Multiband Reconfigurable MIMO Antenna for Wireless Applications

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***Abstract*— This paper presents a compact multi-band frequency reconfigurable MIMO antenna for wireless applications. The antenna is designed and optimized to cover such wireless applications like satellite, Radar, and broadband applications. The frequency reconfigurability is obtained by using only one RF switch (PIN diode) for changing the operating frequency at ON/OFF states of the PIN diode. The dimensions of the 4-Elements MIMO antenna are 45x45x1.6 mm^3 printed on an FR-4 epoxy substrate with relative dielectric constant $\varepsilon r = 4.3$, loss tangent tan (δ) = 0.002 and 50 Ω microstrip feed line. The proposed antenna has two patch side arms connected by a single PIN diode. The antenna introduces three resonant frequencies under (S11 $\leqslant$ -10 dB) which are: 12 GHz, 13.95 GHz, and 14.91 GHz in the ON-state and OFF-state of the PIN diode with a fractional bandwidth of 1.85%, 6.66%, and 4.15 % respectively. The obtained simulated gain is ranging from 8 to 10.45 dB and the maximum simulated gain is 10.45 dB at 17 GHz. The lowest return loss is obtained to be (-50) dB at 13.95 GHz. Detailed simulation results are explored and studied in this research. The return loss, Envelope Correlation Coefficient ECC, and Isolation are obtained to be less than -20 dB, less than 0.02, and less than -17 dB respectively. The CST software is used to design and optimize the proposed MIMO antenna.**

Keywords*——: Reconfigurable antenna, MIMO, Broadband, Satellite, Radar, PIN diode, CST, S11

I. Introduction

The significant consideration from the research community in the past years has drawn toward the advent of Multiple Input Multiple Output (MIMO) in the present and future wireless communications standards. The MIMO system is used to improve the throughput and increase the transmission rate in wireless communications such as cellular, wireless local area network WLAN, and satellite communications without requiring any additional bandwidth [1]-[6].

The reconfigurable antennas are being used in single and multiple in the same substrate to produce MIMO configuration and the used widely in the MIMO system to enhance the characteristics of the system such as improve the quality of the communication path, the efficient of spectrum utilization, compact size, multipath effects, and interference reduction. The frequency reconfigurability is achieved by using RF switches such as PIN and varactor diodes, RF MEMS, switched capacitors, and field-effect transistors switches [2]-[10].

The important parameters in the reconfigurable MIMO antenna are the compact size, the isolation greater than 12 dB [2]-[8], Envelope Correlation Coefficients ECC is the criterion of the MIMO antenna that is able to confirm similarity in the radiation pattern and it's less than 0.5 [11] and some researches proposed ECC less than 0.3 [2], and diversity gain DV around 10 [12]. The ECC is related to the S-parameter and is used to measure the field coupling between the antenna elements. The diversity gain DV is related to the ECC and they can be calculated from the equations below [2],[8], [12]:

$$ECC = | S^*_{11} S_{12} - S^*_{21} S_{22} |^2 / (1-| S_{11} |^2 - | S_{21} |^2)(1-| S_{22} |^2 -| S_{12} |^2) \quad (1)$$

$$DV = 10 (1-|ECC|)^{1/2} \quad (2)$$

Where: ECC is the envelope correlation coefficient parameter, DV is the diversity gain parameter, S11, and S22 are the S-parameters of the antenna, S12, S21 are the coupling coefficients between the antenna elements.

The literature used in this paper is classified into four parts two or greater similar reconfigurable PIFA MIMO antenna for mobile applications, two or greater similar reconfigurable UWB MIMO antenna for MIMO applications, two or greater similar reconfigurable MIMO antenna for various wireless applications, and two or greater reconfigurable MIMO antenna with single or multiple UWB sensing antenna for cognitive radio applications.

References [10], [13][15], MIMO reconfigurable PIFA antennas are presented for mobile handset applications using PIN diodes. Reference [11], the antenna covers four multiband 900 MHz, 1.8 GHz, 2.4 GHz, and 3.5 GHz for GSM900, DCS, WLAN/WiFi, and WiMAX applications with a peak gain of 4.9 dBi at 3.5 GHz and coupling less than 15 dB. Reference [13] the antenna operates at low-frequency bands from 0.69-0.96 GHz and high-frequency bands from 1.71-2.69 GHz which are used in LTE700/2300/2500, GSM850/900, DCS, PCS, UMTS and applications with isolation better than 10 dB. Reference [14], a 3G/4G MIMO reconfigurable PIFA printed on a table GND plane and operates at frequency reconfigurability from (0.69-2.69) GHz with an ECC less than 0.35. Reference [15], a 4-elements reconfigurable MIMO PIFA antenna for LTE applications at 699-960 GHz, and 1.71-2.69 GHz. The antenna works with isolation less than 10.5 dB, and ECC less than 0.1.

