennas make it difficult to repeatedly achieve the same desired operating frequency. Bandwidth enhancement resulting from increased loss may also be beneficial in applications where the antenna has a tendency to de-tune due to coupling effects associated with the surrounding environment.

Based on the studies presented in this report following points have been concluded

● The impedance bandwidth of the proposed design is above 100% in all the cases studied with good radiation characteristics.

● The antenna presented here proves to be electrically small and is the best candidate for MIMO applications.

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