Design Of A Compact Two-Port MIMO Antenna For UWB Applications

Felix Urimubenshi; Dominic B. O. Konditi; Edward N. Ndung'u

Abstract: In this paper, a small two port ultra-wideband multiple input multiple output antenna (UWB-MIMO) is proposed. The proposed antenna consists of two identical modified semi-circular annular ring radiators placed at the end of taped feedline excited using CPW technology. These two radiators are placed orthogonal to each other for good isolation and share the common ground plane. Antenna has a compact size with an overall surface area of $1095.12mm^2$, a bandwidth of 8.472 GHz starting from 3.8GHz up to 12.272 GHz and a return loss less than -10dB. Over the entire bandwidth, the antenna has stable radiation pattern with quasi-omnidirectional characteristic. The achievable gain is in the range of 2.883dBi to 4.682dBi, and efficiency is 79.4%-99.3%. The MIMO performance has been investigated based on Envelope Correlation Coefficient (ECC) and Diversity gain (DG). Proposed antenna has ECC<0.01 and DG>9.9, with port to port isolation S2, 1<-12.5dB.

Index Terms: Microstrip antenna, CPW, Annular Ring, Ultra-wideband, MIMO, Envelope correlation coefficient, Diversity Gain, taped feed

1. INTRODUCTION

In recent development of wireless systems, the requirement for miniaturized devices within high data rate transmission and low power consumption is becoming more and more important. Ultra-wide band (UWB) systems have received a tremendous attention in both industries and academia due to their ability for higher data transmission and reception of signals with less power consumption (<-41.3dBm/MHz) [1]. UWB systems have other advantages such as easy integration with system circuits, better radiation characteristics, and wider bandwidth to support various applications like medical imaging systems, mobile systems, vehicular radar systems, sensor network, and RFID readers especially for short-range applications [2],[3],[4],[5], high-resolution reliable data. According to U.S FCC regulations [6], the frequency band allocated to UWB systems ranges from 3.1 GHz-10.6 GHz , and 6.0 GHz-8.5 GHz for European regulations. In general, UWB antennas are an intentional radiator that, at any point in time, have a fractional bandwidth of at least 20% or has -10 dB bandwidth greater 500 MHz regardless of the fractional bandwidth [7].

Despite its advantages, the performance of UWB systems are seriously degraded by multipath fading environment [8].Without increasing the bandwidth or transmitted power, the quality of communication in UWB systems can be improved by means of Multiple Input Multiple Output (MIMO) technology [9]. It uses multiple antennas at both transmitter and receiver, and requires higher isolation between antenna elements for better space diversity[10]. Different decoupling techniques for enhancing isolation between elements have been reported in literature. . In [8],[11], a rectangular shaped ground plane with an extruded T-shaped stub have been reported to enhance isolation below -20 dB and providing an envelope correlation coefficient (ECC) less than 0.02 and diversity gain (DG) greater than 9.95 dB. The Elements are oriented orthogonally to each other to achieve -15 dB of isolation and ECC less than 0.05 [12]. Extended L-shaped ground stub combined with orthogonal oriented elements has been shown to achieve isolation of -16dB with ECC of 0.1 [13]. Low mutual coupling between antenna elements has been achieved by using neutralized line formed by rectangular ring and a straight line[14]. In the design of UWB antennas, different geometries have been proposed in the literature in which the microstrip line and coplanar waveguide (CPW) feeding techniques are used to keep the planar structure. However, most UWB antennas using such feeding techniques are symmetrical in structures which affects the overall dimension of the antenna [15]. By cutting these antennas into halves, a wider operating bandwidth and miniaturized antennas can be achieved with better impedance matching than the full-sized antenna can provide[16]. In the present work, orthogonal orientation combined with half-cutting of circular annular ring is investigated to build a UWB-MIMO antenna with improved isolation.

