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Hexa-band MIMO CPW Bow-tie Aperture Antenna Using Particle Swarm Optimization

A-K. Hamid, W. Obaid
Department of Electrical and Computer Engineering, College of Engineering, University of Sharjah, UAE

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ABSTRACT

A MIMO hexa-band Bowtie Antenna for Wi-Fi is proposed. The MIMO antenna can operate at six frequency bands: 2.4, 4.4, 6.1, 8.5, 10.25 and 12.8 GHz. The MIMO antenna consists of four loaded bowtie hexa-band antennas having the same structure. Each single antenna element is loaded with six metallic strips as well as interconnected parasitic rectangular components. The presented HFSS simulations will show that the MIMO loaded antenna can operate at six frequency bands including 2.4 GHz by obtaining the return loss results, radiation patterns, and other antenna parameters. It will be shown also that the MIMO bowtie antenna has a very low mutual coupling at all the operating frequencies for the specific loaded metallic strips width which was obtained using Particle Swarm Optimization technique.

Corresponding Author:

A-K. Hamid,
Department of Electrical and Computer Engineering,
College of Engineering, University of Sharjah, Sharjah, UAE.
Email: akhamid@sharjah.ac.ae

1. INTRODUCTION

Many optimization methods were developed in the last decades such as the Genetic Algorithm, Particle Swarm Optimization and others for optimizing the antennas and their parameters [1]. Optimizing antenna parameters using such techniques is very important in order to obtain significant results related to different antenna parameters such as the return loss or impedance. Obtaining such improved antenna parameters using optimization techniques makes adding extra components on the antenna to achieve similar results to be dispensable.

Genetic Algorithm is an optimization method which performs mutation, crossover, and selection over a set of possible individuals. It can take a list of constraints for evaluating the objective function in order to maximize or minimize a specific variable [2]. Particle Swarm Optimization is a much simpler algorithm than Genetic Algorithm and more efficient in terms of computation time. It is a population-based stochastic technique. The iterations in this technique improve the wanted outcome until reaching the desired solution as the case of bird flocking behavior [3]. A design for a spline-shaped antenna was proposed using PSO in [4] for Ultra-wide-band applications. Another optimization design relied on both the Genetic Algorithm and PSO for designing a horn antenna in [5].

Bowtie antenna is very suitable for communication and Wi-Fi technologies and applications because it has some unique features such are the ability to operate at multiple frequencies, the minimum cost of manufacturing, the small size and the lightweight [6]. There were many designs for the bowtie antenna related to tri-band frequency operations such as the ones in [7]-[13]. Other designs were presented to make the antenna at Penta-frequency bands as in [14 - 16]. Hexa-band antenna designs were presented for various applications such as GSM, GPS-L1, WLAN, WiMAX and mobile handset applications [17]-[18].

MIMO antenna designs require reducing the mutual coupling between elements of the antenna. Dual-band Dual-polarized antenna array was proposed in [19] for WLAN. A tri-band E-shaped antenna was proposed for MIMO applications in [20]. One design was proposed for MIMO antenna for a quad-band operation to be used in wireless communications terminals in [21]. A hexa-band MIMO antenna design was proposed in [22] for LTE mobile device application which relied on neutralization line concept in order to reduce the mutual coupling. A design for a 2X2 MIMO patch antenna for multi-band applications was proposed in [23] using groups of rings at four corners and near the stepped cut in addition to a mid-slot separation in order to reduce the mutual coupling. Another MIMO antenna design was proposed in [24] for four-element Dual-band output which had four bowtie dipole antenna, that design had four types of ground plane patterns which are full, cornered spatial, crossed middle, and spiral. A low mutual coupling dual-band MIMO microstrip 2X2 antenna with parasitic air gap to reduce the mutual coupling was proposed in [25]. These MIMO antenna designs which were proposed for multiple frequency operations had complicated structures and they did not have a very low mutual coupling compared to the return losses for their corresponding MIMO antenna elements.

The proposed MIMO bowtie antenna may operate at six frequency bands by the added six internal metallic strips and the rectangular interconnected parasitic elements for each MIMO antenna element [26]. The metallic strips are fixed vertically but variable by width horizontally for tuning the frequency. The interconnected parasitic elements are fixed in their dimensions. The proposed MIMO bowtie antenna consists of four loaded elements with the same structure; each antenna element is placed at a corner. Next sections will discuss the structure and the obtained results for the MIMO bowtie antenna.

2. ANTENNA GEOMETRY AND DESIGN

CPW antennas can have variety of shapes such as square, rectangle and triangle. The location of the antenna feed line is directly related to the radiated cross-polarized components and surface excited currents in CPW antennas. RF frequency applications, antenna arrays and radar applications are examples of applications for CPW antennas. The original single unloaded bowtie antenna has the following substrate (Arlon CuClad 217 (tm) with a 2.17 dielectric constant) dimensions: width=64 mm, length=34 mm and height=2 mm [27] as shown in Figure 1. It can operate at one frequency band around 10 GHz, The lumped port feed has 50 Ohms between the CPW antenna feedline.

