

A single port frequency reconfigurable antenna for underlay/interweave cognitive radio

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ABSTRACT

A frequency reconfigurable antenna is presented in this paper as a novel single port system gathering the functionalities of both underlay and interweave cognitive radio. This $25 \times 30 \times 0.8$ mm³ system involves a wide slot antenna to cover the ultra wide band (UWB) range with resonating stubs that are used to prohibit/work-only-in specific bands within the UWB frequencies. Here, six positive intrinsic negative (PIN) diodes are used to decide the active sections of the antenna that leads to select its operation as UWB/filtering/multiband antenna. Diodes' configuration results in eight useful operation modes that include a scanning mode, four single band-notch modes and three dual band communication modes. The scanning mode covers the entire UWB range while one of the bands allocated for WiMax, Cband, wireless local area network (WLAN) or Xband is to be excluded in each of the band-notch modes. On the other hand, each communication mode is able to work in one of the ranges that cover WiMax/Cband, Cband/WLAN or Xband/international telecommunication union (ITU). S11, realized gain, voltage standing wave ratio (VSWR) outcomes of this design that is simulated by computer simulation technology (CST) v.10 all confirms the proposed system's ability to work in the intended modes. Its novelty to work as interweave/underlay cognitive radio system, highly candidates this design to address many of the UWB communication issues related interference and multiband operation.

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1. INTRODUCTION

High data rates, large operation bandwidth, flat gain, and compactness the merits offered by microstrip ultra wide band antennas were so attractive for the new demands of the fast grow in mobile communications world [1]. But unfortunately, portions of the range (3.1-10.3 GHz) that is declared by federal communications commission (FCC) for ultra wide band (UWB) communications [2] can be used by other wireless technologies like WiMax, Cband, wireless local area network (WLAN), Xband, and international telecommunication union (ITU) that are granted the bands (3.3-3.6 GHz), (3.7-4.2 GHz), (5.15-5.825 GHz), (7.25-7.75 GHz), and (8.02-8.4 GHz) respectively [3]. Clearly, this dual use of the same frequencies by different wireless technologies can result in interference that requires antennas with filtering capabilities to prohibit the undesired radiation. On the other hand, antennas with multiband operation capabilities day after day become a crucial demand for many modern wireless systems to reduce the size,

complexity and cost of the mobile unit. This requires an antenna that can be controlled to work in the desired frequency ranges [4], [5].

Regarded to interfere technologies, underlay cognitive radio based on excluding specific regions within a wide band seems optimum to address this problem. In this approach and as reported in the survived works, an UWB antenna is modified to notch the interfered bands. A positive intrinsic negative (PIN) diode is used to configure the UWB antennas of [6], [7] to filter WLAN frequencies. This diode has the effect to cancel/allow the effect of the u-shaped slot in the feed-line of [6], while it links/splits the halves of the modified circular radiator of [7] and in both designs, this leads the antenna to work either in an UWB mode or in a WLAN-notched mode. The antennas of [8]–[10] are designed to prohibit WiMax/WLAN, WLAN/Xband, and WLAN/ITU respectively. Two PIN diodes inside the forked shaped monopole of [8], four PIN diodes controlling the notching stubs in the back plane of [9] and two PIN diodes within the H-shaped resonator in the rear side of [10] result either in an UWB or a band-reject operation in each of these designs. Triple band exclusion targeting upper and lower regions of WLAN and WiMax frequencies is implemented by six PIN diodes that control the three u-shaped notching stubs of [11].

On the other hand, the second issue regarded to have a single port antenna with multiband operation can be addressed by interweave approach of cognitive. This paper surveys a number of single port antennas that are reconfigurable to work either in the wide or ultra wide band mode or switched/tuned to specific bands within this wide range that accomplish the main goal of interweave cognitive radio. Previous research [12], [13] present circular monopoles that cover the whole range allocated for UWB and can be switched to specific ranges within it. Cui *et al.* [12] reconfiguration to WiMax and WLAN is achieved by three PIN diodes that couple/decouple a microwave filter to the its feed-line, while Jacob and Kulkarni [13] can be switched into fifteen narrow band modes by four PIN diodes used to connect/disconnect the three filtering structures to its feed-line and partial ground. Seven PIN diodes-one in the feed-line and six in the line slot in the ground plane-are used to control the elliptical monopole of [14] to scan UWB and global system for mobile (GSM) regions or to select one of six communication modes. While antennas of previous studies [15], [16] are designed to cover the wide bands (2.35-4.98 GHz) and (4.5-8.45 GHz), they also performs narrow band operation. Plus the wide band mode, antenna is tuneable in [15] three narrow band modes by A PIN diode and a pair of varactor diodes, while [16] depend three PIN diodes to be switch the antenna into one of its four communication modes.