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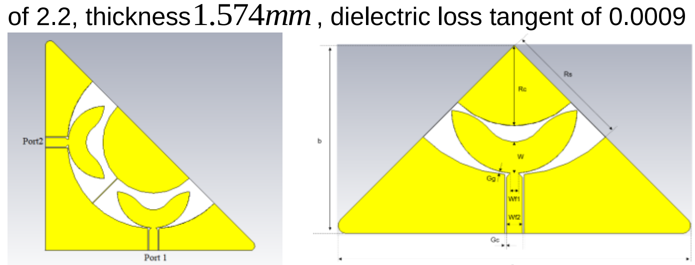
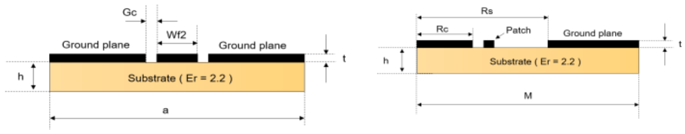
2 ANTENNA DESIGN

2.1 Antenna Configuration

The layout of proposed UWB-MIMO antenna is shown in Fig.1. It consists of two identical modified semi-circular annular ring radiators placed at the end of taped feedline. These two elements have a common ground. The overall antenna in Fig.1. (a) has a right triangle shape composed of two identical isosceles shaped triangles shown in Fig.1. (b). The area occupied by the proposed antenna is $A = 0.5 \times (a \times a)\, mm^2$ equivalent to $1095.12mm^2$ where a be the length of front view in fig. 1 (c) for both antenna elements. The antenna is printed on RT/Duroid5880 substrate having relative permittivity of 2.2, thickness $1.574mm$, dielectric loss tangent of 0.0009



(a) (b)



(c) (d)

***Fig.1**. (a) Proposed UWB-MIMO antenna, (b) Single Element: Top View, (c) Single Element: Front View, (d) Single Element: Side View*

W=3.9mm, Rs=16.099mm, Rc=7.6mm, Gg=0.2mm, Gc=0.2mm, a=46.8mm, b=23.4mm, Wf1=0.5mm, Wf2=1.5mm, h=1.574mm, t=0.018mm

2.2 Mathematical Preliminaries

For the design of an antenna, the desired value of antenna dimension (R_{in}) at operating frequency considering (TM_{nm}) mode can be estimated by using [17],[18],[19],[20] .

$$f_{r,nm} = \frac{x_{nm}c}{2\pi Rin\sqrt{\varepsilon_r}} \qquad (1)$$

Where, R_{in} is the inner radius of the ring, TM_{nm} is the m^{th} zero of the derivative of Bessel function of order n , c is the velocity of electromagnetic waves in free space, ε_r is the relative dielectric constant of substrate. For TM_{11} , $x_{nm} = 0.6773$ [21]. The outer radius of the annular can be approximated by $R_{outer} = R_{in} + W$, and W being the width of the ring.

3 RESULTS AND DISCUSSION

The proposed UWB-MIMO antenna performance was investigated and optimized by using CST Microwave studio full wave EM simulator.

3.1 Return loss, VSWR, and Input impedance

To achieve the UWB spectrum of proposed MIMO antenna, different techniques have been applied. These include: half cutting of the circular annular ring patch antenna, use of taped feedline, controlling the gap between the patch and ground (Gg and Rc parameters). In fig. 2, the results shows that the proposed antenna has an impedance bandwidth of 8.472 GHz starting from 3.8GHz up to 12.272 GHz with a return loss less than -10dB. On another hand, S1, 2 and S2, 1 are used to characterize the mutual coupling between elements of proposed UWB-MIMO antenna. Because of the symmetry of the proposed antenna, and identical physical structures, S1, 1=S2, 2, and S1, 2=S2, 1. Except for a portion of bandwidth (3.8GHz-4.8GHz) where the mutual coupling is less than -12.5dB, the rest of spectrum of the proposed antenna has mutual coupling less than -15dB. Thus, antenna has a lower mutual coupling.