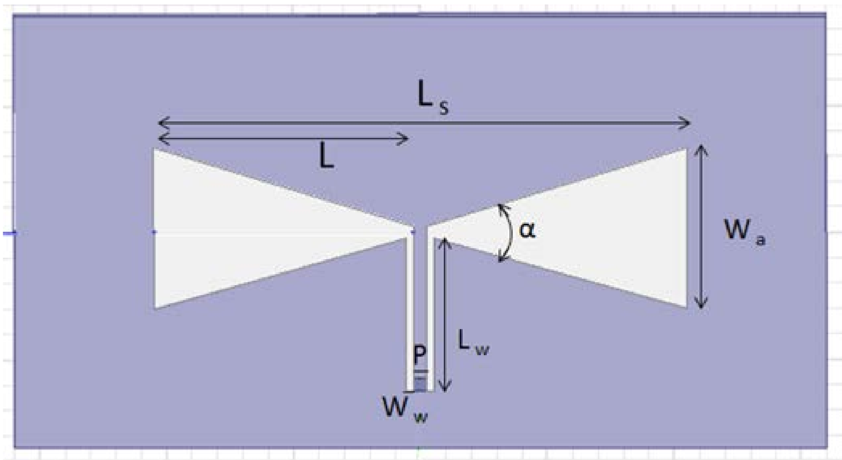


Figure 1. Dimensions for the unloaded single bowtie antenna: La=42 mm. L=20.5 mm, Wa=12.7 mm, Lw=12 mm, Ww=0.6 mm, α=52 and P=1 mm [27]

Figure 2 shows the structure for a loaded single MIMO antenna element with the metallic strips and the interconnected parasitic rectangular components. Figure 3 demonstrates the structure of the MIMO antenna which consists of four identical loaded antennas with the same structure of metallic strips and interconnected parasitic rectangular components. The width Ws for the metallic strips was set to a specific value in order to achieve six frequency bands for all the four loaded antenna elements. The horizontal distance between the edges of the vertical MIMO element pairs is 22 mm and the vertical distance between the edges of the horizontal MIMO pairs is 20.6 mm. The dimensions of the MIMO antenna substrate are 128 mm for length and 68 mm for width.

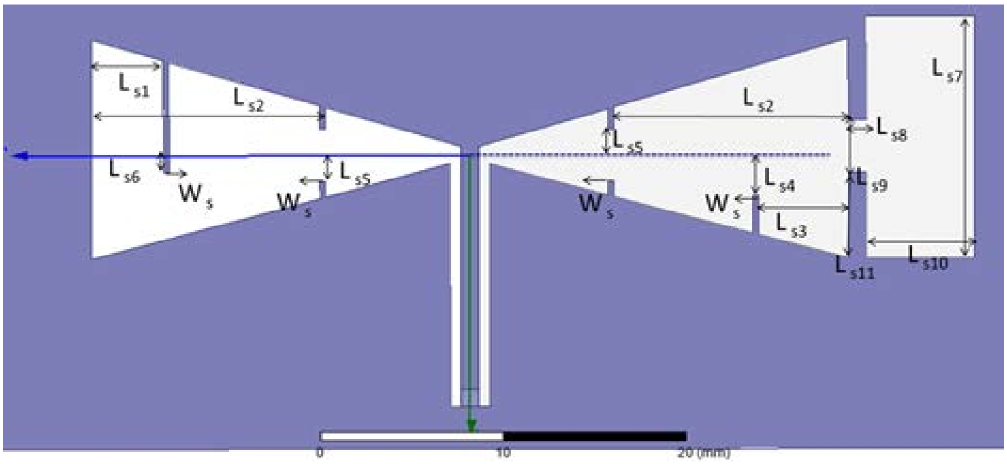


Figure 2 A loaded bowtie antenna element structure with the following dimensions: Ls1=4 mm. Ls2= 13 mm, Ls3=5 mm, Ls4=2.4 mm, Ls5=1.5 mm, Ls6=1 mm, Ls7=14 mm, Ls8=1 mm, Ls9=3 mm, Ls10=6 mm, Ls11=5 mm

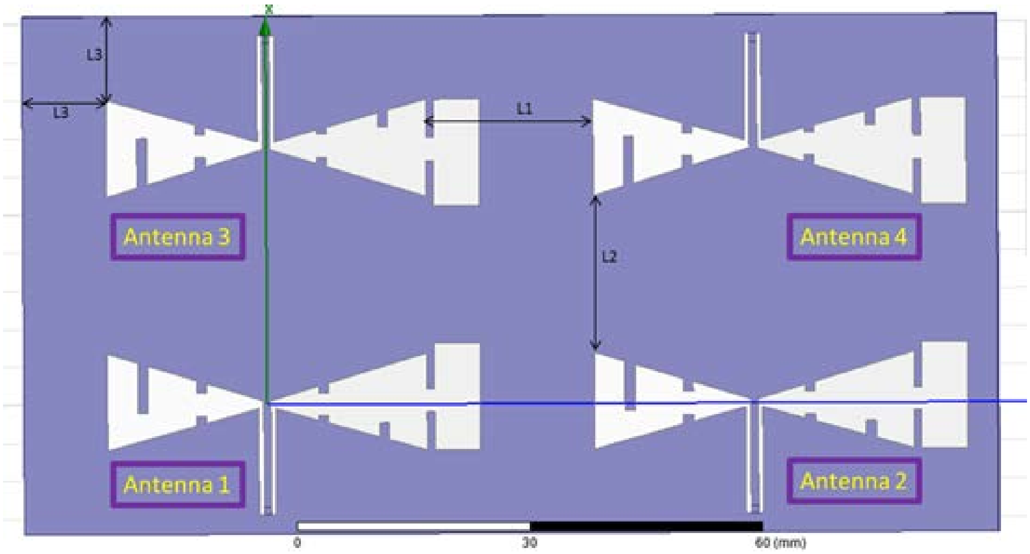


Figure 3 The MIMO antenna structure with the following dimensions: L1=22 mm, L2=20.6 mm and L3=11 mm

3. SIMULATION RESULTS AND DISCUSSION

The original return loss for the unloaded single antenna is shown in Figure 4 [24]. FR4_epoxy having a 4.4 dielectric constant material was used as a substrate for the MIMO antenna. Figure 5 shows the return loss for a single loaded antenna element with a variable Ws. It can be seen from Figure 5 that a single loaded MIMO antenna element can operate at six different frequency bands by changing the width of the metallic strips on the surface of the loaded antenna. Figure 6 shows the return loss for the MIMO bowtie antenna. It can be noticed that the MIMO antenna is able to operate at six frequency bands resulting from each one of the loaded bowtie MIMO antenna elements with the following return losses: S11, S22, S33, and S44.