Reference [16], a reconfigurable UWB MIMO antenna is presented for MIMO applications. The antenna operates on frequency reconfigurability from 0.45-0.7 GHz and operates with UWB range from 0.45-5 GHz. The antenna works with ECC < 0.5 and isolation less than 25 dB.

References [7], [11], [17], a frequency reconfigurable MIMO antennas for various wireless applications are presented. Reference [7], a frequency reconfigurable printed monopole MIMO antenna operates at 2.3 and 3.5 GHz with low ECC < 0.05 and isolation better than 12 dB. Reference [11], a pattern reconfigurable MIMO antenna covers 5.15-5.35 GHz for WLAN system with high isolation < 21 dB and low ECC < 0.03. Reference [17], a frequency reconfigurable MIMO antenna operates with dual bands from 1.35-1.62 GHz, and from 1.95-2.2 GHz with isolation < 20 dB and ECC < 0.0164 using varactor diodes.

References [18]-[25], reconfigurable MIMO antennas are presented for cognitive radio applications. Reference [18], the antenna works with sensing UWB band from 3-6 GHz and frequency reconfigurability from 3.8-4.3 GHz with isolation less than 15 dB and ECC less than 0.04. Reference [19], the antenna consists of 2-elements reconfigurable antennas operate with frequency tuning from 0.7-2.8 GHz using varactor diodes and a single UWB sensing antenna can cover a band from 0.74-3.44 GHz with isolation less than 11.5 dB and ECC less than 0.015. Reference [20], a 4-elements reconfigurable MIMO antenna operates on 1.77-2.51 GHz tuning using varactor diodes and an UWB sensing antenna covers a band from 0.75-7.65 GHz with isolation < 10 dB and ECC < 0.248. Reference [21], a 4-elements reconfigurable MIMO antenna operates on 743-1240 and 2400 MHz tuning using combination of PIN and varactor diodes with isolation < 12 dB and ECC < 0.027. Reference [22], a 2-elements reconfigurable MIMO antenna operates on 1.75-2.48 GHz tuning using varactor diodes and an UWB sensing antenna covers a band from 0.75-7.65 GHz with isolation < 10 dB and ECC < 0.1815. Reference [23], a 2-elements hexagonal-shaped frequency reconfigurable MIMO antenna and UWB sensing antenna with defective GND plane structure DGS to enhance isolation and for size reduction are presented for cognitive radio applications. The antenna operates with a frequency tuning range from 1.41-2.26 GHz with isolation better than 12 dB and ECC less than 0.2. Reference [24], a frequency reconfigurable 2-elements MIMO antenna with wideband 2-elements MIMO antenna for cognitive radio applications. The wideband sensing antenna operates with a frequency range from 2.35-5.9 GHz, while the reconfigurable antenna operates from 2.6-3.6 GHz using varactor diodes. The antenna operates with gain ranging from 3.5-5 dBi, ECC < 0.5, isolation better than 15 dB. Reference [25], a 2x2 frequency reconfigurable MIMO with UWB MIMO antenna for cognitive radio applications. The proposed antenna operates in three modes, UWB sensing mode, MIMO reconfigurable mode, and MIMO UWB mode. The UWB and reconfigurable modes are obtained from switching on and off states of the PIN and varactor diodes, where it achieves the UWB spectrum from 1-4.5 GHz and reconfigurability range from 0.9-2.6 GHz. The antenna has an isolation of less than 12 dB and ECC less than 0.19 for all operating bands.

In this paper, a new compact multiband 2-elements and 4-elements frequency reconfigurable MIMO antenna for broadband, satellite, and radar applications are designed and optimized with two and four polarized configurations. The proposed design is different from the literature and the contributions in this paper are:

a. A 2-elements and 4-elements frequency reconfigurable antenna with wide frequency reconfigurability range from 11.7-15.4 GHz.

b. A compact single element design having a single patch and partial GND plane with areas of 10 x 21 mm^2 and 14 x 30 mm^2 respectively.

c. A compact overall design of 2-elements and 4-elements with an optimized size of 30 x 45 x 1.6 mm^3, and 45 x 45 x 1.6 mm^3 while providing isolation greater than 17 dB.

d. A Genetic Algorithm optimization is used to optimize the reconfigurable MIMO antenna dimensions to operate in the MIMO system.

