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UWB-MIMO HIGH DIVERSITY ANTENNAOF FOUR RADIATORSWITH SINGLE-BANDREJECTIONFOR WIRELESS APPLICATIONS

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ABSTRACT

In this paper, Ultra-Wideband Multi-Input-Multi-Output (UWB-MIMO) antenna with band-notched features is introduced. The band notch of the antenna is designed by inserting T-strip into the radiating patch to eliminate the interference with WiMAX applications from 3 to 4 GHz. To improve the isolation and the diversity between the radiators, the antenna radiators are arranged orthogonally and decoupling structure is added between them. The proposed antenna has a compact sizeof 42×42 mm^{2}and its bandwidth extends from 2.5 GHz up to 12 GHz. This antenna has been manufactured and its characteristics have been measured. The results showed that the proposed UWB-MIMO antenna has a good performance with bandwidth from 2.5 GHz to 12 GHz, excluding the notched band for WiMAX applications. Furthermore, it has high isolation with a value higher than 18 dB and with a correlation coefficient lowers than 0.05 through the operated frequency bands. These properties made it good candidate for diversity

Keywords:*MIMO antenna; UWB antenna;High isolation;WiMAX;Band notch*.

1. INTRODUCTION

The frequency band3.1 GHz–10.6 GHz became available for wireless systems when the Federal Communications Commission (FCC) approved it[1]. The wideband technology has several advantages, such as high capacity, low power level, and high security. However, there are other narrowband communication systems which may cause possible interference of electromagnetic waves of different applications, such as WiMAXat 3.3–3.7 GHz and WLAN at 5.15– 5.825 GHz.To reduce the interference with other UWB applications, antennas with band-notched features have been studied. In the literature, several methods were reported, such as using a different shape of parasitic strips and slots etched in the radiating patch [5, 7], two open-loop resonators [8-9], parasitic strip lumped capacitors and Defect Ground Structure (DGS) technique [10].

Moreover, UWB technology has more advantages, but it is limited by the multipath problem. To solve this problem, a MIMO (multiple-input multiple-output) technology using multiple antennas at the transmitter and receiver is merged with UWB technology to enhance the quality of the system and increase the channel capacity. Several challenges arise when designing the MIMO antenna; the main issue is designing MIMO antenna with compact size and low correlation and with an increased number of elements in the antenna to improve the link data rate and high isolation to be used in portable devices. To increase the isolation in the system, there should be a distance between the antenna elements, which in turn increases the antenna size. Therefore, various techniques are used for improving the system's isolation

Several studieshave used many types of decoupling techniques to reduce the correlation among the radiation elements as mentioned in [11-15].

In [11], two rectangular-shaped DGS are etched in serial on the ground plane with an area of 2.2×12.97 mm^2. These slots etched into the center of the ground near the feed line act as a shield between the MIMO elements. In [14], a neutralization line with two metal strips and a metal circular disc is inserted between the radiating elements. In [15], for improving the UWB performance, floating parasitic decoupling is placed between the radiating elements on the backside of the antenna. The decoupling network has a significant effect on improving the isolation of the MIMO system; however, it has a complex structure and the design is large in size. Recently, simple stubs or strips with different shapes were placed between the radiating elements [16-17], acting as reflectors

This paper introduces a new design of the UWB-MIMO antenna with a small size and notched band from 3 to 4 GHz for WiMAX.The proposed antenna is fabricated on a low-cost FR-4 substrate that has a thickness of 1.6 mm with a compact size of 42×42 mm^2.The antenna was simulated using the CST Microwave Studio program. Four identical radiators are placed perpendicular to each other with four stubs between them to enhance system isolation. The band-notched characteristics were achieved by etching a T-strip on the radiating elements. The simulated antenna was confirmed with the measured one.All results proved that the proposed antenna can be used for UWB applications.