Whereas all the related works, and to the best of author's knowledge work either as underlay or interweave cognitive radio systems, this paper presents a novel design that a single port antenna is designed to cover the UWB range, prohibit radiation in the interfered bands within this range and radiate only in the desired regions of specific wireless technologies. This design that groups the two brands of cognitive radio is built over a $25 \times 30 \times 0.8$ mm³ Rogers RT/duroid 5880 substrate gathers the functionality of underlay and interweave cognitive radio. The proposed work is based on an UWB antenna with stubs added to exclude/allow radiation in specific bands. Six PIN diodes are used to connect/disconnect specific sections of the antenna to work in either the UWB mode, notching WiMax, Cband, WLAN and Xband, or radiating in WiMax/Cband, Cband/WLAN and Xband/ITU regions. Simulation of this design is carried out by CST v.10. The results of input reflection coefficient, realized gain, voltage standing wave ratio (VSWR) and surface current all proofs the feasibility of this compact and simple design as an underlay/interweave single port antenna that can be used for various cognitive radio applications.

2. ANTENNA DESIGN

A two-sided $25 \times 30 \times 0.8$ mm³ Rogers RT/duroid 5880 substrate is the base where the antenna in this paper is to be constructed. Copper thickness on each side of this substrate is 0.035 mm while it has a 2.2 relative permittivity and 0.0009 tangential loss. The final geometry of the proposed design is shown in Figure 1, where Figures 1(a) and (b) display the front and rear palnes of the design respectively with the following dimensions in mm.

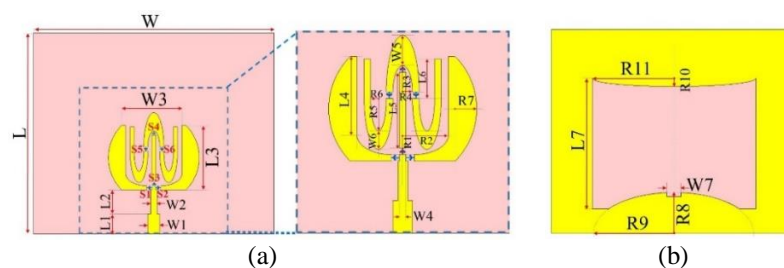


Figure 1. Antenna geometry: (a) front plane, (b) rear plane

$L=25, L1=2.5, L2=3, L3=8, L4=6, L5=5.8, L6=3, L7=16, W=30, W1=1.5, W2=0.75, W3=8, W4=0.5, W5=2.3, W6=1.4, W7=1.75, R1=1.5, R2=3.5, R3=2, R4=0.75, R5=2.5, R6=0.6, R7=2.2, R8=5, R9=10, R10=1, \text{ and } R11=10.$

Final design is accomplished through a sequence of steps that firstly aims covering the UWB range by a wide slot antenna. Design procedure then involves modifying this UWB antenna by inserting stubs with different shapes to get band-reject and multiband operation. Finally, switching elements are incorporated to reconfigure the antenna to the desired operation mode.

2.1. UWB operation

In this design, the UWB antenna that is the keystone of the cognitive radio system is deduced from a square patch wide slot antenna. This antenna is subjected to sequential modifications until covering the UWB range. These modifications can mainly be illustrated by the designations (a-b) of Figure 2. S11 (stands for input reflection coefficient) response of the $8 \times 8 \text{ mm}^2$ square patch of designation -a- that only covers the band (3.13-5.81 GHz) is enhanced to cover a wider band (3.15-10.4 GHz) in -b-. This is mainly due to curving the upper and lower edges of the ground slot, having a graded feed-line and removing a rectangular slit from the ground plane just below the feed-line end. Bowing the sides of the patch results in better response as seen in the S11 curve related to designation -c-. Finally, making a slot in the central part of the patch as illustrated in designation -d- results not only in covering the whole UWB range but also in providing the space to include the stubs that will cause the notching/communication behavior of this antenna.