II. PROPOSED MIMO ANTENNA DESIGN AND PIN DIODE MODELING

A. Proposed MIMO Antenna Design

The proposed structure is designed from a single port element, dual-port elements, and 4-port elements. The proposed design of a single port, 2-port elements, and 4-port elements are shown in Fig. (1-a, b, c). After the study of the latest researches and determine which applications to cover by the antenna the proposed antenna shape is chosen after some parametric study of the patch dimensions to be completely different from the literature. The antenna consists of a patch printed on an FR-4 substrate with εr=4.3, tan (δ) =0.002 relative dielectric constant and loss tangent respectively, the thickness of (1.6 mm) and 50Ω microstrip feed line. The overall antenna size of single port, 2-port elements, and 4-port elements are 30x30x1.6 mm^3, 30x45x1.6 mm^3, and 45x45x1.6 mm^3, which is applicable in the wireless applications and meet the compact antenna properties and classifications. The antenna dimensions are optimized at each MIMO design to meet the requirements of the compactness of the MIMO system. The optimum parameters of the multiband 1-elements, 2-elements, and 4-elements MIMO antenna are summarized in table I, table II, and table III respectively. Only single (DSM8100-000 Mesa Beam-Lead) from Skyworks PIN diode used to modify the length of the patch to reconfigure the resonant frequency to meet other bands of frequencies. The PIN diode is placed in an optimized position to achieve the desired operation. The design equations of the communicating antenna can be listed at equations from " (3)" to "(7)" respectively [26].

$$W = V_0 \, [2/(\varepsilon_r + 1)]^{1/2} / 2f_r \quad (3)$$

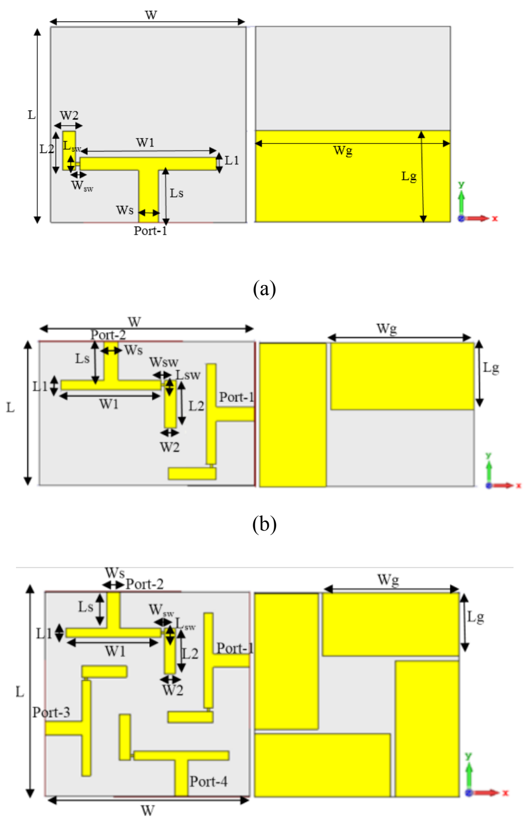
$$\varepsilon_{eff} = (\varepsilon_r + 1)/2 + (\varepsilon_r - 1)/2\,[1+12\,h/w]^{-1/2} \quad (4)$$

$$\Delta L = 0.412\,h\,(\varepsilon_{eff} + 0.3)(w/h + 0.264) / (\varepsilon_{eff} - 0.258)\,(w/h + 0.8) \quad (5)$$

$$L_{eff} = L + 2\Delta L \quad (6)$$

$$L = V_0 /(2\,f_r\,\varepsilon_{eff}^{1/2}) - 2\Delta L \quad (7)$$

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 and
L: the actual length of the patch.



(a)

(b)

(c)

Fig. 1. The proposed multiband MIMO reconfigurable antenna. (a) Single element, (b) 2-elements, (c) 4-elements.

