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DUAL-BAND RECONFIGURABLE MIMO ANTENNA FOR WIRELESS APPLICATIONS

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Abstract: This article presents design and simulation of a new compact four-element dual-band MIMO frequency reconfigurable antenna that can be reconfigured for WiMAX and LTE applications. The antenna includes four elements at the same FR4 substrate with an optimized overall size of 65x65x1.6 mm^3 and an optimized partial GND plane of 30x11.125 mm^2. The reconfiguration rate is between 2.41 and 3.99 GHz that can cover the WiMAX and LTE wireless devices by applying just one RF (PIN) switch to change the operating frequency. The antenna operates on the two states of the PIN diode under its two states ON and OFF with (2.7 GHz, and 2.8 GHz) resonant frequencies respectively. The proposed antenna produces acceptable simulation results for the MIMO system by achieving gain from (3-7.2) dBi, less than -14.5 dB coupling effect, less than 0.28 envelope correlation coefficient, and diversity gain range from 8.4-10.

Keywords: *MIMO, Reconfigurable antenna, PIN diode, WiMAX, LTE*

1. Introduction

Multiple output (MIMO) technology and diversity due to the high data rate and high spectrum efficiency both in industry and universities have been the focus of recent years. [1]. The wireless systems that have multiple antenna elements at both the receiver and transmitter sides called the wireless MIMO systems as presented in figure (1). These systems are used firstly in the 1980s by computer simulations, and later they explored analytically from papers [2]. The MIMO system can be used with several wireless communication systems such as Long Term Evolution (LTE), WCDMA, and IEEE 802.11 standard for wireless local area networks [1]-[2]. In addition, without additional bandwidth the MIMO system improves transmission performance and transmission rates of the wireless communications systems [3].

By increasing the number of antenna elements on the transmitter and/or the receiver side of the MIMO system, the data rate (capacity) of a wireless link can be increased without requiring additional power or spectrum in rich scattering environments. Because of the limited space of small mobile devices, the number of antenna elements is restricted and because of the correlation coefficients between MIMO antenna items, the total efficiency of MIMO elements could be significantly degraded by mutual coupling. The benefits of using multiple antenna elements on the sides of the transmitter and receiver include increasing channel capacity,

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suppressing interferences and reducing multipath effects. [1].

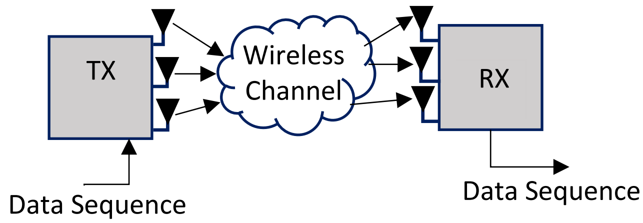


Figure 1. The block diagram of the MIMO system

The reconfigurable antennas, in single or multiple versions, are used in the same substrate for the production of MIMO configurations and are used in the MIMO system to improve system properties, including improving the quality of communications path, efficient spectrum use, compact size, and interference reduction. The frequency reconfiguration is achieved by using RF switches such as pin and varactor diodes, RF MEMS, switched capacitors, or field-effect transistors [4]-[19].

The most important parameters of the MIMO antenna system are compact size, isolation greater than 12 dB, ECC less than 0.5, and the DV range is about 10 [1], [6], [10], [12]-[13].

The ECC is a MIMO antennas criterion that can confirm radiation pattern similarity and measure the field coupling between the antenna elements"and it can be calculated as in "(1)". The diversity gain (DV) is used to describe the gain enhancement of a multiple-antenna system in a combined signal over time-averaged SNR, and it can be calculated from "(2)" [1] ,[12], [20]-[22].

$$\rho_e = \frac{|S^*{}_{11}S_{12} - S^*{}_{21}S_{22}|^2}{(1-|S_{11}|^2-|S_{21}|^2)(1-|S_{22}|^2-|S_{12}|^2)} \qquad (1)$$

$$DV = 10\sqrt{1-|\rho_e|} \qquad (2)$$

Where:

ρ_e is the ECC.