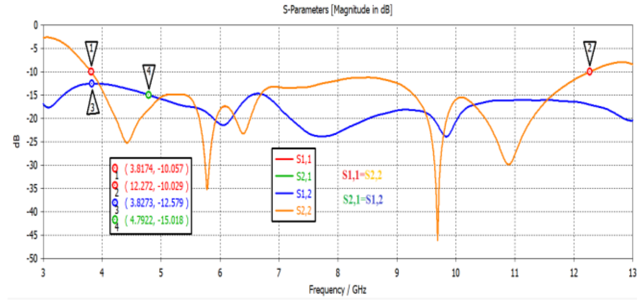


***Fig.2**. Simulated Return loss |S11|= |S22| versus frequency*

Impedance matching is extremely important for maximum power transfer. Since the antenna is just a load to a transmission line from the circuit point of view, the reflection coefficient, return loss and voltage standing wave ratio (VSWR) can be used to establish how well a load is matched to the transmission line. For a feedline with characteristic impedance of 50 Ohms, there is a range of antenna input impedances (25 Ohms up to 100 Ohms) where the antenna is matched to the feedline and VSWR ranges from 1 to 2 [22]. VSWR and input impedance (Z1, 1 and Z2, 2) of the proposed antenna are given in fig.3 and fig.4 respectively. For the entire bandwidth, the VSWR falls in acceptable range (2:1)

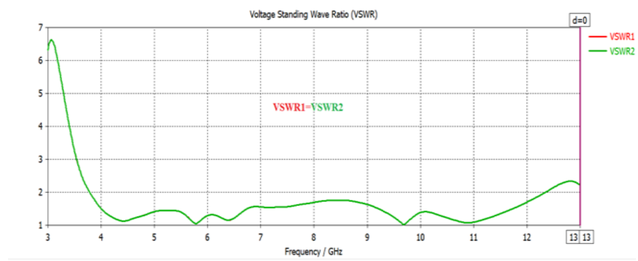
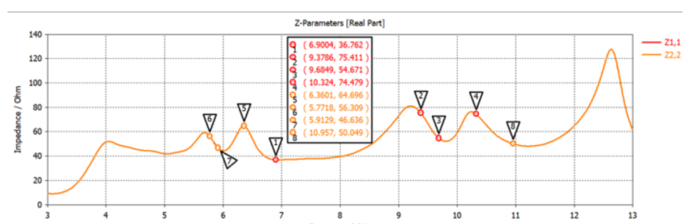
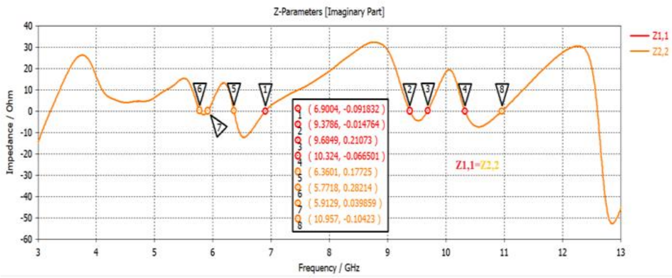


***Fig.3**. Voltage standing wave ratio (VSWR) of proposed antenna.*



(a) Real part of Input impedance



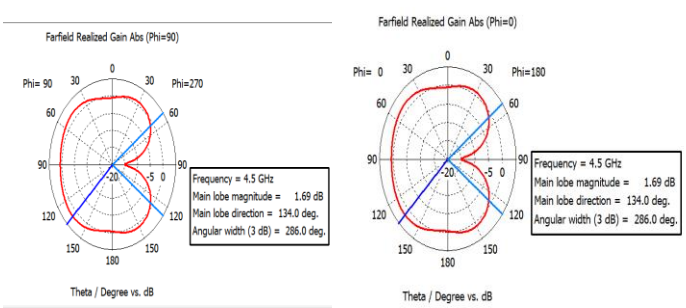
(b) Imaginary part of Input Impedance

***Fig.4**. Input impedance of proposed antenna*

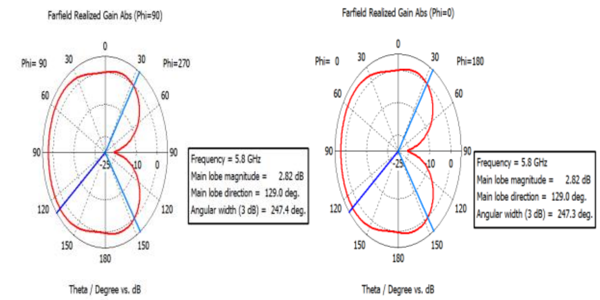
It can be observed in Fig.4. (a), that input impedance for entire bandwidth has minimum and maximum value of 37.135 Ohms at 6.847GHz and 88.7 Ohms at 12.27GHz respectively, with nine different frequencies where the antenna has input impedance of 50 Ohms. These frequencies are: 3.956GHz, 4.13GHz, 5.5GHz, 5.8 GHz, 6.15GHz, 6.53 GHz, 8.559GHz, 10.9GHz, and 11.525GHz. In Fig.4. (b), it is clear that there are 8 different points where the imaginary part of the antenna is equal to zero. These points are 6.9 GHz with an impedance of Z=36.762 Ohms, 9.3 GHz with Z=75.5Ohms, 9.6GHz with 54.671 Ohms, 10.324 GHz with Z=74.479 Ohms, 6.36 GHz with Z=64.696 Ohms, 5.8GHz with Z=56.39 Ohms, 5.9 GHz with 46.636 Ohms, and 10.957GHz with Z=50.049 Ohms. These points are essentials for antenna resonance.

