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UWB-MIMO Antenna Design with Four Band-Rejection Capability and Isolation

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UWB-MIMO Antenna Design with Four Band-Rejection Capability and Isolation

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KEYWORDS:
Ultra-Wide Band-MIMO antenna, orthogonal symmetrical structure, multi-slot-multi-slit, high isolation, four notched band characteristic

***Abstract*— Multi-element Ultra-Wideband (UWB) antennas with multi-input multiple-output (MIMO) capability are available. Mutual coupling between antenna elements is considerably reduced since this antenna created utilizing contemporary symmetrical shape, orthogonal arrangement technology. In addition, antenna sizes are efficiently miniaturized by applying two sides of symmetric configuration, partial and faulty ground structure, to increase their bandwidth of impedance, they used a decoupling structure in addition to multi-slot and multi-slit systems. The antenna has a low-profile design with a tiny size 40 mm × 47 mm ×1.6 mm. In addition, by combining varied form slots and slits on the circular radiating elements and the decoupling structure, the suggested antenna provides four notched band characteristics. This antenna has a larger bandwidth of (2-11) GHz. In addition, this antenna also has low mutual coupling (<-15dB), (Multiplexing Efficiency<-5.0dB), low envelope correlation coefficient (ECC<0.06, excepting the four notched bands), constant gain, and radiation patterns quasi-omnidirectional throughout the bandwidth impedance. A good output exchange is therefore obtained for the antenna. This antenna might be used in UWB-MIMO wireless communication systems, including portable UWB-MIMO systems.**

I. INTRODUCTION

MULTIPLE antennas are mounted on the transmitter and the receiver together in MIMO systems so that signals with different fading properties can be transmitted and received [1]. This gives multiplexing benefits as well as diversity gains, allowing the channel capacity and connection efficiency to be increased [2]. The mutual coupling in a MIMO device between the antenna components should be at least 15 dB, which may be accomplished to keep the space between the antenna components ≥ µ /2 [3], which µ is the lowest operating wavelength. Though, MIMO antennas scale will increase. The construction of a lightweight, high-isolation MIMO antenna is incredibly difficult.

The goal of this study is to demonstrate a proposed UWB-MIMO antenna with a four-notch band that realizes high impedance matching, and good diversity efficiency across the whole UWB (2-11 GHz).

II. DESIGN AND ANALYSIS OF ANTENNAS

A. Single Element of Antenna

CST software and MATLAB are used to achieve the proposed design and simulation. Fig.1, Table.1 demonstrates the proposed antenna's geometry. It has an FR4 substrate with

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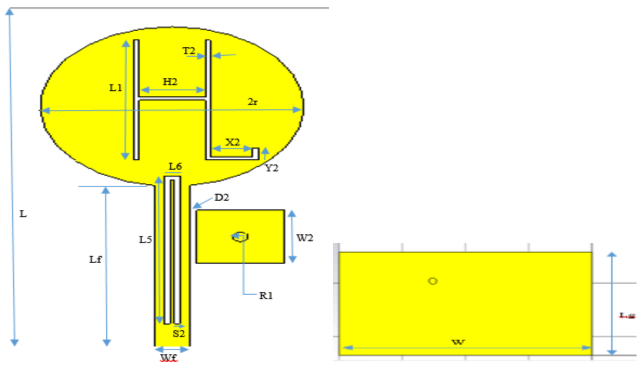
a 4.4 relative permittivity, the width of 0.019 mm, and a total area of 40 ×47 mm^2. A 50 Ω microstrip line feeds the antenna. These four center frequencies are accomplished with a graded H-L slot in an inverted U-shape slot positioned inside the feed line, and the radiation patch. The 1st notch (3.3–3.8 GHz) is mostly governed by the size of the H-L designed slot (L1, H1, X2, and Y2), the 2nd notch (5.1—5.8 GHz) is determined by the size of a mushroom-like electromagnetic band gab EBG (W2 and R1), the 3rd notch (2.2–2.8 GHz) and the fourth one (7.09 – 7.92 GHz) are governed by the dimensions of the inverted U (L6, L5 and S2), respectively.