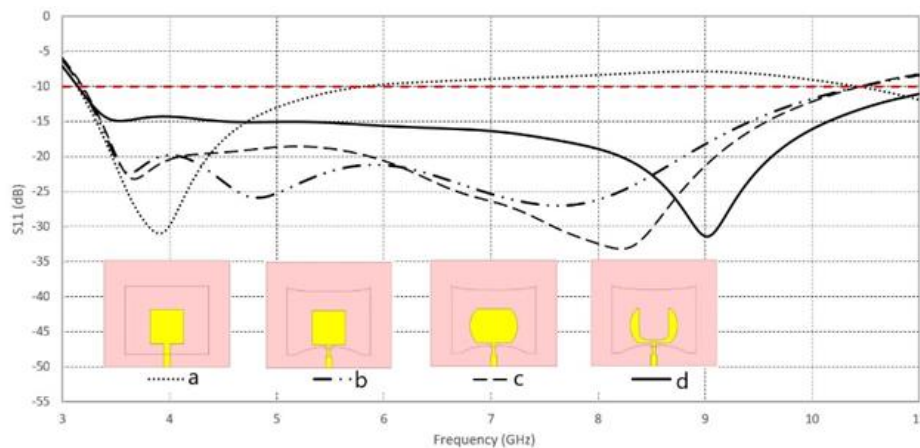


Figure 2. S11 as an UWB antenna

2.2. Band-notch/communication operation

The space created inside the antenna patch is the place to build the structures responsible for filtering/communication processes. The first structure to be attached to the patch is a bar shape stub. This l-stub when inserted in the center of the patch slot and with proper dimensions will result in notching Xband frequencies as shown in Figure 3(a). To block another band, a \cap -stub with proper parameter values is linked the l-stub. The resultant structure will ban WLAN frequencies as shown in Figure 3(b). Another band exclusion can be obtained when a j-stub is connected to one of the ends of the \cap -stub as illustrated in Figure 3(c).

This will lead to prohibit the Cband frequencies when considering the optimum dimensions of the inserted stub. Finally, having another j-stub on the opposite side of the \cap -stub will shift the notched band to the WiMax region as seen in Figure 3(d). As it was mentioned here that dimensions of the of these stubs are chosen to fit the desired excluded frequencies. So, these dimensions are optimized by lots of parametric iterations in the simulation where samples of them are illustrated in Figures 3(a)-(d).

While these attached stubs have the effect of blocking specific bands within the UWB range, they can also be used to get the multiband operation. To achieve this goal, the main patch of the antenna has to be disconnected in order to cancel the UWB operation. Then the feed-line is to be linked to the inserted stubs. As it can be seen in Figure 4(a) that the l-stub that is added to notch Xband in the previous paragraph will result in an antenna that works in Xband and ITU regions. Another dual band operation including WiMax and Cband will be obtained by linking the inverted \cap -stub to the l-stub as seen in Figure 4(b). Again, it deserves to mention that many parametric trials are needed to get the results where samples of them are included in Figure 4.