3.2 Radiation Pattern, Gain, and efficiency

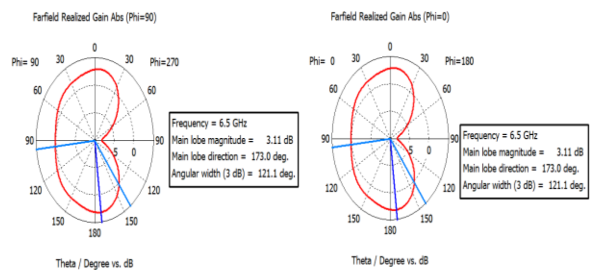
The radiation pattern of UWB-MIMO antenna at sampled frequencies 4.5 GHz, 5.8GHz, 6.5GHz, and 9.5 GHz in both Phi=90^0 and Phi=0^0 are shown in fig.5. It is observed that the radiation patterns are stable and quasi-omnidirectional in both planes containing electric and magnetic fields over entire operational band. The proposed antenna has a peak gain of 4.682 dBi at 5.8 GHz and minimum gain of 2.882 dBi at 3.8GHz as indicated in Fig.6 which is enough for UWB indoor applications. The radiation efficiency is depicted in Fig.7. It has minimum value of 79.41 % at 6.2GHz and 99.33% at 5.2 GHz.