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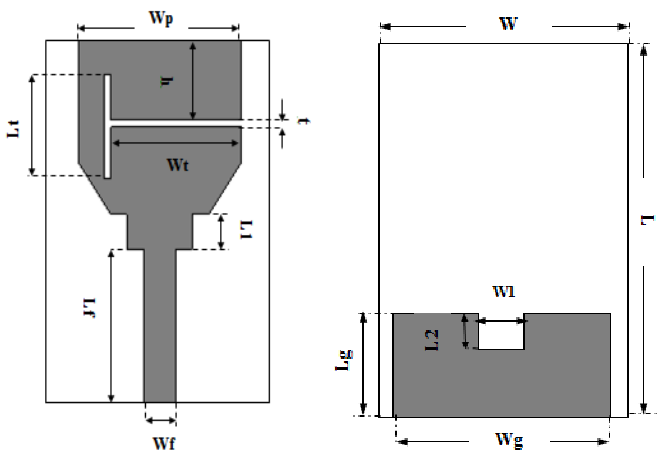
2. Single-Element Configuration

A single UWB radiator with a single band-notched feature is displayed in Fig. 1 and its dimensions are shown in Table 1.The radiating element was designed in a rectangular shape with a stepped cut in the lower part of the radiating element and with a partial ground plane for achieving the desired wide bandwidth. The layout of the antenna was designed on a low-cost material (FR4) with a permittivity of 4.4 and a height of 1.6 mm. To achieve the desired band-notched frequency from 3 to 4 GHz (WiMAX applications), a T-shaped strip equivalent to quarter wavelength was etched into the radiating element (Fig.1). The notched band of the antenna can be controlled by adjusting the length of the T-shaped strip. The total length of the strip is 14 mm (Lt + Wt) that is the quarter wavelength at the center of the notch (3.5 GHz) [2]. The simulation results of the single-element antenna are shown in Fig.2. The return loss of the antenna has a value lower than −10 dB through the operating frequency range. However, at the 3–4 GHz notchedband, its value increases to around −1 dB. The proposed antenna has compact dimensions ($14 \times 21\ mm^2$). It operates at2.5–12 GHzband that is suitable for UWB applications. A T-shaped length used for realizing a band notch frequency can be calculated using the following equation [2]:

$$L_{total} = \frac{\lambda g}{4} = \frac{c}{4 f_{notch}\sqrt{\varepsilon eff}} \quad (1)$$

$$\text{where} \varepsilon eff = \frac{\varepsilon r + 1}{2}$$



(a) (b)

Fig. 1: The proposed antenna layout for a single element: (a) the top layer and (b) the bottom layer.

Table 1: Values of parameters of the initial monopole antenna.

Parameter	Value	Parameter	Value
W	21	Lt	6
L	14	Lf	9
Wg	12	Wt	8
Lg	6	Wf	2
W1	3	Wp	10
L1	2	h	5
L2	2	t	0.2

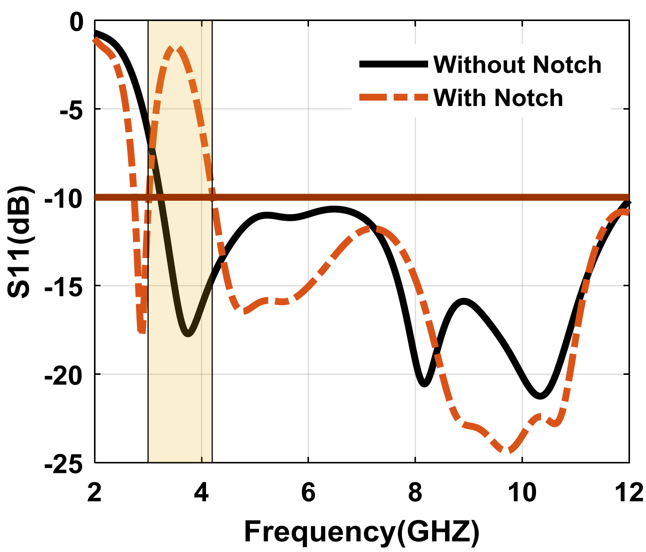


Fig. 2: The simulated return loss results of a single-element UWB antenna.