TABLE I. THE OPTIMUM PARAMETERS OF MULTIBAND 1-ELEMENTS RECONFIGURABLE ANTENNA

Parameters	Values in mm	Parameters	Values in mm
W	30	Wsw	0.7
L	30	Lsw	0.7
Wgnd	30	Ls	8
Lgnd	13.86	Ws	3
L1	2	t	0.035
W1	21	h	1.6
L2	10	W2	2.5

TABLE II. THE OPTIMUM PARAMETERS OF MULTIBAND 2-ELEMENTS MIMO RECONFIGURABLE ANTENNA

Parameters	Values in mm	Parameters	Values in mm
W	45	W1	21
L	30	L2	10
Wgnd	30	W2	2.5
Lgnd	13.86	Wsw	0.7
L1	2	Lsw	0.7
Ls	8	Ws	3
t	0.035	h	1.6

TABLE III. THE OPTIMUM PARAMETERS OF MULTIBAND 4-ELEMENTS MIMO RECONFIGURABLE ANTENNA

Parameters	Values in mm	Parameters	Values in mm
W	45	Lsw	0.7
L	45	Ls	8
Wgnd	30	Ws	3
Lgnd	13.86	t	0.035
L1	2	h	1.6
W1	21	L2	10
Wsw	0.7	W2	2.5

B. Pin Diode Modelling

The states of the electronic switch are ON and OFF. They can be realized by biasing the PIN diode in the forward or reverse bias. At the ON state, the switch is forward bias and it has low impedance acts as a short circuit and the current can pass through the diode, while in the OFF state the switch is reversed bias and it presents a high impedance and acts as an open circuit which indicates no current flown through the diode. An electrical circuit is shown in Fig. 2, which explain the forward and reverse biased, where the only resistor of (3.5 ohms) in series with an inductor of (0.15 nH) in the ON state and a combination of (1Kohm) resistor in parallel with the capacitance of (0.025 pF) all in series with an inductor of (0.15 nH) [27].

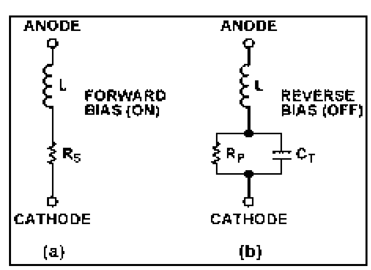


Fig. 2. PIN diode modeling under (a) forward (b) reversed biased condition

III. Results and Discussion

The CST software is used to simulate the proposed reconfigurable multiband MIMO antennas. The obtained multi-bands of the 4-elements MIMO reconfigurable antenna with the (S11) through the two states of the PIN diode are pragmatically shown in Fig. 3, where obtained lowest S11 of (-50 dB) in the (13.95 GHz). There are three resonant frequencies under the (S11 ⩽ -10 dB) condition have resulted in the ON and OFF states of the PIN diode, they are (12, 13.95, and 14.91) GHz, which are applicable to cover Satellite, Radar, and broadband systems, where the 13.95 GHz frequency is obtained from the T-shaped while the 12 GHz and 14.91 GHz frequencies are obtained from the inverted-L shaped sidearms of the patch, after some important parametric study on the antenna dimensions. The gain is ranging from 8 to 10.45 dBi and the maximum simulated gain is 10.45 dB at 17 GHz as shown in Fig. 4. The isolation between the 4-elements is < -17 dB as shown in Fig. 5, and listed in the table IV . The simulated envelope correlation coefficient (ECC) of the proposed 4-elements MIMO antenna is obtained < -0.5 at all resonant frequencies where the worst-case produces (ECC = 0.021) as shown in Fig. 6, which make the proposed antenna can operate in the MIMO system. The diversity gain is around 10 for all the frequency bands as shown in Fig. 7, which is one of the requirements of the MIMO system. The simulated VSWR of the proposed antenna meets the practical requirements of (VSWR ⩽ 2) at all the resulted multiband frequencies, where the VSWR is a measure for how the line is matching with the load.

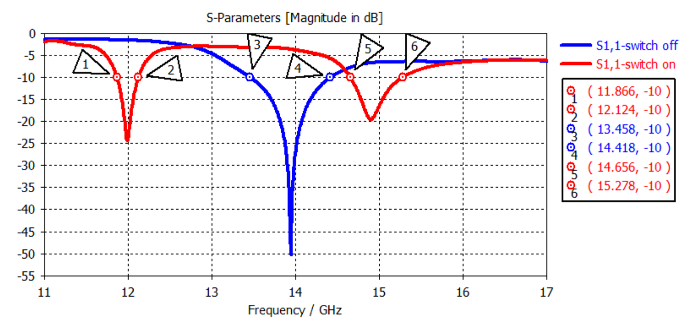


Fig. 3. The simulated (S11) parameter versus frequency of the 4-elements MIMO antenna