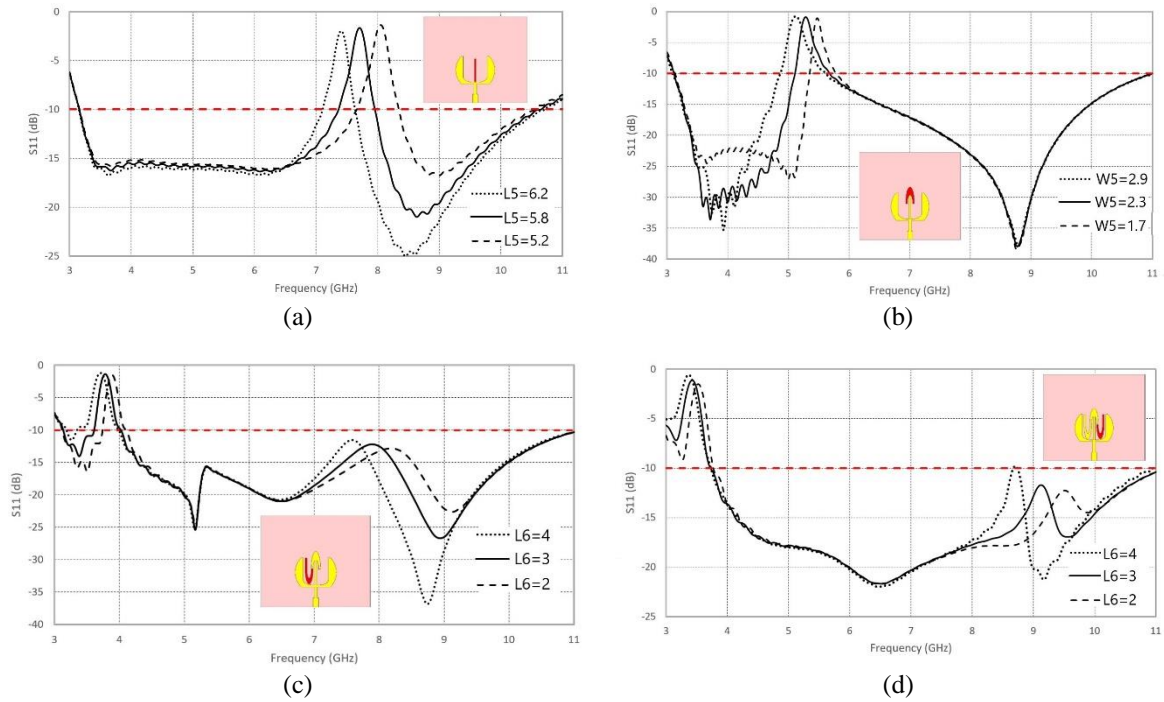


Figure 3. S11 as a band-notch antenna that rejects: (a) Xband, (b) WLAN, (c) Cband, and (d) Xband

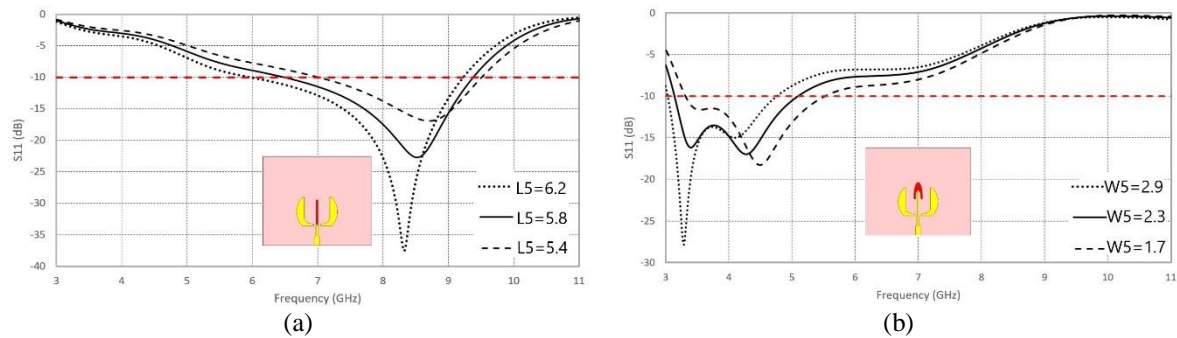


Figure 4. S11 as a communication antenna that works in (a) Xband+ITU and (b) WiMax+Cband

2.3. Configuration

Clearly, this antenna needs switching elements that can link/dislink the stubs as intended. PIN diodes are widely used as switching elements in reconfigurable antennas [17], [18]. In this design, six HPND-4005 PIN diodes [19] are inserted to select its mode of operation. Reverse/forward biasing of PIN diode leads the diode to act as open/short circuit. The equivalent circuits of the HPND 4005 PIN diode in its ON and OFF states are shown in Figure 5(a) and Figure 5(b) respectively. As useable operation modes, the configuration of the diodes in this work produces only eight modes. These modes, related switching state of the six diodes (denoted as S1, S2, S3, S4, S5, and S6) and other operation details are listed in Table 1.

Table 1. Configuration of the proposed cognitive radio system

Mode	S1	S2	S3	S4	S5	S6	Cognitive radio	Functionality	Targeted bands
U	1	1	0	0	0	0	Underlay/interweave	Scanning	UWB
N#1	1	1	1	1	1	1	Underlay	Band-notching	WiMax
N#2	1	1	1	1	1	0	Underlay		Cband
N#3	1	1	1	1	0	0	Underlay		WLAN
N#4	1	1	1	0	0	0	Underlay		Xband
C#1	0	0	1	1	0	0	Interweave	Communication	WiMax+Cband
C#2	1	0	0	0	0	0	Interweave		Cband+WLAN
C#3	0	0	1	0	0	0	Interweave		Xband+ITU

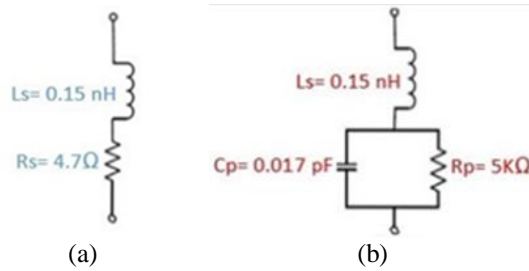


Figure 5. HPND-4005 PIN diode equivalent circuit in the (a) ON-state and (b) OFF-state