(a) Top view (b) Back view
Fig. 1. Antenna geometry with four notched bands
(a) Top view (b) Back view

TABLE I
DIMENSIONS OF UWB ANTENNA

Parameter	Value (mm)	Parameter	Value (mm)
W	*40*	*Lg*	*19.3*
L	*47*	*H2*	*5*
H	*1.6*	*T2*	*0.4*
Wf	*2.6*	*X2*	*3.2*
Lf	*20.3*	*Y2*	*1.5*
L1	*15*	*R1*	*0.58*
r	*10*	*W2*	*6.65*
D2	*0.55*	*L5*	*10.5*
S2	*0.46*	*L6*	*1.23*

B. Design of 4-Elements Uwb-Mimo Antenna

Fig.3 illustrates the conformation of four UWB-MIMO antennas. There are four symmetric antenna elements in total. The four antenna elements are orthogonally aligned without the need for any extra construction or decoupling element, which is often used to improve isolation between the antennas. With no decoupling devices, the recommended design of UWB-MIMO antenna ensures that the four input ports are well isolated. The four elements that radiated are positioned on the substrate's top side, whereas the four planes of ground are positioned on the bottom side. Reflection coefficient (S11) indicated as shown in Fig.2 with very good results where S11< -10dB overall the operating band except for the four notches.

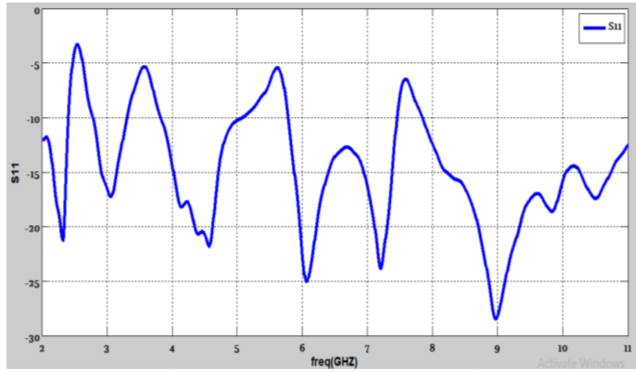


Fig. 2. The S11 of the single antenna design with the four-notched band.

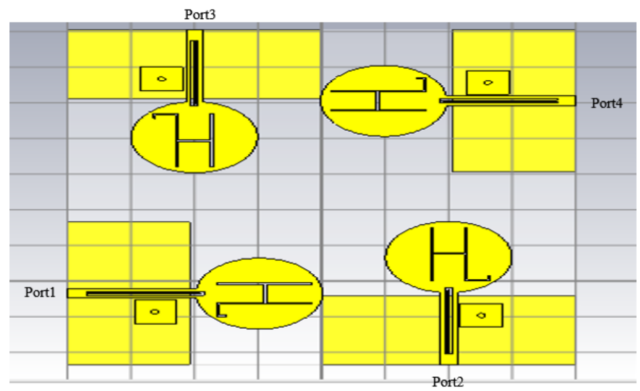


Fig. 3. The proposed antenna layout for UWB-MIMO

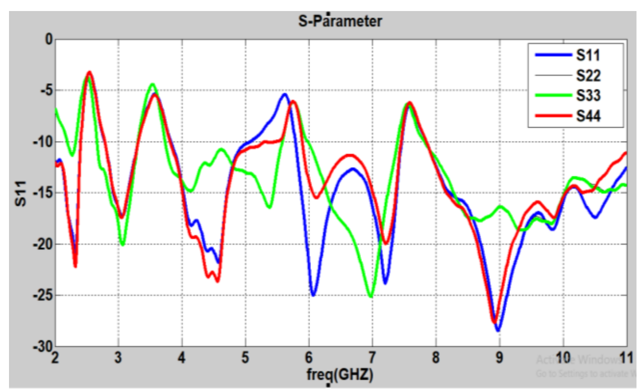


Fig. 4: The S11, S22, S33 and S44 of the MIMO antenna design with four-notched bands

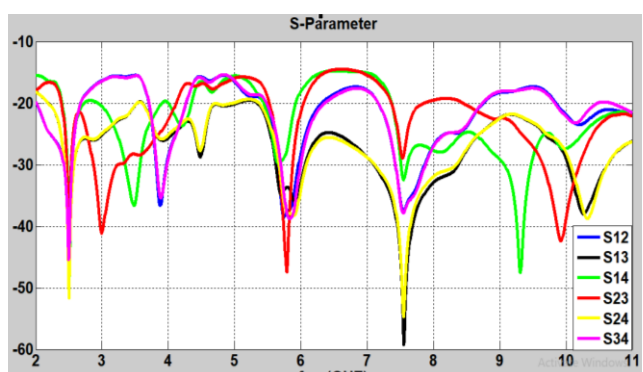


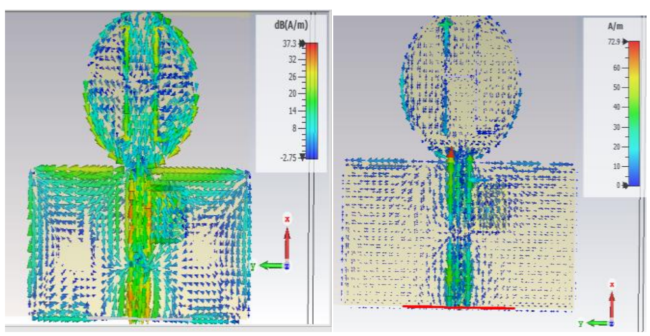
Fig. 5. S-parameter of MIMO antenna S12, S13, S14, S23, S24 and S34