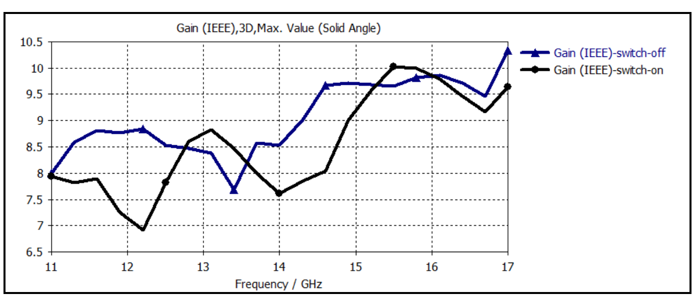


Fig. 4. The gain variation with the frequency of the proposed reconfigurable antenna

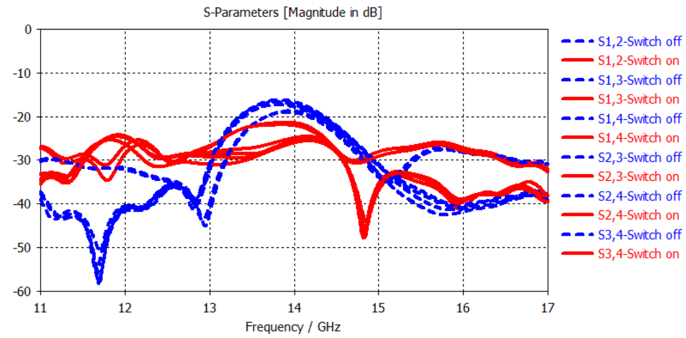


Fig. 5. The simulated isolation of the 4-elements multiband MIMO antenna

TABLE IV. THE ISOLATION OF MULTIBAND 4-ELEMENTS MIMO RECONFIGURABLE ANTENNA

Coupling Coefficients	Frequencies Switch off	Frequencies Switch on	
	13.95 GHz	12 GHz	14.91 GHz
$P_{1,2}$ & $P_{2,1}$	-17.6	-26.4	-41.5
$P_{1,3}$ & $P_{3,1}$	-18.8	-28.6	-28.7
$P_{1,4}$ & $P_{4,1}$	-16.5	-24.5	-39.6
$P_{2,3}$ & $P_{3,2}$	-17	-24.9	-41.1
$P_{2,4}$ & $P_{4,2}$	-19	-26.7	-29.8
$P_{3,4}$ & $P_{4,3}$	-17.1	-24.7	-40.9

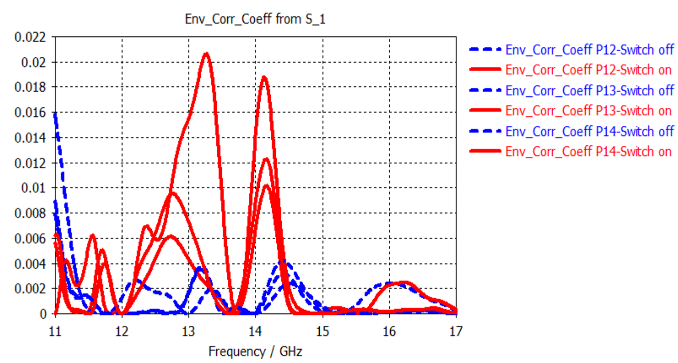


Fig. 6. The simulated envelope correlation coefficients (ECC) of the 4-elements multiband MIMO antenna

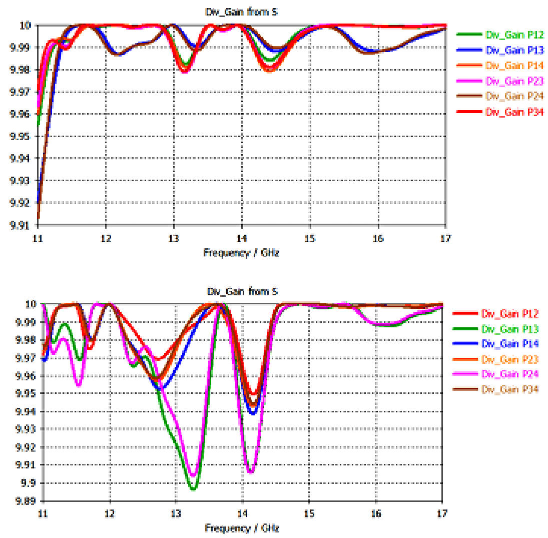
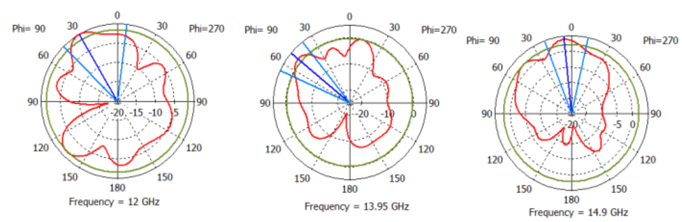
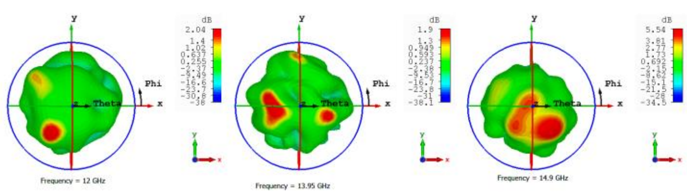