3. RESULTS AND DISCUSSIONS

Results that show the functionality of this single port cognitive radio system for both underlay and interweave operation are presented in this section. Starting by input reflection coefficient which is one of the basic parameters that decides the operation bandwidth of the antenna by indicating the reflected power due to termination mismatch, Figure 6(a) shows that a (-10 dB) bandwidth is obtained along the UWB when S1 and S2 are in ON state and all other switches are in OFF state. Changing the configuration of the six diodes to that in modes N#1, N#2, N#3, or N#4 of Table 1, it can be seen that S11 is above (-10 dB) line for the bands (3.1-3.75 GHz), (3.7-4.15 GHz), (5.15-5.72 GHz), and (7.17-7.86 GHz) which blocks WiMax, Cband, WLAN, and Xband respectively as shown in Figure 6(b). By turning diodes' states to one of the modes C#1, C#2, or C#3; S11 results of Figure 6(c) show that this antenna functions as a dual band communication antenna. It can be seen here that the S11 response is (-10 dB) for the bands (3.14-5.25 GHz), (3.68-6.56 GHz), and (6.38-9.47 GHz) in the dual band operation covering WiMax/Cband, Cband/WLAN, and Xband/ITU respectively.

The plot of Figure 7(a) exhibits a satisfactory gain along the band (3.1-10.6 GHz) with a maximum value that exceeds (4.5 dBi) at (7 GHz). While configuring the antenna in a notching mode will result in a sudden reduction in the gain value that drops to (-0.8 dBi), (-2.3 dBi), (-1.8 dBi), and (1.4 dBi) at (3.4 GHz), (3.8 GHz), (5.4 Hz), and (7.4 GHz) in the gain plots of N#1, N#2, N#3, and N#4 respectively as illustrated in Figure 7(b). On the other hand, setting the antenna to the configuration of modes C#1, C#2 and C#3 result in a positive gain that exceeds (3 dB) along each of the targeted bands. This can be seen in Figure 7(c) where peak values of (3.8 dBi), (4 dB), and (4.4 dBi) are achieved for the communication modes of WiMax/Cband, Cband/WLAN, and Xband/ITU respectively.

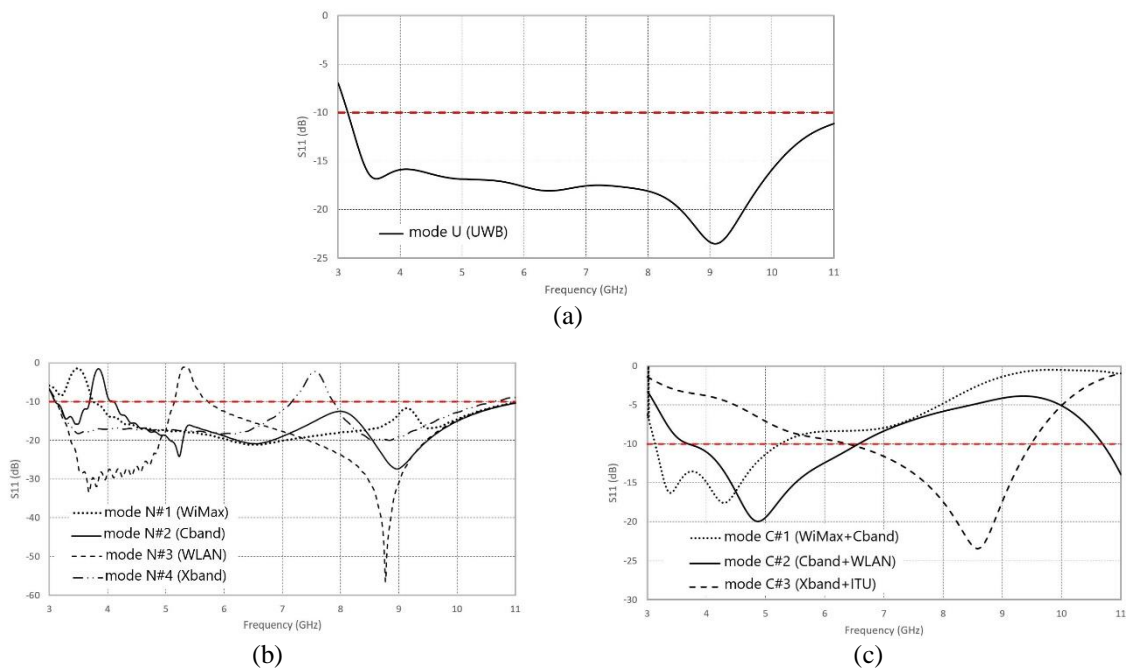


Figure 6. S11 Of the antenna at: (a) UWB mode, (b) band-notch modes, and (c) communication modes