III. SIMULATION OUTCOMES

Except for the four-band rejection, the reflection coefficients, S11 <− 10 dB, are given in Fig 4. One of the four ports in the mutual coupling between elements 1, 2, 3, and 4 is active, while the other three are closed to 50 equivalent matched loads. The symmetry of S12, S13, S14, S23, S24, and S34 are the same as S21, S31, S41, S32, S42 and S43. Fig.5 indicates that the coupling is <−15 dB through the frequency of operation. Note that by using separate or linked ground planes, according to simulation results, across the whole UWB, the proposed design with interconnected ground planes ensures minimum mutual interaction between antenna parts.

Fig.6.a shows the surface current distribution simulation at 11GHz and Fig.6.b displays the distribution of surface current simulation at 6.5GHz when port 1 is activated and the remaining three ports have been closed. It should be observed that the four unexcited antennas have no leakage current, indicating that the antenna components are well isolated. Plotting the current distributions at the four-band rejection's core frequencies allows for the investigation of the four notch band output.

The excited currents spread destructively throughout the H-L-shaped slot at f = 3.5 GHz, contributing to the 3.5 GHz resonant band, at f = 5.5 GHz, the spreading of current circulates the EBG's form. Current flows in reverse directions between the inside and outside edges of the parasitic strips in a U-shape, resultant radiation beams are significantly attenuated at the resonance frequency of 2.4, 7.5GHz.

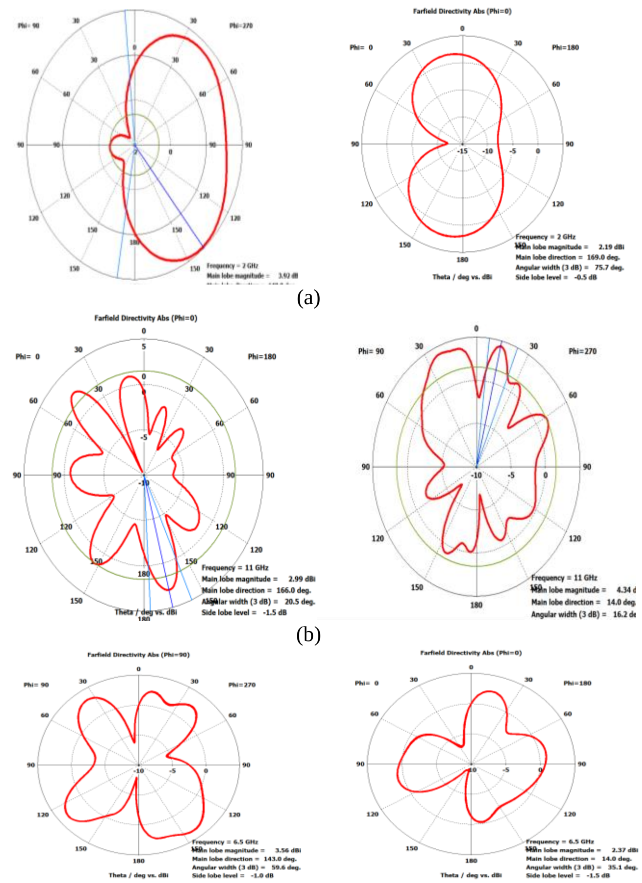


(a) (b)

Fig. 6. Surface current distribution

IV. RADIATION PATTERNS

The normalized far-field radiation patterns of the recommended UWB-MIMO antenna in the y-z plane and the x-z plane at three different 2, 6.5, and 11 GHz frequencies are illustrated in Fig.8. The MIMO antenna is y-polarized and built in the x-y plane. For practically all working frequencies, the radiation pattern in the H-plane is quasi-omnidirectional, as displayed in Fig.7, but the radiation pattern in the E-plane is comparably dull-shaped (monopole-like). Higher frequencies have more distortion in the radiation pattern than lower frequencies. Higher frequencies have more distortion in the radiation pattern than lower frequencies. However, over the very large frequency range of service, this is still appropriate (2-11 GHz).