3. Antenna Parametric Study Results

The design of the proposed antenna has the availability of variation in the design parameters to provide a good design with high performance. More than one parameter in the proposed design has a significant effect on antenna performance, such as length, width, and position of the slot. These parameters affect the notched band characteristics of the design, which are described in this section. Moreover, these parameters are studied when only one parameter is variable and the otherparameters are kept constant at their original values.

a. Effect of the Length of the Slot

Fig 3 illustrates the simulated return loss of the proposed design at different lengths of the T-slot. The center frequency of the rejected notch is changed by changing the slot's length. When the slot's length is increased, the center frequency of the notched band is moved to a lower value because by increasing the slot's length, the equivalent reactive components of the antenna are increased leading to a decrease in the resonance frequency.

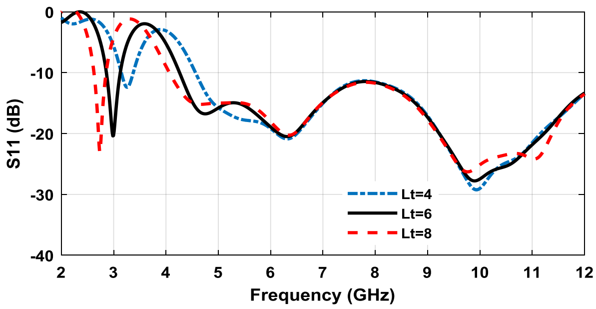


Fig. 3: Simulated S11 of the antenna with variations of the length of the radiator's slot.

b. Effect of the Width of the Slot

The proposed antenna is simulated at different values of the slot's width. Fig 4 shows the effect of the slot's width on the antenna performance. By increasing the slot's width, the center frequency of the notched band is shifted to a lower value.

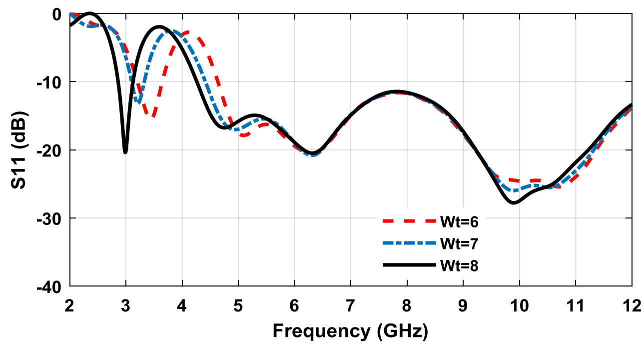


Fig. 4: Simulated S11 of the antenna with variation in the width of the radiator's slot.

c. Effect of the Position of the Slot

Fig 5 illustrates the effect of the position of the T-slot etched on the radiator on the return loss of the antenna. The return loss of the proposed antenna is simulated by different values of h. These values are 4 mm, 5 mm, and 6 mm. The position of the slot has a significant effect on the band rejection characteristics. With increasing distance h, the notched band becomes wider.

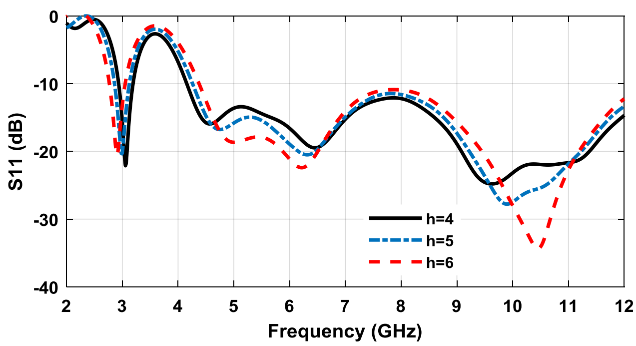
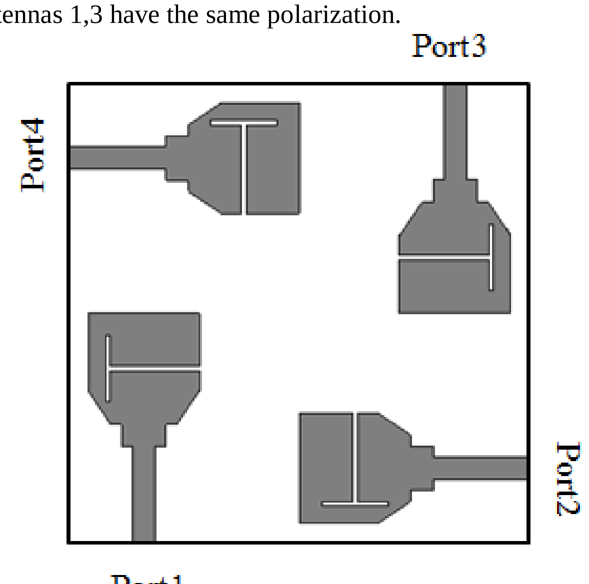