S11 and S22 are the S-parameters of the antenna. S12, and S21 are the coupling coefficients between the antenna elements

DV is the diversity gain between any two elements of the MIMO antenna.

The main idea of the proposed 4-elements reconfigurable MIMO antenna is the same idea of the proposed antennas of [20]-[22] but with different shape of the antenna strucutre and it works different frequencies and applications.

This work has been designed and optimized for single, and four elements polarized configurations with a new compact, dual-band, reconfigurable MIMO antenna for WiMAX & LTE applications. The contributions of the proposed design are:

1. The proposed antenna provides wide frequency reconfigurability from 2.41 GHz to 3.99 GHz.
2. The proposed antenna has a compact design of single element with 11.5x30 mm^2, 20.5x15 mm^2 of the patch an partial GND plane areas respectively.
3. The proposed design of the 4-elements MIMO antenna has an optimized overall size of 65x65x1.6 mm^3 with coupling effect more than 14.5 dB.
4. The partial GND plane of the 4-elements MIMO antenna is optimized using the Genetic Algorithm to be 11.125 x 30 mm^2 in order the antenna operates on the MIMO system.

2. The Proposed Antenna Design

2.1 Single element antenna structure

The proposed design is a double band reconfigurable MIMO antenna that can operate with frequency bands that are covering the WiMAX and LTE applications. The single element is presented in figure (2) that shows the antenna front side consisting of a printed monopoly patch, linked to a single PIN diode for frequency tuning, and the rectangular partial ground plane is showing on the backside. The proposed antenna design uses the FR4 epoxy substrate with properties of 1.6 mm thickness (h), 4.3 dielectric constant, 0.002 loss tangent, 50 Ω microstrip line feed, and the overall antenna substrate size, partial GND plane, and patch dimensions are 30x30x1.6 mm^3, 11.5x30 mm^2, and 20.5x15 mm^2 respectively. Table (1) outlines all the optimal parameters obtained from the reconfigurable antenna parametric study as presented in Figure (3). The antenna has a single Skyworks PIN diode (DSM8100-000 Mesa Beam-Lead) that is optimized and used to change an antenna length to restructure the resonant frequency to other frequency bands [24]. The proposed antenna is designed using equations from "(3)" to "(7)" [20]-[23].

$$W = \frac{V0}{2fr}\sqrt{\frac{2}{\varepsilon r+1}} \tag{3}$$

$$\varepsilon eff = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1 + 12\frac{h}{w}\right]^{-\frac{1}{2}} \tag{4}$$

$$\Delta L = 0.412\, h\frac{(\varepsilon reff+0.3)(\frac{w}{h}+0.264)}{(\varepsilon reff-0.258)(\frac{w}{h}+0.8)} \tag{5}$$

$$Leff = L + 2\Delta L \tag{6}$$

$$L = \frac{V0}{2fr\sqrt{\varepsilon eff}} - 2\Delta L \tag{7}$$

Where:
W: the width of the patch.
V0: velocity of light.
εr: the dielectric constant.
fr: the resonant frequency.
εreff: the effective dielectric constant.
h: the substrate height.
ΔL: length due to the fringing effect.
Leff: the effect patch.
L: the actual length of the patch.

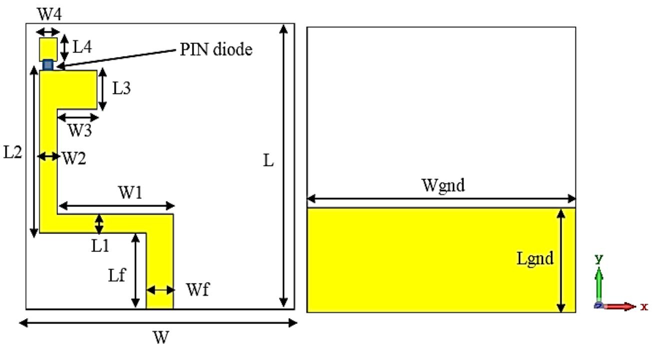


Figure 2. The proposed single-element reconfigurable antenna.