The mutual coupling results between the MIMO antenna elements are shown in Figures 7-10 and it can be seen that the mutual coupling parameters S12, S13, S14, S23, S24, and S34 are lower than the return losses S11, S22, S33 and S44 at each of the operating frequency bands when the width of the metallic strips Ws is 1.66mm. This width value was obtained using Particle Swarm Optimization technique with the following constraints between the return losses and mutual coupling parameters: S11 >=S12, S22 >=S24, S33 >=S31, and S44 >= S42. Figure 11 shows the radiation pattern for the original single unloaded bowtie antenna in addition to other antenna parameters like the radiation efficiency [24].

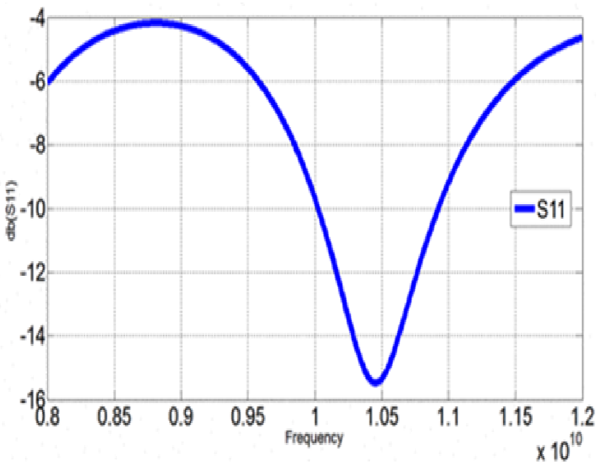


Figure 4. Simulation result for S11 for the unloaded bowtie antenna [27]