Fig. 7. The simulated diversity gain of the 4-elements multiband MIMO antenna for (a) switch off, (b) switch on.

The 3D radiation pattern of the proposed antenna is shown in Fig. 7, and the 3D surface current distribution for both cases of the PIN diode is shown in Fig. 8. The surface current distribution presented in Fig. 8-b shows the OFF state of the PIN diode where no current flown to the second arm of the patch, while the other state presents the ON state can be shown in Fig. 8-a where the current can flow to the second arm through the PIN diode switch.



(a)



(b)

Fig. 7. The radiation pattern of the proposed reconfigurable MIMO antenna for (a) 2D radiation pattern, (b) 3D radiation pattern.

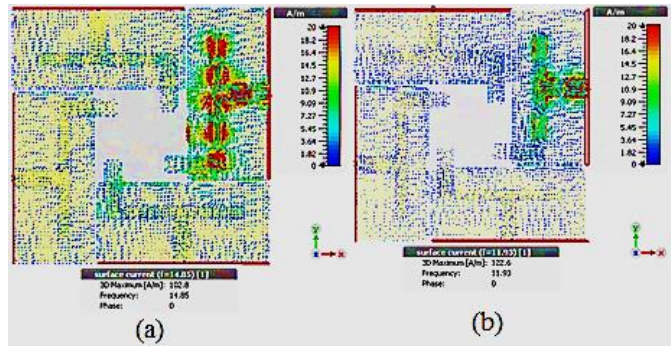


Fig. 8. The (3D) surface current distribution of the proposed MIMO antenna, (a) switch on-state, (b) switch off-state.

TABLE V: A COMPARISON BETWEEN THE PROPOSED MIMO ANTENNA AND THE LITERATURE.

References	**No. of Elements**	**No. and type of switches**	**ECC (≤)**	**Isolation (dB) (≤)**	**Reconfigurable Bands (GHz)**	**Peak gain (dB)**	**Applications**
2	4	12-PIN diodes	0.09	-15	4.5-5.93	-----	High speed WLAN
4	8	8-varactor diodes	0.265	-11	1.6-5.2	3.88	GSM, UMTS, LTE, WiMAX, Bluetooth, WiFi
13	2	4- PIN diodes	-0.01	-15	3.2-5.9	------	Bluetooth, WiMAX, and WLAN
16	2	1-varactor diode and PE42422 discrete switch	0.035	-25	0.44-0.7	------	MIMO applications
18	2	2-PIN	0.05	-15	3.8-4.5	----	Cognitive Radio
20	4	2-varactor	0.248	-12	1.77-2.51	3.89	Cognitive Radio
23	2	2-varactor	0.2	-12	1.41-2.26	2.12	Cognitive Radio
Proposed MIMO Antenna	4	4-PIN diodes	0.021	-15	11.8-15.4	10.45	Satellite, RADAR, and Broadband

IV. CONCLUSIONS

A new compact multiband 4-elements reconfigurable MIMO antenna for wireless communications is presented in this paper with a compact size to meet the requirements for wireless MIMO system integration. The proposed structure operates with only a single PIN diode to obtain three resonant frequency bands appropriate for various wireless applications. The proposed structure is universal in the broadband frequency range and it can be fabricated simply due to a compact size and planar structure, good characteristics such as gain, efficiency, radiation pattern, return loss, ECC, Isolation, and VSWR. The proposed reconfigurable MIMO antenna produced a wide frequency reconfigurability range from 11.7-15.4 GHz. The system has accepted properties to operate in the MIMO system where the worst case of the isolation and ECC are -17 dB and 0.021 respectively.

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