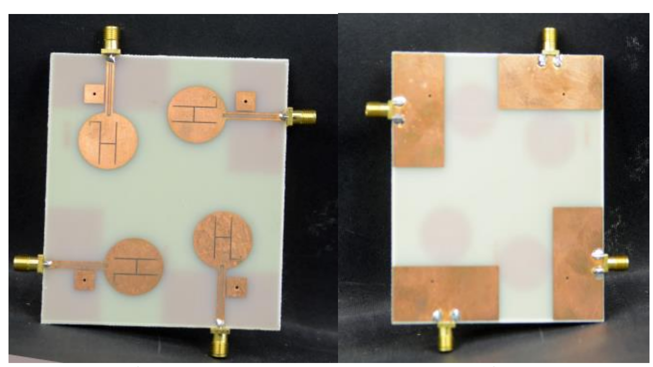


(a) (b) (c)

Fig. 7. At various frequencies, simulations of radiation patterns in the H- and E-planes for the recommended UWB-MIMO design
(a) 2 GHz, (b) 11 GHz, and (c) 6.5 GHz

V. FABRICATION AND MEASUREMENTS

Figure.8 shows the constructed antenna, which is a UWB-MIMO antenna manufactured on FR4 PCB. The Rohde & Schwarz ZVB-20 vector network analyzer is used for all measurements.

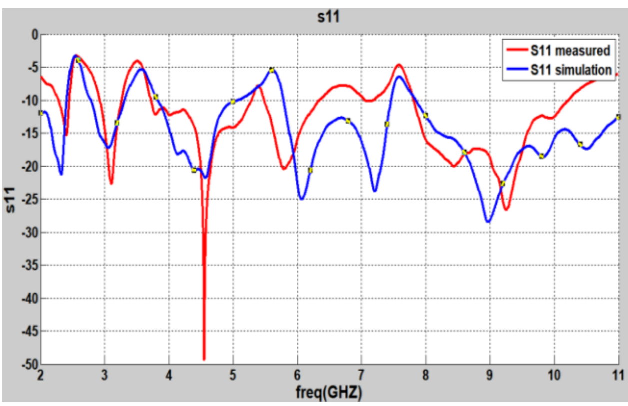


(a) View from the top (b) View from the back

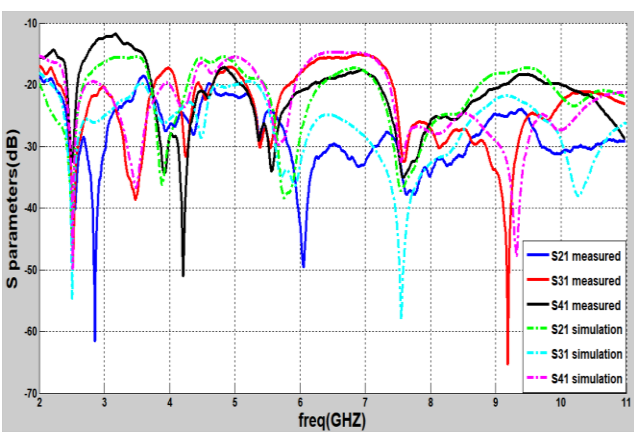
Fig.8 Fabrication of the UWB antenna with four notched b
(a) Top view, (b) Back view

Due to shape differences, there are modest changes between measured and simulated plots, constant of dielectric, thicknesses of the substrate, and feed probe manufacturing restrictions. Fig.9 displays the disparity between the fabrication and simulation results of S-parameters. The simulation and measure (S11) are shown in Fig.9.a Having four notched bands, the designed antenna obtains a larger bandwidth of 2-11 GHz. The four notched bands are good in agreement with the bands of Bluetooth (2.2-2.8GHz), WiMAX (3.3-3.7GHz), WLAN (5.15-5.875GHz) and X-band (7.1-7.9GHz), respectively. At low-frequency bands, those measurements' outcomes are compatible using the simulated outcomes, although there are some minor differences between the measured and simulated outcomes at higher bands of frequency.

S21, S31, and S41 which were simulated and measured are shown in Fig.9. b. The values of S21, S31, and S41 are all lower than -15dB over the whole operational band of frequency. The observed S21, S31, and S41 values correspond well with the simulated values. These findings indicate that the UWB-MIMO antenna has a higher level of isolation. Because of the symmetrical construction of the suggested antenna, the values of S21 and S41 are almost equal, which is compatible with the results.