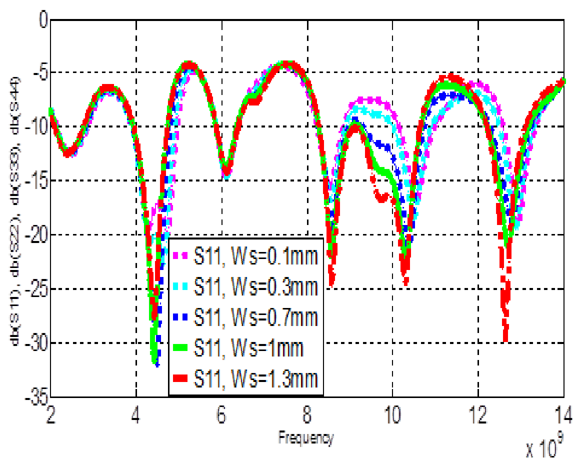


Figure 5. Return loss S11 for the single loaded antenna

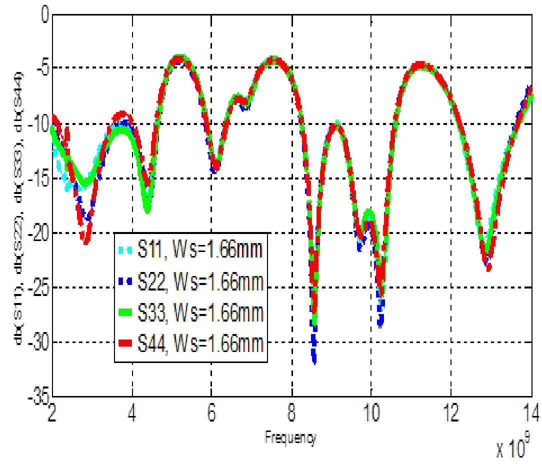


Figure 6. Return losses S11, S22, S33 and S44 for the MIMO antenna

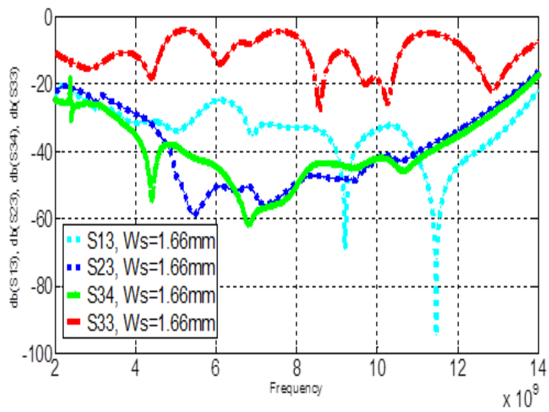


Figure 7. Mutual coupling return losses S13, S23 and S34 for the MIMO antenna

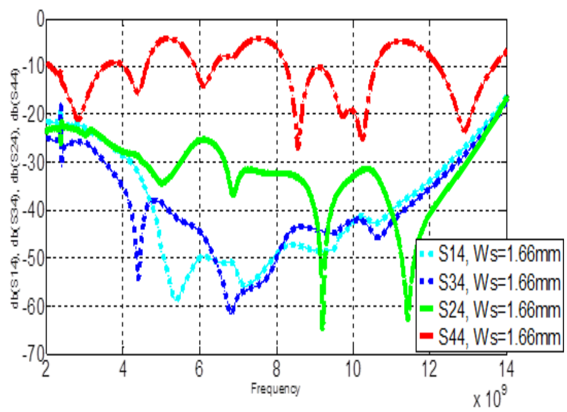


Figure 8. Mutual coupling return losses S14, S34 and S24 for the MIMO antenna

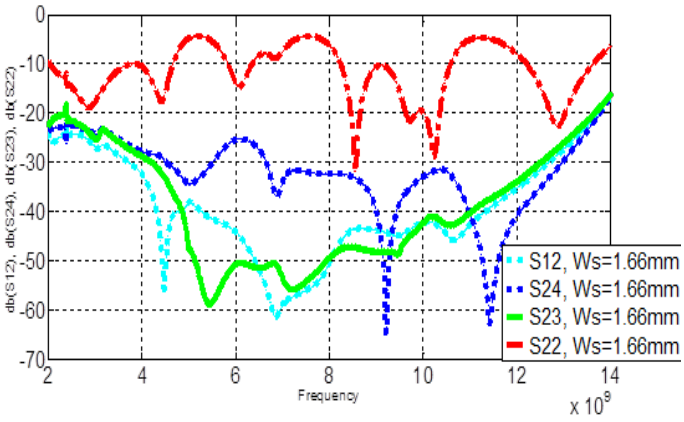
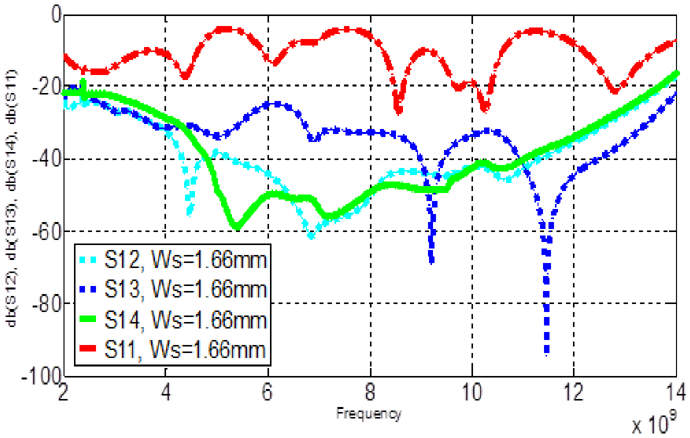
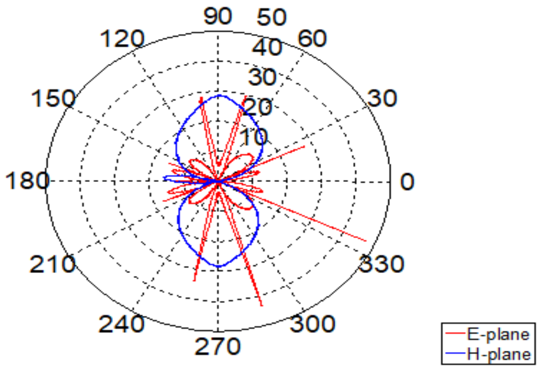


Figure 9. Mutual coupling return losses S12, S24 and S23 for the MIMO antenna



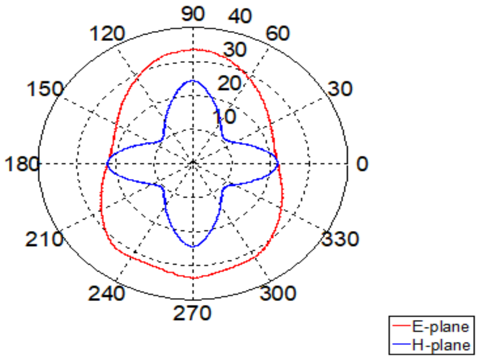


Quantity	Freq	Value
Max U	10.5GHz	0.212329 W/sr
Peak Directivity		2.766441
Peak Gain		2.748283
Peak Realized Gain		2.668264
Radiated Power		0.964512 W
Accepted Power		0.970884 W
Incident Power		1.000000 W
Radiation Efficiency		0.993436
Front to Back Ratio		1.273374
Decay Factor		0

Figure 10. Mutual coupling return losses S12, S13 and S14 for the MIMO antenna

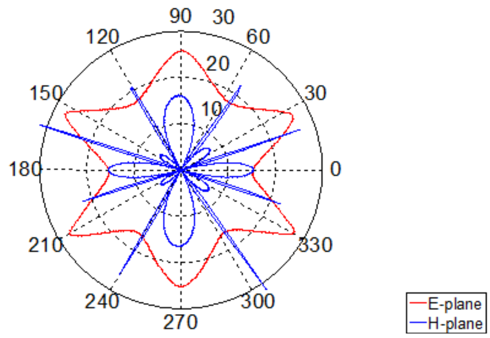
Figure 11. Radiation pattern of the original single unloaded bowtie aperture antenna at 10.5 GHz

Figures 12-17 are for the radiation patterns and other parameters for the MIMO loaded antenna. It can be noted that the radiation efficiency value for the MIMO antenna is above 90% at the frequency band of 2.4 GHz and the efficiency value is above 80% at the frequency bands of 4.4 GHz and 6.1 GHz. The H-plane and E-plane of the radiation pattern are symmetric for the frequency bands of 2.4 GHz, 4.4 GHz, 6.1 GHz, and 8.5 GHz.