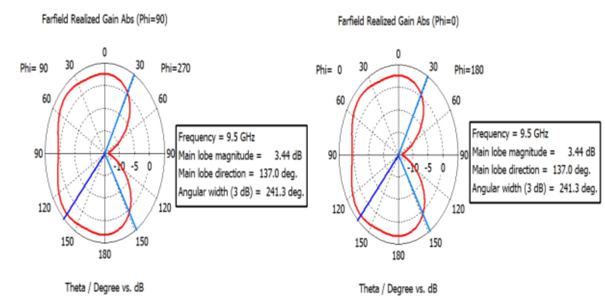
At 4.5 GHz



At 5.8 GHz



At 6.5 GHz



At 9.5GHz

***Fig.5**: Polar plot radiation pattern at sample frequencies*

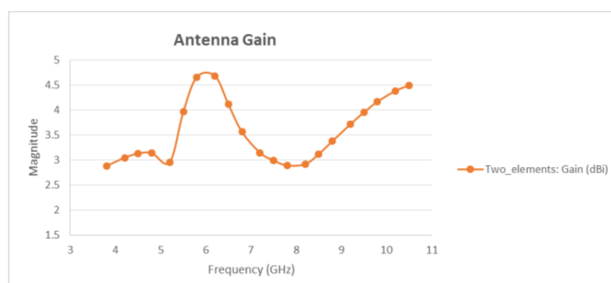


***Fig.6**: Antenna Gain over entire bandwidth*

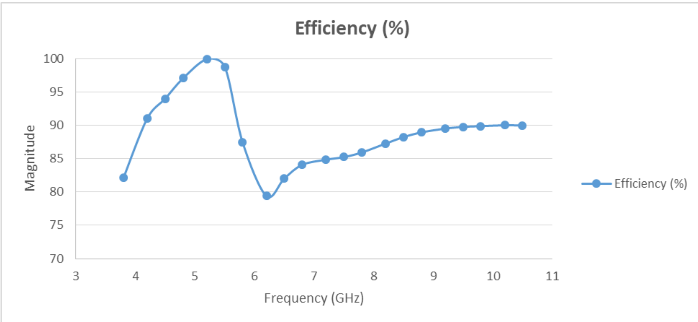


Fig.7.*Antenna Efficiency over entire bandwidth*

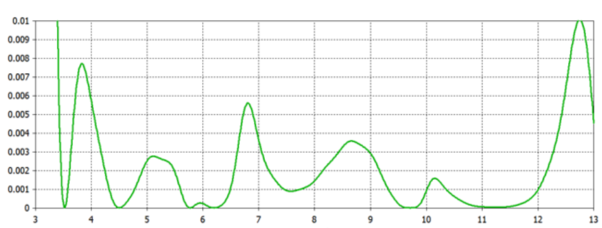
3.3 MIMO Performance

To evaluate the MIMO performance, the envelope correlation coefficient (ECC) and diversity gain (DG) need to be calculated. These metrics can be calculated using S-Parameters as suggested in [23]. Thus, the mutual coupling between the adjacent antenna elements and the amount of correlation between each antenna element can be analyzed in terms of envelope correlation coefficient [11].

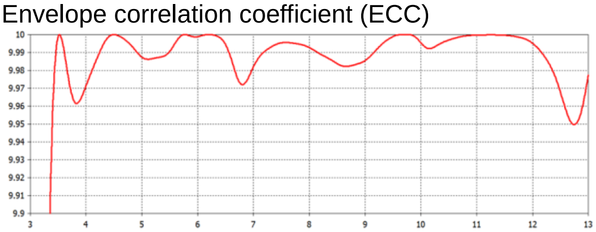
$$ECC = \frac{\left|S_{11}^{*}S_{12} + S_{21}^{*}S_{22}\right|^{2}}{\left(1-\left|S_{11}\right|^{2}-\left|S_{21}\right|^{2}\right)\left(1-\left|S_{22}\right|^{2}-\left|S_{12}\right|^{2}\right)} \quad (2)$$

$$DG = \sqrt{1-ECC^{2}} \quad (3)$$

Ideally, the value of ECC should be equal to zero for decoupled antenna elements. However, ECC<0.5 is accepted. In fig.8, the value of ECC is less than 0.01 and DG is more than 9.9 for entire UWB bandwidth which demonstrate better diversity performance and make the proposed antenna to be suitable for MIMO applications.



Envelope correlation coefficient (ECC)



Diversity Gain (DG)

Fig.8: *Simulated ECC and Diversity Gain (DG)*

In Table 1, the parameters of interest: Bandwidth, Gain, radiation efficiency, ECC, DG, size of the proposed antenna has been compared to already existing works in literature [24],[25],[26],[27],[28],[29]. The present antenna shows to have better performance in terms of radiation efficiency, gain (2 elements compared to 4 elements), and small dimensions.

TABLE 1

COMPARISON OF PROPOSED ANTENNA WITH EXISTING ANTENNAS

Reference Paper	Number of elements	Dimension (mm^2)	Bandwidth (GHz)	Gain (dBi)	Efficiency (%)	Isolation (dB)	ECC
[24]	4	40x40 =1600 mm^2	3-18.0	1.5-4	-	-20	0.03
[25]	4	45x45=2025 mm^2	2-10.6	1.5-4.5	-	-17	0.01
[26]	4	36x36=1296 mm^2	3.1-10.6	3.7	58-61	-15	0.02
[27]	4	40x40=1600 mm^2	2.95-12.1	5.4	74-91	-15	0.04
[28]	4	48x48=2304 mm^2	3-11	4.7	65-92	-17	-
[29]	2	50x90=4500 mm^2	1.85-10.6	3.5	60-80	-10	0.2
[14]	4	75.19x75.19 =5653.5 mm^2	3.1-17.3	5	-	-15	0.1
[15]	4	40x40=1600 mm^2	2.94-14	5	75-88	-17	0.03
This work	2	$\frac{1}{2}(46.8\times 46.8)$ =1095.12 mm^2	3.8-12.27	4.68	79-99	-12.5	0.01

5. CONCLUSION

A compact Two-port UWB-MIMO antenna with Low mutual coupling and high radiation efficiency has been proposed in this work. The performance of proposed antenna has good impedance matching, good diversity performance over entire UWB spectrum and make it well suitable for UWB-MIMO applications.

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