(a) S11 measured and simulation



(b)

Fig. 9. Simulation and measurement of S-parameter of MIMO antenna

VI. DIVERSITY CHARACTERISTICS

In the subsections that follow, the envelope correlation coefficient (ECC), diversity gain (DG), multiplexing efficiency (ME), channel capacity loss (CCL), Mean effective gain (MEG), and total active reflection coefficient (TARC) are important parameters for determining MIMO antenna capability and performance, all of these properties will be described and estimated for the proposed antenna.

A. *Envelope Correlation Coefficient (Ecc)*

The radiation patterns of the antenna components should not be correlated, which is an important criterion for variety in a MIMO antenna system. S-parameters or radiation patterns can be used to calculate an ECC, is the parameter used to measure the association between radiation patterns. [4], [5]. The S-parameter may be used to compute the ECC of a 4-element MIMO system. [6]:

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

Where: $\rho e(i,j,N)$ is the ECC between antennas, i and j is MIMO antenna system with N elements, N is the total number of element Si, n, Sn, j is the S-parameter of the antenna for MIMO.

For i = 1, j = 2, and N = 4, Over whole operational frequency range (2–11 GHz), The four-element MIMO system's ECC is determined. Fig.10 illustrates the estimated ECC values using simulated and evaluated S-parameters. (a) ECC values simulated and calculated are lower than 0.0015, except for four bands. The ECC value should be less than 0.5 for excellent diversity performance [7]. This demonstrates that the suggested UWB-MIMO antenna has a very low correlation between the elements of the antenna (ECC <0.06) to achieve superior efficiency in terms of diversity.

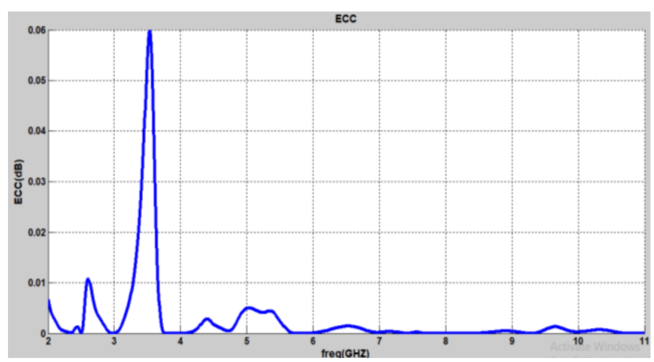


Fig.10. The suggested UWB-MIMO antenna's simulated MIMO diversity performance: ECC

B. *Diversity Gain (DG)*

Another important factor to consider while evaluating the diversity of UWB-MIMO is the diversity gain (DG). The ECC and DG are strongly intertwined Because the correlation between antenna components is smaller, the diversity gain is greater, and vice versa. The ECC and DG have a relationship that can be described as follows [8]:

$$DG=10\sqrt{1-ECC^{2}} \quad (2)$$

Equation (2) demonstrates that a low ECC value guarantees a high DG, this is necessary for MIMO applications. Using simulated and calculated ECC values, Fig.11 shows the DG values as a function of frequency. The DG of the recommended UWB-MIMO antenna is larger than 9.6 dB and exceeds 10 dB over the whole working frequency range (2-11 GHz), essentially four rejected. This shows the high gain in the diversity of the UWB-MIMO antenna proposed.

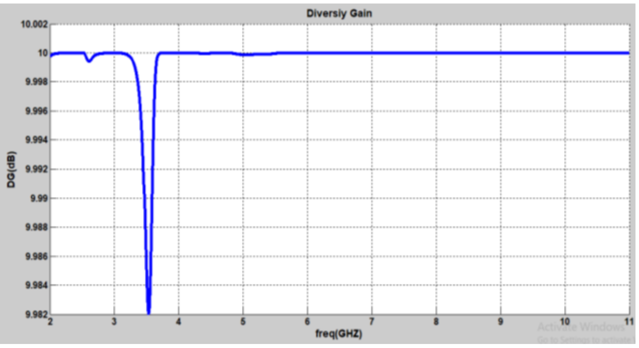


Fig. 11. The suggested UWB-MIMO antenna's simulated MIMO diversity performance: DG