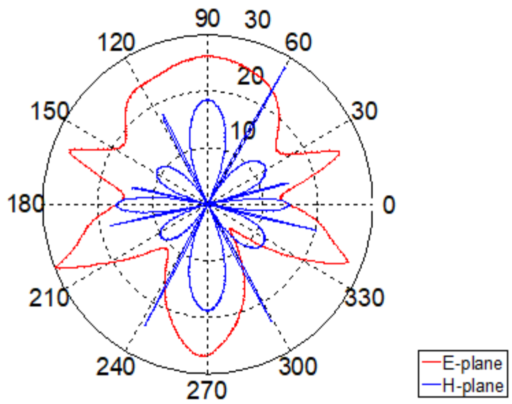
Quantity	Freq	Value
Max U	2.4GHz	0.124831 W/sr
Peak Directivity		0.475341
Peak Gain		0.437633
Peak Realized Gain		0.392176
Radiated Power		3.300166 W
Accepted Power		3.584517 W
Incident Power		4.000000 W
Radiation Efficiency		0.920672
Front to Back Ratio		1.250085
Decay Factor		0

Figure 12. Radiation pattern for the MIMO antenna at 2.4 GHz



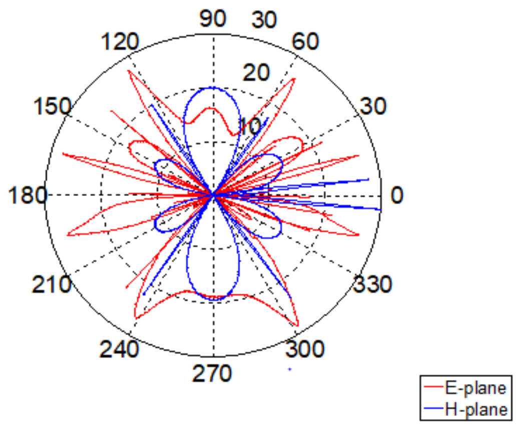
Quantity	Freq	Value
Max U	4.4GHz	0.494197 W/sr
Peak Directivity		1.860011
Peak Gain		1.56781
Peak Realized Gain		1.552604
Radiated Power		3.338913 W
Accepted Power		3.961204 W
Incident Power		4.000000 W
Radiation Efficiency		0.842903
Front to Back Ratio		1.559555
Decay Factor		0

Figure 13. Radiation pattern for the MIMO antenna at 4.4 GHz



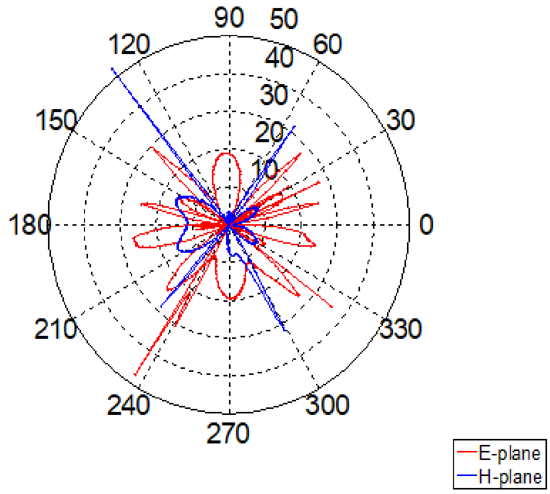
Quantity	Freq	Value
Max U	6.1GHz	0.646758 W/sr
Peak Directivity		2.62885
Peak Gain		2.123217
Peak Realized Gain		2.0319
Radiated Power		3.091693 W
Accepted Power		3.827965 W
Incident Power		4.000000 W
Radiation Efficiency		0.80766
Front to Back Ratio		1.307033
Decay Factor		0

Figure 14. Radiation pattern for the MIMO antenna at 6.1 GHz



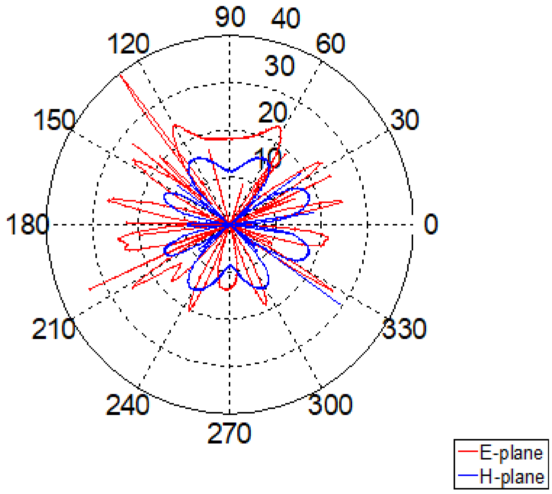
Quantity	Freq	Value
Max U	8.5GHz	1.738396 W/sr
Peak Directivity		7.34928
Peak Gain		5.472787
Peak Realized Gain		5.461461
Radiated Power		2.972515 W
Accepted Power		3.991723 W
Incident Power		4.000000 W
Radiation Efficiency		0.74467
Front to Back Ratio		5.152409
Decay Factor		0

Figure 15. Radiation pattern for the MIMO antenna at 8.5 GHz



Quantity	Freq	Value
Max U	10.25GHz	1.112328 W/sr
Peak Directivity		4.835576
Peak Gain		3.505287
Peak Realized Gain		3.494563
Radiated Power		2.890711 W
Accepted Power		3.987763 W
Incident Power		4.000000 W
Radiation Efficiency		0.724895
Front to Back Ratio		3.999848
Decay Factor		0

Figure 16 Radiation pattern for the MIMO antenna at 10.25 GHz



Quantity	Freq	Value
Max U	12.8GHz	1.461544 W/sr
Peak Directivity		6.527023
Peak Gain		4.688321
Peak Realized Gain		4.591684
Radiated Power		2.813953 W
Accepted Power		3.917551 W
Incident Power		4.000000 W
Radiation Efficiency		0.718294
Front to Back Ratio		1.854764
Decay Factor		0

Figure 17 Radiation pattern for the MIMO antenna at 12.8 GHz

The following Figure 18 and Figure 19 Show the real and imaginary impedance for the original unloaded antenna and the MIMO antenna respectively. It can be seen that the MIMO antenna is capable of operating at six different frequency bands as the value of the real impedance is very close to 50 Ohms at the six operating frequency bands. The following results in Figures 20-25 show the MIMO antenna Surface current distributions. It can be noticed that the current distribution is concentrated mostly at the center of every MIMO antenna element in addition to the loaded metallic strips at the sides of each MIMO antenna element.