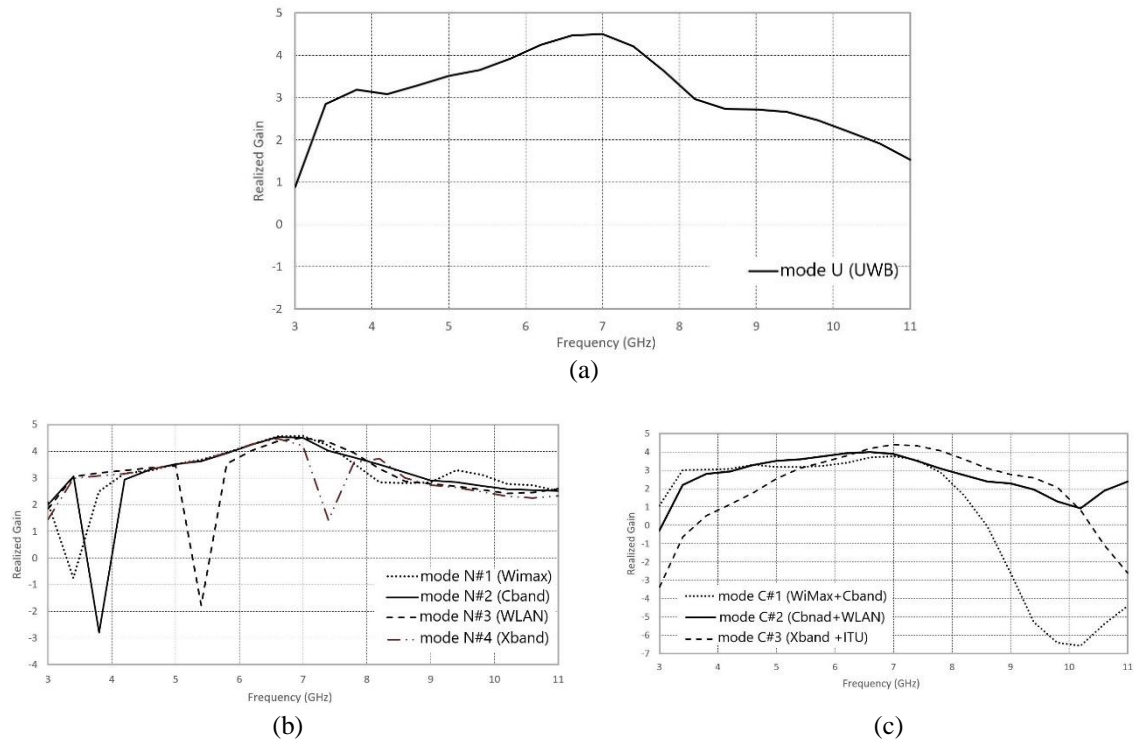


Figure 7. Realized gain of the antenna at: (a) UWB mode, (b) band-notch modes, and (c) communication modes

Furthermore, VSWR results of Figure 8 indicate good rejection characteristics. This is clear from VSWR curves that are greater than 2 across each of the bands to be rejected with high peak values reach (12.2), (11.4), (16.7), and (7.8) at (3.5 GHz), (3.9 GHz), (5.4 GHz), and (7.6 GHz) for excluding WiMax, Cband, WLAN, and Xband respectively.

An interpretation of antenna behavior at different operation modes can be understood by surface current distribution. In the UWB mode, Figures 9(a)-(d) show that surface current nearly has the same distribution at (3.5 GHz), (5.5 GHz), (7.5 GHz) and (9.5 GHz) respectively. It can be seen that at these four frequencies within the UWB range the surface current is mainly concentrated in the feed-line and the two sides of the patch. Figures 10(a) through 10(d) on the other hand, show that large portion of the current will be focused in the stubs responsible for band-notching in each underlay mode. Current distribution of modes C#1 and C#2 illustrated in Figure 11(a) and Figure 11(b) demonstrate that majority of the current will be concentrated in the I and $I\cap$ stubs with minor distribution at the deactivated sides of the patch. Finally, for the mode C#3 the current is focused only in the connected side of the patch as presented in Figure 11(c).