C. Channel Capacity Loss (CCL)

The channel capacity of any standard MIMO device can be increased by increasing the number of antenna components. CCL, on the other hand, is caused by a link between closely spaced antenna components. The CCL is a crucial metric for determining the effectiveness of a MIMO system since it establishes the channel's transmission rate upper bound for efficient communication. The UWB-MIMO CCL should be less than 0.4 b/s/Hz for efficient transmission [9]. The S-parameter can be used to calculate the CCL of a 4-element UWB-MIMO system as follows [10], [11]:

$$CCL = -\log_2 \det\left(\psi^R\right) \tag{3}$$

For a 4-element of MIMO antenna (R = 4), which ψ^R is the correlation matrix for receiving antennas, may be represented as a

$$\psi^R = \begin{vmatrix} H_{11} & H_{12} & H_{13} & H_{14} \\ H_{21} & H_{22} & H_{23} & H_{24} \\ H_{31} & H_{32} & H_{33} & H_{34} \\ H_{41} & H_{42} & H_{43} & H_{44} \end{vmatrix} \tag{4}$$

Where $H_{ii} = 1 - \left|\sum_{n=1}^{N=4} s_{i,n}^* s_{n,i}\right|$ and $H_{ij} = -\left|\sum_{n=1}^{N=4} s_{i,n}^* s_{n,j}\right|$

i, j =1, 2, 3 or 4

It should be noted that the computed CCL values for the entire operating frequency range are less than 0.4 bits/s/Hz (2-11 GHz) shown in Fig.12, except for the four band-notches where it exceeds the criterion values of 0.4 (b/s/ Hz). This shows that the suggested design performs on high channel capacity.

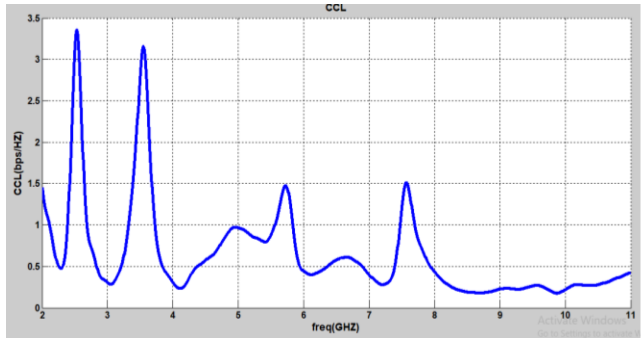


Fig. 12. The suggested UWB-MIMO antenna's simulated MIMO diversity performance: CCL

D. Total Active Reflection Coefficient (Tarc)

The TARC is the square root of the ratio of total reflected power to total incident power, as well as the overall MIMO antenna system's apparent return loss [12]. Except for the four notched bands, TARC for the MIMO system is less than -10 dB for the whole band [13] shown in Fig.13.

$$TARC = N^{-0.5}\sqrt{\sum_{i=1}^{N}\left|\sum_{k=1}^{N} s_{ik}\, e^{j\vartheta(k-1)}\right|^2} \tag{5}$$

For N=4, θ=0:180, i, k=1:4

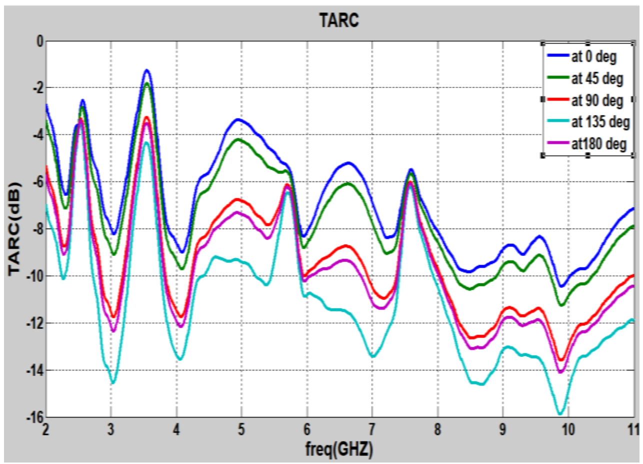


Fig. 13. The suggested UWB-MIMO antenna's simulated MIMO diversity performance: TARC

E. Multiplexing Efficiency (Me)

Multiplexing efficiency refers to the signal-to-noise ratio (SNR) deterioration caused by bad MIMO antennas (with nonzero correlations and non-unity antenna efficiencies) at a given capacity level. It is larger than -6 dB at 2-11GHz and only in the lower narrow frequency region does, it drops below -6 dB (2.3-2.9GHz), as illustrated in, the UWB-MIMO antenna's multiplexing efficiency is very good Fig.14.

The following equation is employed to compute multiplexing efficiency (η_{mux}): [14].

$$\eta_{mux} = \sqrt{\eta_i \eta_j \left(1 - |pe|^2\right)} \tag{6}$$

Where η_i, η_j are the total efficiency of the i[th], j[th] antenna port, which extracted from CST Program.