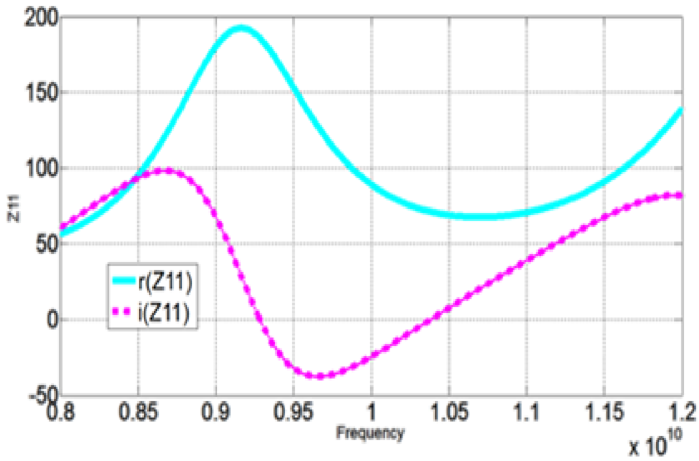


Figure 18. The impedance for the original unloaded antenna [27]

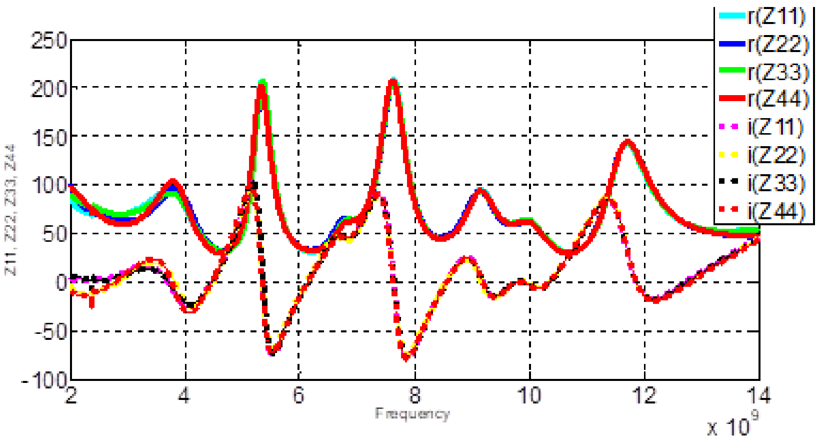


Figure 19. The real and imaginary impedance of the MIMO antenna

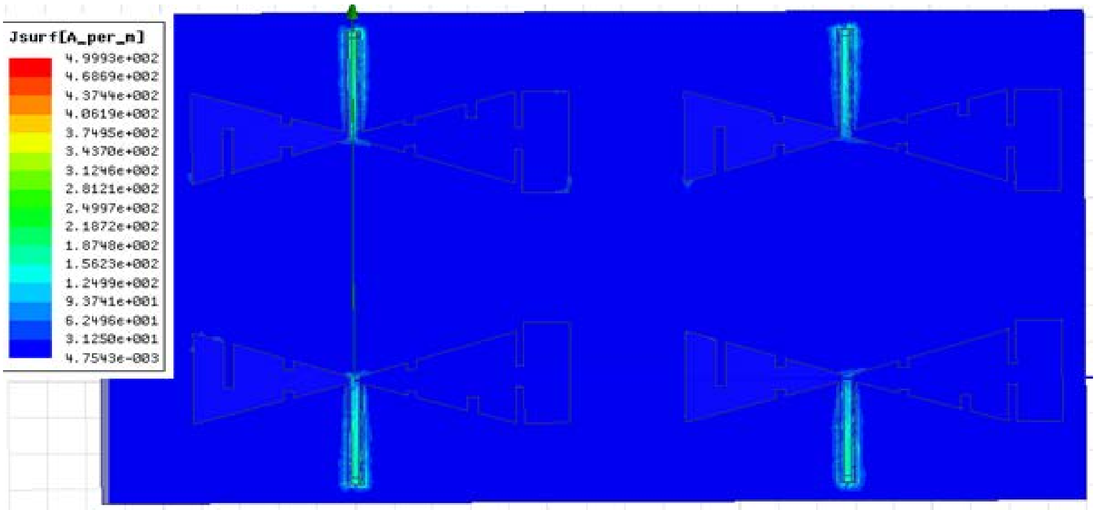


Figure 20. Surface current distribution of the MIMO antenna at 2.4 GHz

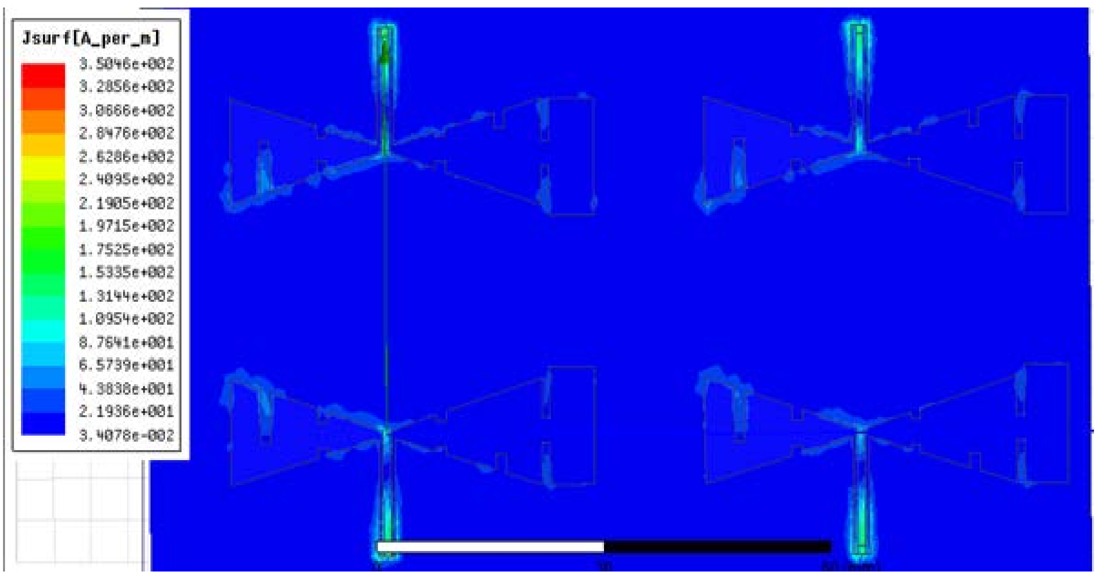


Figure 21. Surface current distribution of the MIMO antenna at 4.4 GHz

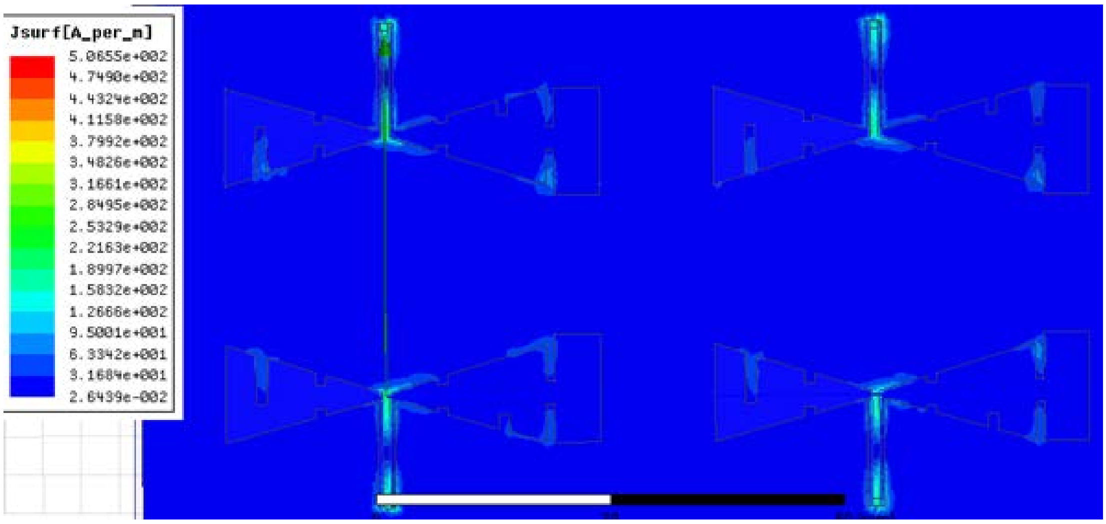


Figure 22. Surface current distribution of the MIMO antenna at 6.1 GHz

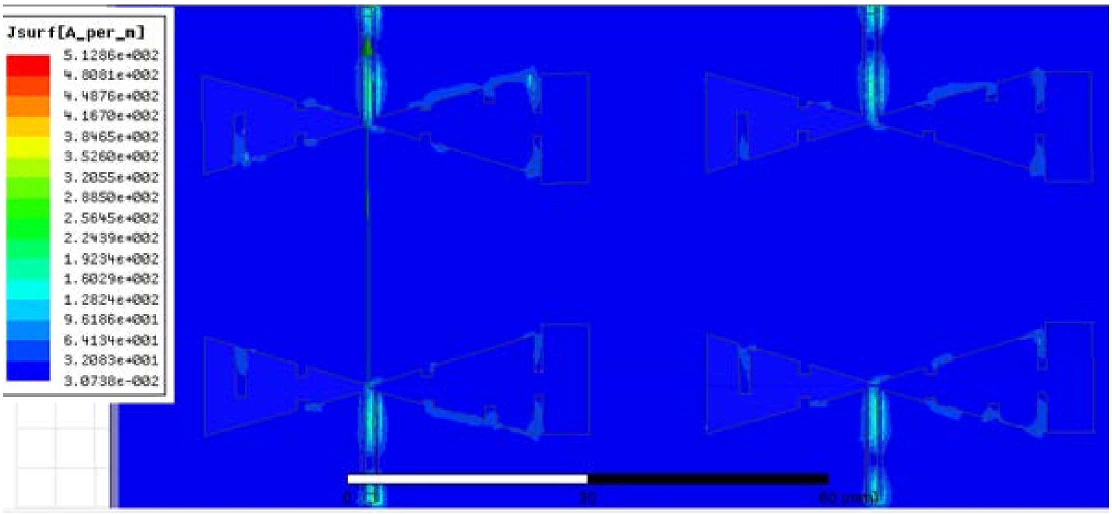


Figure 23. Surface current distribution of the MIMO antenna at 8.5 GHz

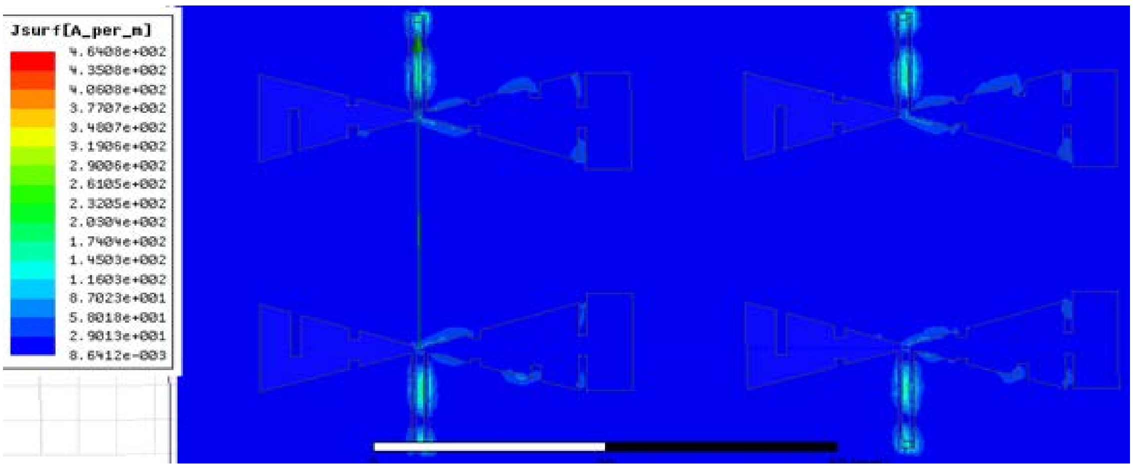


Figure 24. Surface current distribution of the MIMO antenna at 10.25 GHz

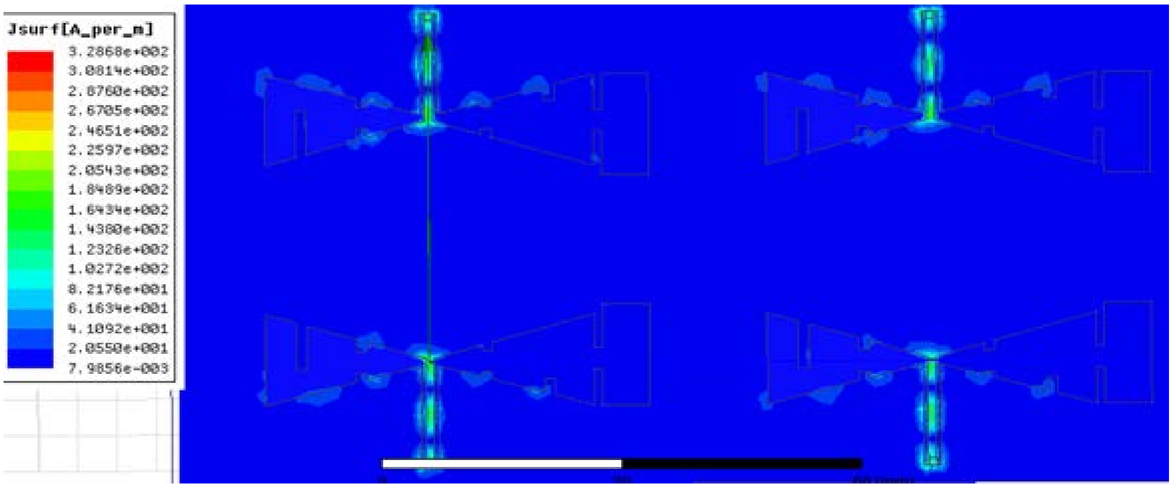


Figure 25. Surface current distribution of the MIMO antenna at 12.8 GHz