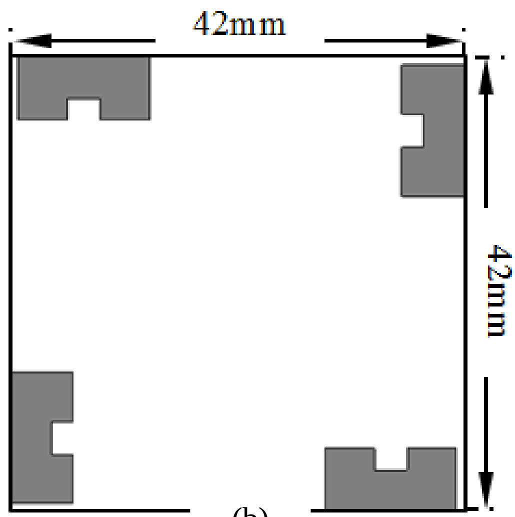
Fig. 5: Simulated S11 of the antenna with variation in the position of the radiator's slot.

4. Initial Design of a Four-ElementMIMO Antenna

The MIMO antenna layout is shown in Fig. 6 which has a compact size of 42 mm × 42 mm and consists of four symmetric elements. The antenna is printed on the same substrate same as the previous part. The antenna elements were organized orthogonally to each other to enhance the isolation between the proposed design elements without increasing antenna size. Fig.7demonstrates the simulated results ofS-parameters for MIMO design. The four elements of the antenna are identical, so only Port 1 was excited and the other ports were loaded with 50ohms. As shown from the figure, the isolation among the antennas 1,2 and antennas 1,4 equals 20 dB;however, the isolation between 1 and 3 is lower than 15 dB because antennas 1,2 and antennas 1,4 are orthogonal to each other, whereas antennas 1,3 have the same polarization.



(a)



(b)

Fig. 6: Four-element MIMO antenna layout: (a) the top layer and (b) the bottom layer.

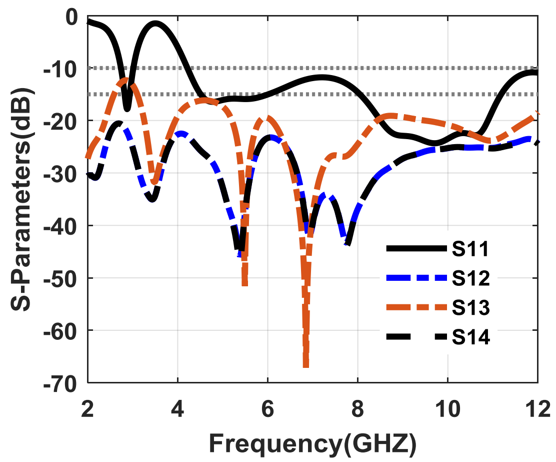
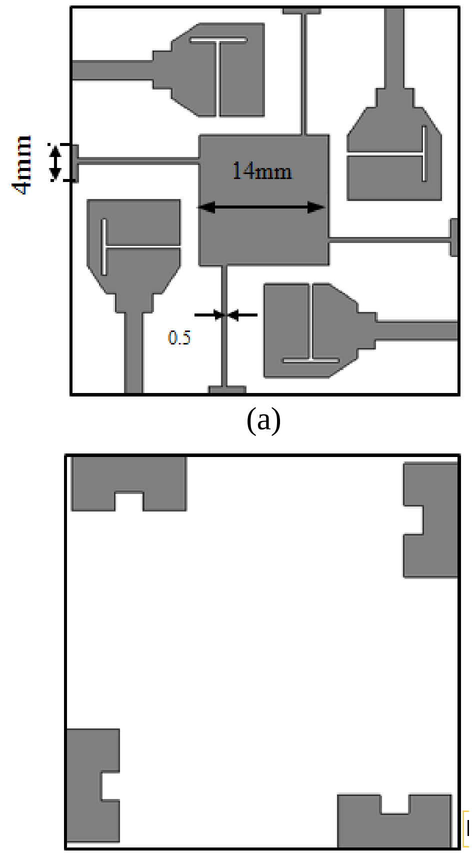


Fig.7: Simulated S-parameters of the MIMO antenna.