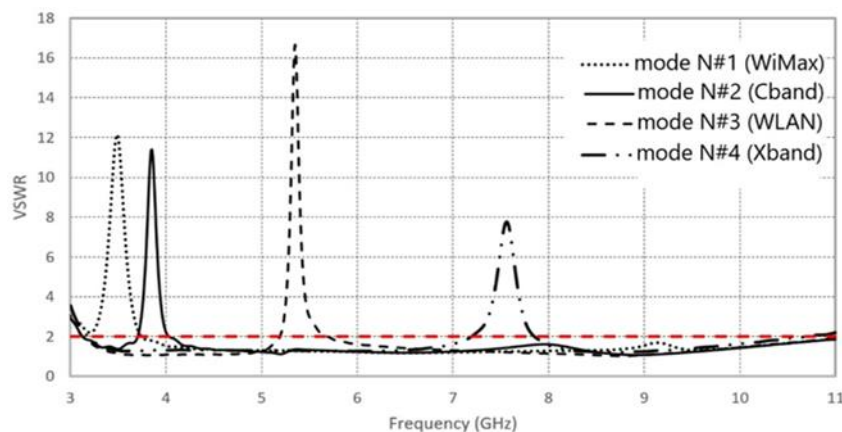


Figure 8. VSWR of the antenna at the band-notch modes

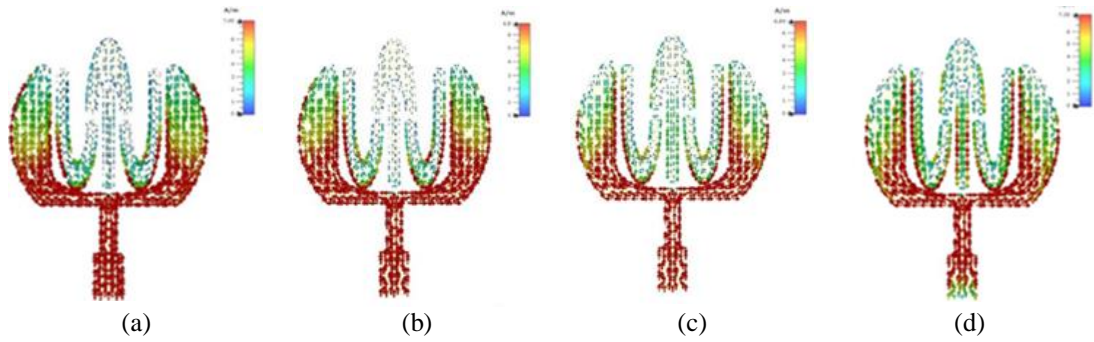


Figure 9. Antenna's patch surface current of the UWB mode at: (a) 3.5 GHz, (b) 5.5GHz, (c) 7.5 GHz, and (d) 9.5 GHz

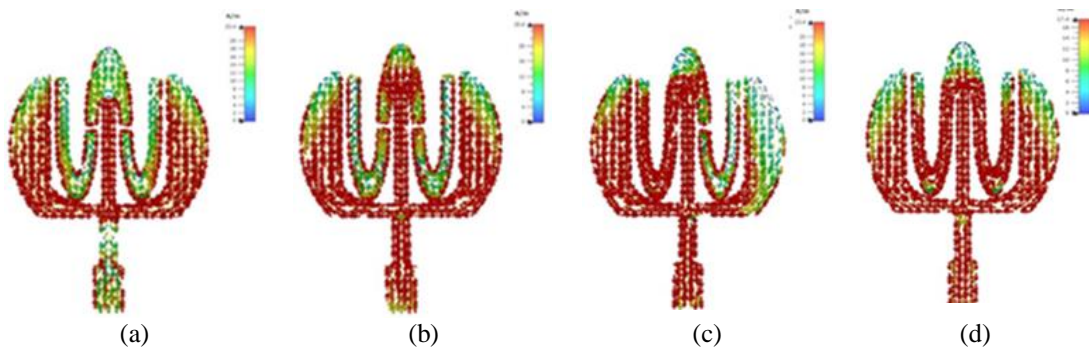


Figure 10. Antenna's patch surface current of the band-notch modes in: (a) mode N#4 at 7.6 GHz, (b) mode N#3 at 5.4 GHz, (c) mode N#2 at 3.9 GHz, and (d) mode N#1 at 3.5 GHz