The following Table 1 demonstrates comparison between the proposed MIMO bowtie antenna design and other proposed MIMO antenna designs from the previous work. The proposed MIMO bowtie antenna does not use extra components on the surface of the MIMO antenna to reduce the mutual coupling between the MIMO antenna elements. The proposed MIMO antenna design has small surface area and low surface structure complexity compared to most of other MIMO antenna designs in the previous work in addition to more operational frequency bands compared to other MIMO antenna designs in the previous work.

Table 1. Comparison between the Proposed MIMO Antenna Design and Other Proposed Designs

MIMO antenna designs	Using extra components to reduce the mutual coupling	MIMO Antenna structure complexity	MIMO Antenna substrate surface area	Operational frequency bands
The design in [19]	no	high	large	2.25-2.26 GHz and 4.95-6 GHz
The design in [22]	yes	high	100x40	0.7 GHz,1.8 GHz,1.9 GHz, 2.3 GHz,2.5 GHz, and 2.4 GHz WLAN
The design in [23]	yes	high	142x90	1.8 GHz, 2.4 GHz, 3.5 GHz, 5.2 GHz, and 5.5 GHz
The design in [24]	yes	high	270x210	1.8 GHz and 2.3 GHz
The design in [25]	yes	high	n/a	1.8 GHz and 2.35 GHz
Our proposed design	no	Low	128x68	2.4 GHz, 4.4 GHz, 6.1 GHz, 8.5 GHz, 10.25 GHz, and 12.8 GHz

4. CONCLUSION

The simulated MIMO hexa-band bowtie antenna using HFSS was able to operate at six different frequency bands: 2.4 GHz, 4.4 GHz, 6.1 GHz, 8.5 GHz, 10.25 GHz and 12.8 GHz. The width of the loaded metallic strips on the surface of MIMO antenna elements was determined using Particle Swarm optimization technique to be 1.66 mm and that resulted in a very low mutual coupling between every MIMO antenna element at all the operating frequency bands. The MIMO antenna has an efficiency value above 90% at 2.4 GHz frequency and an efficiency value above 80% at the 4.4 GHz and 6.1 GHz frequency bands. It was shown that the H-plane and E-plane are symmetric for the 2.4 GHz, 4.4 GHz, 6.1 GHz, and 8.5 GHz frequency bands. The surface current distribution for each MIMO antenna element is concentrated mostly at the center in addition to the loaded metallic strips.

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