5. AProposed MIMO Antenna Structure

The layout of the proposed structure of the UWB-MIMO antenna with a band notch frequency is represented in Fig.8. Its size is equivalent to the previous antenna. To enhance the isolation of the previous design shown in Fig.6,a decoupling structure has been added between the radiating elements.



(a)

(b)

Fig. 8: Layout of the proposed antenna:(a) the top layer and (b) the bottom layer.

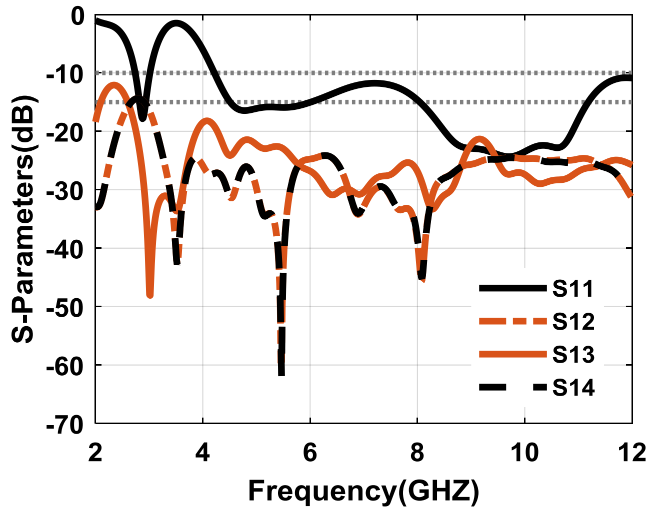
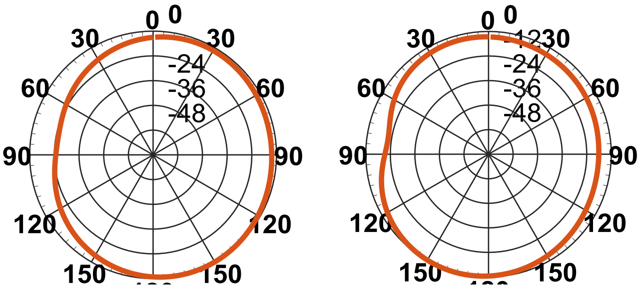


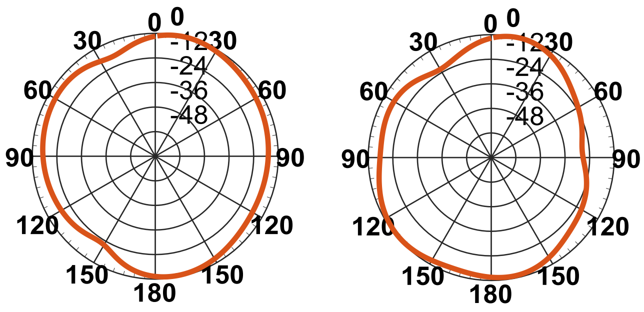
Fig.9: Simulated S-parameters of the proposed antenna.

The simulated results of the proposed band-notched UWB-MIMO antenna are shown in Fig .9. A T-shaped stub was used to get a band notch around 3.5 GHz to prevent interference with WiMAX systems. To further improve the isolation between the antenna elements, parasitic stubs were placed between them as a decoupling structure. The decoupling structure was printed on the top layer of the substrate as in Fig.8. Without using the isolation technique, the couplingbetween Ports 1 and 3 (S_{13}) is lower than −15 dB because these two ports have the same orientation.The stubs can act as a reflector and decrease the surface current between antenna elements. The stubs have aneffect on the isolation between antennaelements. The isolation is around 18 dB within the antenna operated frequency bands.