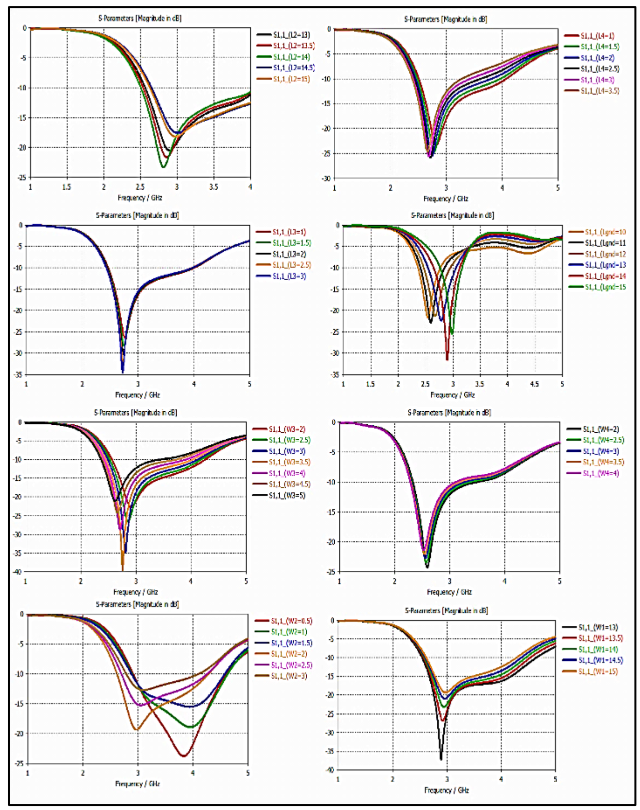


Figure 3. The proposed single-element reconfigurable antenna.

Table 1. The single elements Reconfigurable Antenna Optimum Parameters from parametric study

Parameters	***Values in mm***	***Parameters***	***Values in mm***
W	30	L3	4.5
L	30	L4	2.5
Wgnd1	30	t	0.035
Lgnd2	11.5	h	1.6
L1	2	W2	2.5
W1	15.5	W3	4.5
L2	18	W4	2.5

2.2 Four elements MIMO antenna structure

The second proposed 4-elements polarized reconfigurable MIMO antenna is presented in figure (4). The proposed antenna consists of four polarized elements with spacing between them less than (λ/2) each one having a single PIN diode for frequency tuning. The proposed antenna has overall dimensions of 65x65x1.6 mm^3, that makes it compact and appropriate for the MIMO system. All optimum parameters obtained from the parametric study of the communicating antenna are summarized in table (2). The proposed antenna has only a single PIN diode at each element that placed in an optimized position for frequency reconfigurability.

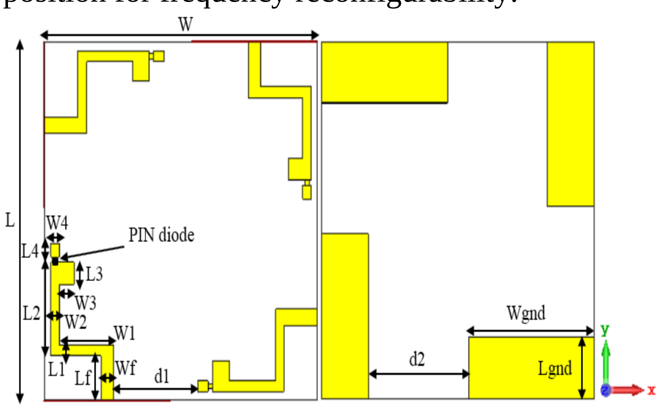


Figure 4. The proposed four elements MIMO antenna

Table 2. The 4-elements Reconfigurable MIMO Antenna Optimum Parameters from parametric study

Parameters	***Values in mm***	***Parameters***	***Values in mm***
W	65	L1	2
L	65	W1	15.5
Wgnd1	30	L2	18
Lgnd2	11.5	L3	4.5
L4	2.5	W2	2.5
d1	21	W3	4.5
d2	25	W4	2.5

The optimization procedure has been applied to the proposed antenna using CST software technology after the completion of the parametric study. The S11 parameter set to the Genetic Algorithm as a goal function to optimize the antenna dimensions for the best multiband operation. For each dimension of the reconfigurable MIMO antenna, the GA algorithm parameters set 32 population number, 30 iterations, and 497 maximum number of evaluations so that the optimized antenna dimensions are presented in table (3).