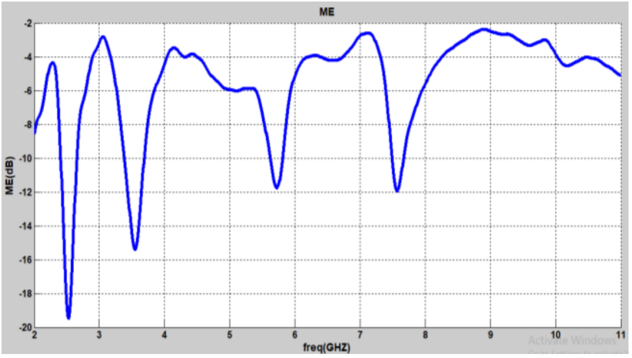


Fig. 14: The suggested UWB-MIMO antenna's simulated MIMO diversity performance: ME

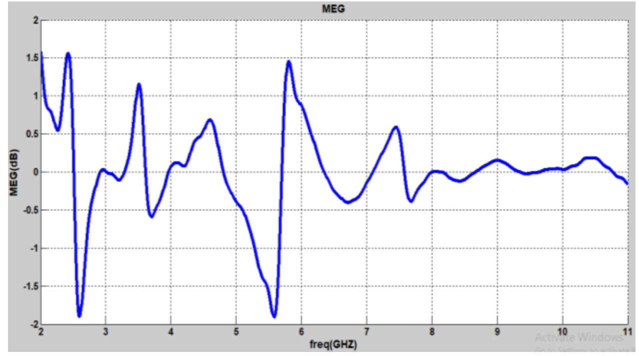


Fig. 15: The suggested UWB-MIMO antenna's simulated MIMO diversity performance: MEG

F. Mean Effective Gain (Meg)

In multi - path situations, mean effective gain (MEG) is defined as the average effective gain. It specifies how much power the antenna receives. MEG values for all antenna elements should be equal for optimal antenna design, as shown in Fig.15. Power patterns of antenna radiation, efficiency of antenna, and effects of propagation are all included in this section.

For different propagation models, MEG's generalized formulation is as follows: [15]:

$$MEG = 0.5\left(1 - \sum_{i}^{n} \left|S_{ij}\right|^{2}\right) \qquad (7)$$

Where: i= port number, n= number of antenna (MEG < 3 dB)

VII. COMPARISON OF PERFORMANCE

A comparison of representative UWB-MIMO antennas published in recent years is shown in Table 2. The element's size is defined using the "Size/Port" notion in Tab.2. While the analogy is not detailed, the proposed UWB-MIMO technology is almost up to date. The comparison findings showed that the MIMO had the right size, bandwidth, gain, radiation pattern, insulation, and diversity (ECC, DG, ME, CCL, MEG and TARC), band-set features and elements number are obtained from the proposed antenna.

TABLE II
COMPARISONS OF PERFORMANCE TO PREVIOUSLY PUBLISHED LITERATURE

Reference number	**MIMO Dimension W L (mm2)**	**Element Dimension W L (mm2)**	**Substrate Material**	**Number of elements**	**Rejected bands**	**Impedance bandwidth**	**ECC**	**CCL**	**Mutual coupling (dB)**
Proposed work	80×94	40×47	FR4	4	Bluetooth WLAN WiMAX X-band	9 GHz (2-11)	< 0.0015 except notches	< 0.4 except notches	< -15
[16]	55×55	26×26	FR4 epoxy	4	-	9.2 GHz (3.1-12.3)	<0.02	-	< -20
[17]	50×39.8	-	Rogers TMM4	4	WLAN	9.3 GHz (2.7-12)	-	-	-17
[5]	60×60	30×30	FR4 epoxy	4	WLAN	7.95 GHz (2.73-10.68)	< 0.0015	-	-15
[18]	40×40	15×18.2	FR4 epoxy	4	-	7.9 GHz (3.1-11)	< 0.002	< 0.4	-20
[19]	50×39.8	15×22.45	Rogers TMM4	4	-	9.5 GHz (2.5-12)	< 0.03	-	-17
[20]	100×50	18×20	FR4	4	-	100 MHz (2.4-2.5)	< 0.15	-	-10
[21]	80×80	40x40	Taconic ORCER RF-35	4	-	420 MHz (1.63-2.05)	< 0.01	-	-24
[22]	40×40	15×20	FR4 epoxy	4	-	9.6 GHz (2.4-12)	< 0.002	-	-15
[23]	36×36	18x18	FR4 epoxy	4	WLAN	9 GHz (3-12)	< 0.5	-	-20
[24]	60×50	11.5×26	FR4 epoxy	4	-	7.6 GHz (3-10.6)	< 0.004	-	-18
[25]	78×78	39×39	FR4 epoxy	4	WLAN WiMAX X-band	11.45 GHz (2.3-13.75)	<0.02	<0.2	<-20