The radiation characteristics of the proposed antenna have been measured at Port 1 and other ports are terminated with 50 Ω load. The simulated radiation patterns (x-z and y-z planes) at 3.5 and 10 GHz are plotted in Fig. 10, where the radiation pattern of the designed antenna is omnidirectional at x-z and y-z planes.



(a) (b)



(c) (d)

Fig. 10:Normalized simulated radiation pattern of the proposed antenna of Port 1: (a) x-z plane at 3.5 GHz; (b) y-z plane at 3.5 GHz; (c) x-z plane at 10 GHz; (d) y-z plane at10 GHz.

Fig 11 shows the simulated results of peak gain and the total efficiency of the proposed antenna at Port 1. The average peak gain is around 3.5 dB through the whole band, except at the notched frequency it drops to −3 dB. The simulated efficiency of the antenna is above 85% through the UWB spectrum and drops to 20% at the notch 3.5 GHz.

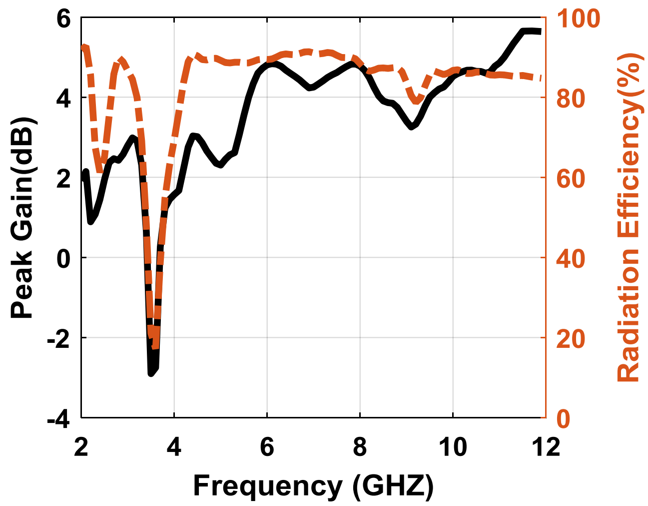
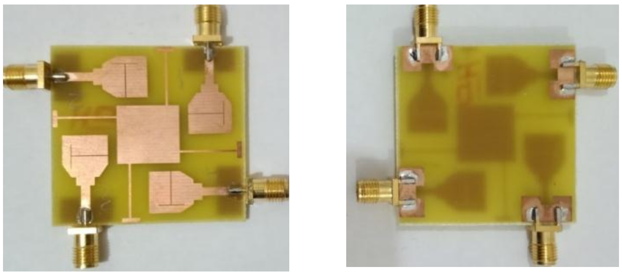


Fig. 11: Simulated realized peak gain and radiation efficiency of the proposed design.

6. Results and Measurements

The proposed antenna has been fabricated and measured.Fig.12shows the prototype of the proposed UWB-MIMO antenna. The antenna measurements have been realized using the vector network analyzer. Fig.13 and Fig.14demonstrate the measurements and simulation results of return loss and the coupling between antenna elements of the proposed design when the excitation has been fed on Port 1 and other ports have been ended with a 50-ohm load. The measured results show that the proposed design provides the −10 dB matched impedance from 2.5 to 12 GHz, with a notched band from 3 to4 GHz. It is clear that the measured S21 and S41 are below −22 dB and S31 is lower than −18 dB through the bandwidth designed range. The measured and simulated results have the same trend, confirming the antenna design.



(a) (b)

Fig. 12: The prototype of the proposed antenna: (a) top layer; (b) the bottom layer.

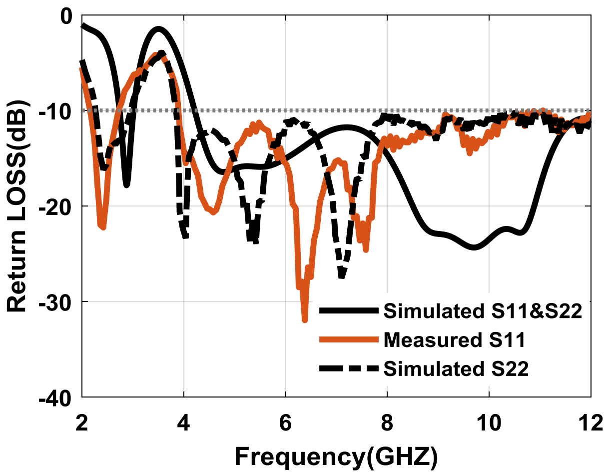


Fig. 13: The measured and simulated return loss of the proposed antenna.