Table 3. The 4-elements Reconfigurable MIMO Antenna Optimum Parameters from GA optimization

Parameters	***Minimum value in mm***	***Maximum value in mm***	***Optimized value in mm***
W	60	70	65
L	60	70	65
L1	1	3	2
W1	13	18	15
L2	15	18	17
W2	1.5	3	2
L3	3	5	4
W3	3	5	4.5
L4	1.5	3	2.5
W4	1	3	2
d1	18	25	20
d2	20	25	23.5
Lgnd1	10	12	11.125
Wgnd1	28	32	30

3. Results and Discussion

3.1 Simulation Results

The results are obtained with the software CST by simulating the 4-element double band reconfigurable MIMO antenna. Figure (5) shows pragmatically the double-band that is obtained with (S11) in both PIN statements and where the lowest S11 of (-28 dB) is obtained in (2.75 GHz). under the (S11≤ -10 dB) there are two frequency bands that resulted, they are 2.7 and 2.8 GHz and they can cover the applications in WiMAX and LTE. Figure (6) shows that the simulated coupling effect (S12) between the 4 elements is less than -14.5 dB for all resonant frequencies. As shown in Figure (7), the simulated gain ranged from (3-7.2) dB. The worst-case of the ECC is

0.28 at 1.72 GHz and accepts the value of a MIMO system such that the ECC coefficient in the four-element MIMO antenna as indicated in Figure (8) is less than 0.5 for all resonant frequencies. For all frequency bands, the diversity gain is about 10, as is shown in Figure (9). Figure (10) and figure (11) show the radiation pattern and surface current distribution of the proposed antenna. The surface current distribution as shown in figure (11) shows the OFF status of the pin diode, which shows that the second part of this patch is flowing without current flown, while the other state is the ON status.

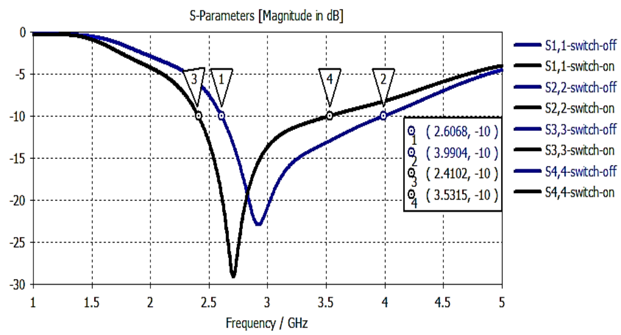


Figure 5. The frequency bands from the parameter S11 of the proposed antenna

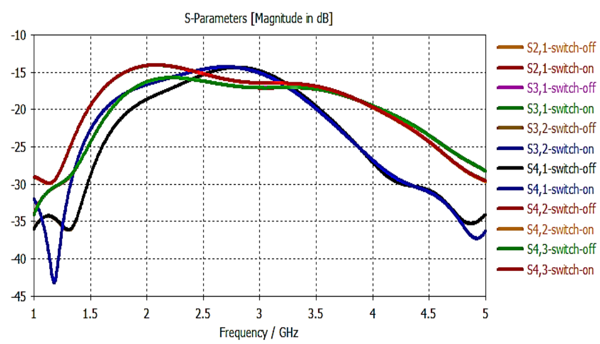


Figure 6. The coupling effect between the four elements of the MIMO antenna structure