VIII. CONCLUSION

The four-element UWB-MIMO design presented in this article provides for extremely wide-band operation, high isolation, and four-band operation, including Bluetooth (2.2-2.8GHz) frequency band suppression, WIMAX (3.3-3.8 GHz), WLAN (5.1−5.8 GHz), and X-band frequencies (7.09-7.92 GHz). CST software is used for UWB MIMO antenna configuration and optimization. The proposed design has been manufactured and experienced, and the measurement results are very similar to the results of the modelling, representative the practicality of the suggested UWB-MIMO antenna. Several criteria, such as VSWR, S11 and the reciprocal coupling and radiation patterns test the efficiency of the suggested design. The bandwidth of interest (2-11 GHz), S11<-10 dB, VSWR<1.5 and a good all-way design but also create four-stop bands for Bluetooth WiMAX, WLAN, and X-band systems with an extremely high rejection. The results also demonstrate that the suggested design delivers a high level of isolation (>20 dB) without the usage of any decoupling mechanisms between the antenna elements. In addition, the suggested design has a greater diversity efficiency relating to ECC (<0.0015), DG (>9.8 dB), and other metrics. CCL (<0.4bits/s/Hz), ME (>-4dB), TARC (<-10) and MEG (< 3 dB).

AUTHORS CONTRIBUTION

UWB MIMO Antenna with four notch band designed and simulated in FR4 PCB with CST and MATLAB program with high performance and high isolation.

Sara K. Ghazy is responsible for
1- Conception and design of the work.
2- Data collection and tools.
3- Data analysis and interpretation.
4- Drafting the article

Hazem H. El-Banna is responsible for
1- Investigation
2- Methodology
3- Data analysis and interpretation.

Hamdy A. El-Mikati is responsible for
1- Supervision
2- Critical revision of the article
3- Final approval of the version to be published

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The author declared that there are no potential conflicts of interest with respect to the research authorship or publication of this article

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Arabic Title:

تصميم هوائي UWB-MIMO مزود بقدرة عزل وعزل رباعي النطاقات

Arabic Abstract:

يتم توفير هوائيات متعددة المدخلات ومخرجات متعددة (MIMO) متعددة العناصر فائقة الاتساع (UWB) مع أداء جيد. تم بناء هذا الهوائي باستخدام شكل متماثل حديث ، وتقنية الترتيب المتعامد ، لذلك ، تم تقليل الاقتران المتبادل بين عناصر الهوائي بشكل كبير. بالإضافة إلى ذلك ، يتم تصغير أحجام الهوائي بكفاءة من خلال تطبيق جانبين من التكوين المتماثل ، هيكل أرضي جزئي وخطأ ، لزيادة عرض نطاق الممانعة ، استخدموا بنية فصل بالإضافة إلى تقنيات متعددة الفتحات والشقوق. يتميز الهوائي بهيكل منخفض الحجم وبُعد صغير ٤٠ مم × ٤٧ مم × ١,٦ مم. بالإضافة إلى ذلك ، من خلال الجمع بين الفتحات والشقوق المختلفة على عناصر الإشعاع الدائرية ، وهيكل الفصل ، يحقق الهوائي المقترح أربع خصائص للنطاق المقطوع. يحتوي هذا الهوائي على عرض نطاق أكبر يبلغ (٢-١١) جيجاهرتز. بالإضافة إلى ذلك ، يحتوي هذا الهوائي أيضًا على اقتران متبادل منخفض (<-١٥ ديسيبل) ، (كفاءة مضاعفة <-٠,٥ ديسيبل) ، معامل ارتباط منخفض للغلاف (ECC 0.06> ، باستثناء النطاقات الأربعة المحززة (، وكسب ثابت ، وأنماط إشعاع شبه شاملة الاتجاهات في جميع أنحاء مقاومة النطاق الترددي. لذلك يتم الحصول على تبادل خرج جيد للهوائي. قد يكون هذا الهوائي مناسبًا لتطبيقات الاتصالات اللاسلكية UWB-MIMO وكذلك أنظمة UWB-MIMO المحمولة.