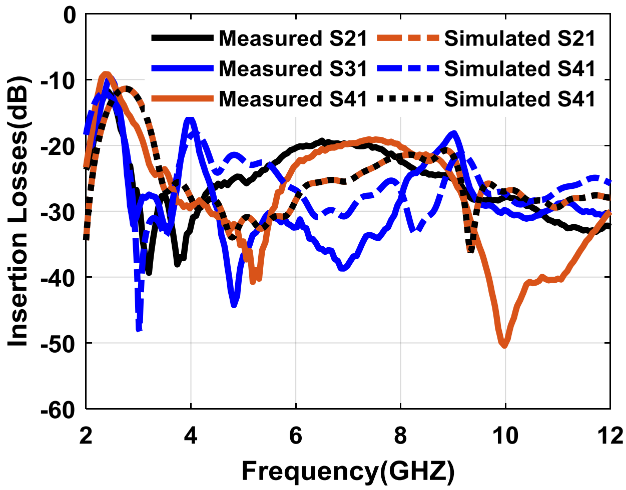


Fig. 14:The measured and simulated insertion of the proposed design.

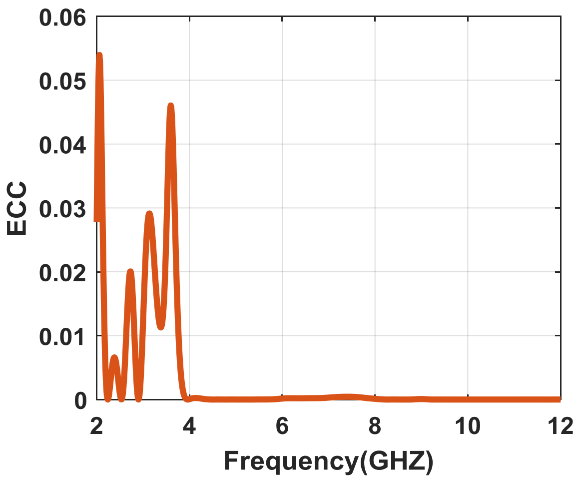
7. Diversity Performance

The MIMO antenna diversity performance can be obtained by developing the correlation between the antenna elements.This can be achieved by studying the envelope correlation coefficient (ECC) and diversity gain (DG). The ECC is utilized to show the correlation between antenna radiating elements and it is better to have a smaller value less than 0.5 [5], calculated in Eq. 2.As shown in Fig.15a, ECC is below 0.05 through the entire bandwidth which proved that our antenna is a good choice for wireless communication systems.

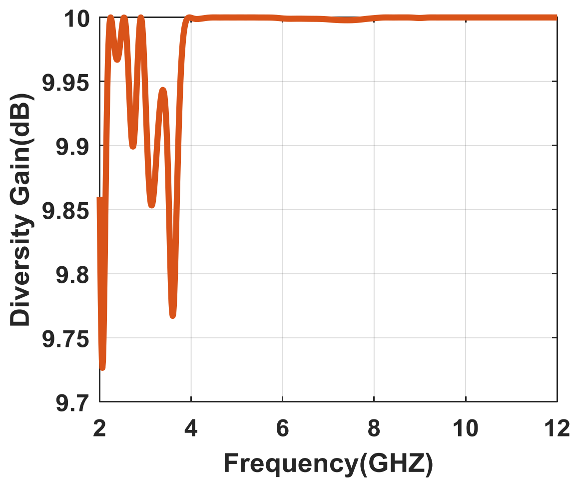
$$ECC = \frac{|s_{ii}^{*}s_{ij} + s_{ji}^{*}s_{jj}|^2}{\left(1 - \left(|s_{ii}|^2 + |s_{ji}|^2\right)\right)\left(1 - \left(|s_{jj}|^2 + |s_{ij}|^2\right)\right)} \quad (2)$$

DG is coupled with ECC and can be calculated using Eq. 3, as shown in [5]. Fig. 15b shows the DG of the proposed antenna. It has a value of 10 dB through the operating band, excluding the notched band frequency.

$$DG = 10 \times \sqrt{1 - |ECC|} \quad (3)$$



(a)



(b)

Fig. 15: (a) ECC and (b) diversity gain.