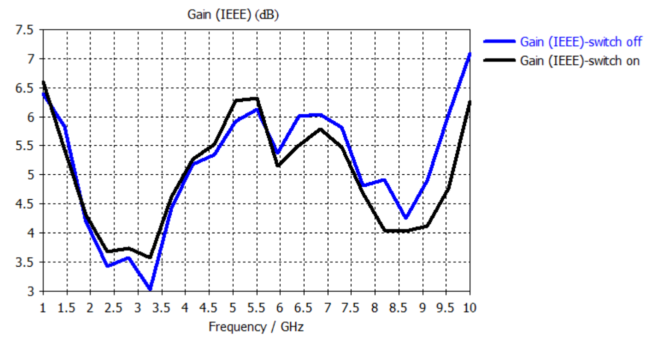


Figure 7. The overall gain variation in relation with frequency

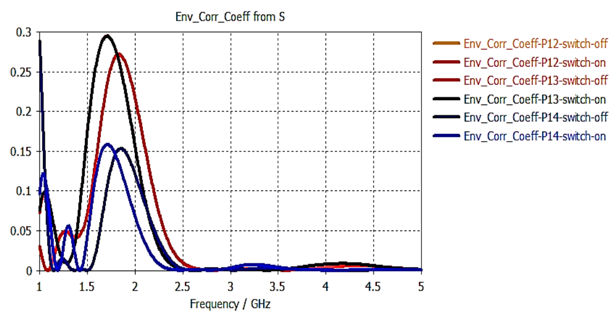


Figure 8. The relationship between the coefficients ECC and the operating frequency for the four elements

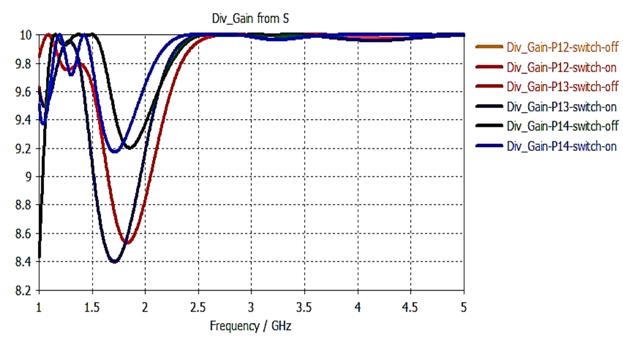
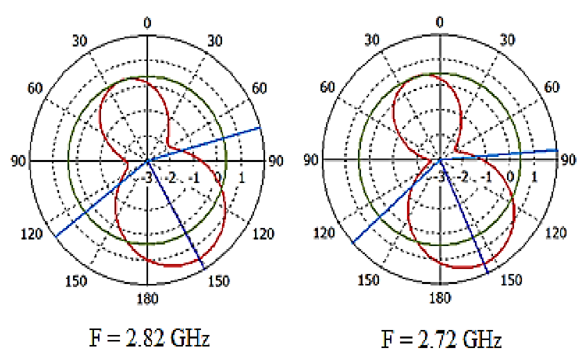
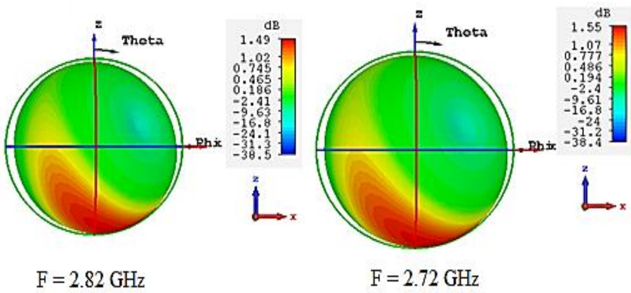


Figure 9. The diversity gain against frequency of the proposed antenna



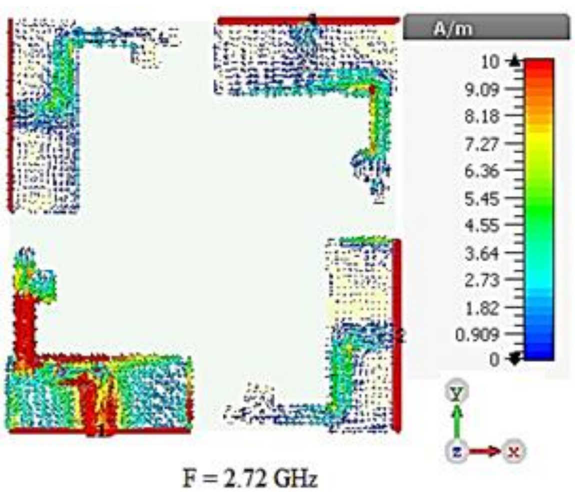
(a)



(b)

Figure 10. Radiation pattern (2D/3D) for the MIMO antenna, (a) 2D radiation pattern, (b) 3D radiation pattern.

(a)



(b)

Figure 11. The surface current distribution at switch cases (a) PIN diode on, and (b) PIN diode off

3.2 Discussions

The results of the 4-elements reconfigurable MIMO antenna are discussed and compared with other references in the literature. Some of the discussions on the results achieved by simulating the proposed model include these following points**:**

1. As presented in figure (5) the reconfigurable MIMO antenna operates with two bands, only single resonant frequency of (2.8 GHz) are obtained from the off-state of the PIN diode and the other resonant frequency of (2.7 GHz) are obtained from the on-state. The antenna at the off-state filters out the band (2.7 GHz) because the PIN diode at the off-state cut out the current from flowing to the second part of the patch so that the length of the patch is changed, hence the current distribution also changed and as a result, the operating frequency is changed**.**
2. The S11 parameter of the 4-elements reconfigurable MIMO antenna presented in figure (5) shows that the antenna operates with S11 of -28 dB and -23 dB for the PIN diode two states, it indicates that it has accepted impedance match at the resonant frequencies**.**
3. The coupling between the 4-elements of the MIMO antenna as shown in figure (6) has a worst case coupling of -14.5 dB without using any isolation enhancement**.**
4. Figure (7) shows that the gain variation in relation with frequency from (3-7.2) dBi indicates that the proposed 4-elements reconfigurable MIMO antenna can be used in the wireless MIMO applications**.**
5. As can be seen in figure (8) the proposed antenna produces worst case ECC of 0.28 < 0.5 at (1.78 GHz) while the ECC is very low at the resonant frequencies so that it indicates accepted performance of the proposed MIMO antenna**.**

6. Figure (9) produces the diversity gain around 10 with worst case of 8.4 at (1.78 GHz) while it's around 10 at the resonant frequencies, this means accepted performance of the proposed MIMO antenna**.**

The results obtained from the proposed MIMO antenna have been compared with other references in the literature as illustrated in the table (4).

Table 4. Comparison between the proposed MIMO antenna with other references in the literature

References	No. of Elements	No. and type of switches	ECC (≤)	Isolation (dB)	Peak gain (dB)	Applications
[7]	2	8-PIN	0.05	-12	-----	cognitive radio applications
[9]	2	4-varactor	------	-11	------	cognitive radio applications
[12]	2	4-PIN	0.01	-15	------	Bluetooth, WiMAX and WLAN
[13]	2	2-varactor	0.2	-12	2.12	GSM, UMTS, LTE, PCS and WiMAX
[20]	4	4-PIN	0.021	-15	9.75	Satellite, RADAR, and Broadband
The Proposed MIMO Antenna	4	4-PIN	0.28	-14	7.2	WiMAX and LTE

4. Conclusion

This paper presents a compact and new 4-elements reconfigurable MIMO antenna for WiMAX and LTE applications, which can be reconfigured to satisfy the MIMO system requirements. Only one PIN diode operates the proposed structure for obtaining dual-band resonant frequencies suitable for various wireless applications, such as WiMAX and LTE systems. The proposed structure works in the UWB frequency range and can be manufactured simply by a small, flat size structure with accepted properties like gain, efficiency, radiation pattern, return loss, ECC, coupling effect, diversity gain, and VSWR. The system has accepted working properties for the MIMO system with -14.5 dB and 0.28 < 0.5, the worst isolation case and ECC respectively.

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Abbreviations

MIMO	Multiple Input Multiple Output
VSWR	Voltage Standing Wave Ratio
CST	Computer Software Technology
ECC	Envelope Correlation Coefficient
UWB	Ultra Wide Band
GND	Ground
WiMAX	Wireless Local Area Network
DGS	Defective Ground Plane Structure

Conflict of interest

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

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