Table2 demonstrates the comparison between the proposed antenna and the other previous works of researchers. It is noticed that antennas in [3] and [4] have a smaller size than the proposed one;however, they have only two elements and lower isolation. When the proposed antenna is compared with antennas in [5], [6],[18], and [19], it is observed that our proposed design has a smaller size and low correlation between elements. This indicates that the proposed antenna is advantageous because of the small size and high performance making it suitable for UWB systems.

Table 2: Comparison between the proposed design and previous research.

Ref	Antenna size	B .W	No of radiators	isolation	notches
This work	42*42	2.5-12	4	<-18	3-4
[3]	50*28	2.8-11.5	2	<-16	3.3-3.9
[4]	38.5*38.5	3.08-11.8	2	<-15	5.03-5.95
[5]	44*44	2.95 -10.8	4	<15.5	5.10 - 5.95
[6]	48*48	2.5 - 12	2	<15	5.1–6
[18]	50*50	2.1-12	4	>17	4.9-6.4
[19]	50*50	2- 12	4	>17	4.91 - 6.41

CONCLUSIONS

A MIMO antenna with four radiators was introduced for UWB applications. Each radiator on the MIMO design has a rectangular shape.Moreover, a bandnotch was realized using a T-shaped parasitic strip in the radiating element to reduce the interference with WiMAX applications (3-4 GHz).The antenna proposed here was designed on a low-cost material (FR-4) with compact size of 42×42 mm^2, which can be operated through a band from 2.5 to 12 GHz. It is characterized by return loss, realized peak gain, and radiation features. All results of simulations confirm the efficient use of the proposed antenna for UWB applications.

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تصميم هوائي ذات حجم صغير ونطاق ترددي واسع وله أكثر من ادخال واخراج مع حذف حيز ترددي للتطبيقات الميكرويفية

الملخص:

لقد قامت لجنة الاتصالات الفدرالية في الولايات المتحدة الامريكية عام 2002 بتحديد الحيز الترددي من 3.1 الي 10.6 جيجا هرتز لتطبيقات الاتصالات الفائقه الاتساع الترددي .حيث يستخدم هذا النطاق الترددي المتسع في العديد من التطبيقات.

ولكن يوجد العديد من التطبيقات التي يمكن أن تتداخل مع تلك التطبيقات التي تعمل في الحيز الترددي من 3.1 الي 10.6 ميجا هرتز مثل ترددات الشبكه المحلية اللاسلكيةWLAN وكذلك شبكات ال .WiMAX ،لذلك عند تصميم هوائي ذو حيز ترددي واسع لابد من ايجاد طريقة لحجب التطبيقات التي تقع تردداتها في حيز النطاق الترددي الواسع وذلك لمنع التداخل بين تلك التطبيقات.

ان أنظمه الاتصالات الحديثه تتطلب رفع سرعة نقل البيانات ،وذلك يمكن الحصول عليه من خلال دمج تقنية النطاق الترددي الواسع وتقنية الهوائيات متعددة المداخل والمخارج والتي لها القدره علي رفع سرعة نقل البيانات بشكل كبير.

في هذه الورقه العلميه تم تقديمتصميم هوائي ذو حيز ترددي واسع مكون من آربعة عناصر ارسال واستقبال وعمل قطع علي شكل حرف ت في العنصر المرسل لحذف حيز ترددي من 3الي 4 لتجنب التداخل مع التطبيقات الأخري.تم عرض النموذج والنتائج التي تم التوصل اليها باستخدام برنامج CST والنموذج المقترح ذات حجم صغير وعزل عالي بين عناصر التصميم ويعمل علي نطاق ترددي واسع وله خصائص مميزه تجعله مناسب للتطبيقات ذات الحيز الترددي العالي.