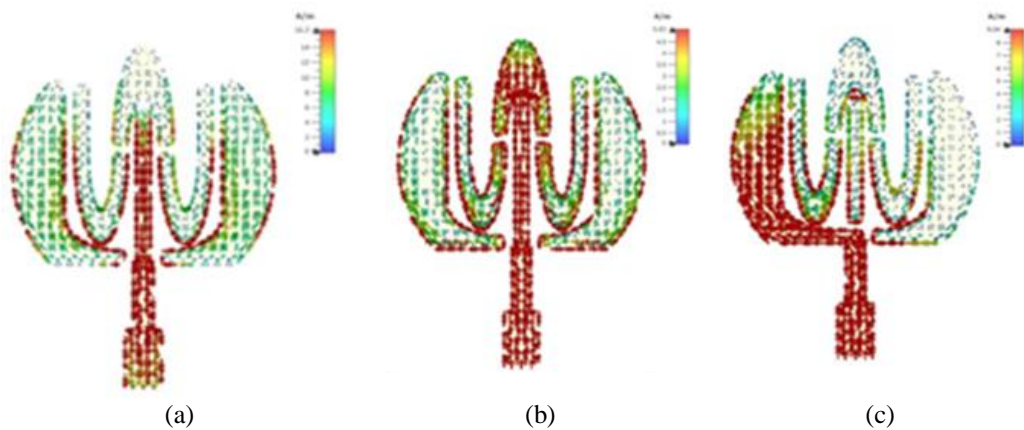


Figure 11. Antenna's patch surface current of the communication modes in: (a) mode C#1 at 4.2 GHz, (b) mode C#2 at 4.8 GHz, and (c) mode C#3 at 8.8 GHz

This work is compared to the recent single port cognitive radio designs. This comparison listed in Table 2 considers antenna size, number of switches, type of cognitive radio, number of operation modes, UWB coverage and the targeted bands. Even when it seems that some of the previous works overcomes this design in one of the comparison aspects, but this design beats them in an important and a novel aspect. This aspect is based on presenting a single port underlay/interweave cognitive radio system and of course without forgetting the other comparison items. Contrastly, none of the previous works combines both functionalities of underlay and interweave cognitive radio in single port antenna.

Table 2. Comparison with single port cognitive radio systems

Ref.	Size (mm ³)	Diodes		Cognitive radio	Op. modes	UWB	Notched bands	Comm. bands
		PIN	Var.					
[6]	30×40×0.787	1	-	Underlay	2	Yes	WLAN	-
[7]	17×19.5×1.6	1	-	Underlay	2	Yes	WLAN	-
[8]	20×20×0.8	2	-	Underlay	4	Yes	WiMax, WLAN	-
[9]	26×28×0.8	4	-	Underlay	4	Yes	WLAN, Xband	-
[10]	22×30×0.76	2	-	Underlay	2	Yes	WLAN, ITU	-
[11]	26×40×0.787	6	-	Underlay	8	Yes	WLAN, Xband	-
[19]	25×25×0.8	4	-	Underlay	12	Yes	WiMax, Cband, WLAN, Xband, ITU	-
[20]	36×32×1.6	3	-	Underlay	4	Yes	WiMax, WLAN	-
[21]	25×29×1	3	-	Underlay	8	Yes	WiMax, WLAN, ITU	-
[22]	35×41×1.5	5	-	Underlay	3	Yes	WiMax, WLAN	-
[23]	28×28×0.8	3	-	Underlay	5	Yes	WiMax, WLAN, ITU	-
[24]	27×32×1.6	3	-	Underlay	4	Yes	WiMax, WLAN	-
[25]	38×40×1.59	4	-	Underlay	7	Yes	WiMax, WLAN, Xband	-
[26]	26×38×1.5	3	-	Underlay	4	Yes	WiMax, WLAN	-
[27]	30×40×0.78	1	-	Underlay	2	Yes	WiMax	-
[12]	40×29×0.5	3	-	Interweave	2	Yes	-	WiMax, WLAN
[13]	40×40×1.6	4	-	Interweave	16	Yes	-	WiMax, Cband, WLAN, Xband, ITU
[14]	135×90×1.6	6	-	Interweave	7	Yes	-	CDMA GSM, UMTS, WLAN, WiMax
[15]	50×30×1.52	1	2	Interweave	4	No	-	WiMax, Cband
[16]	30×15×1.6	3	-	Interweave	5	No	-	WLAN, 5G- sub-6GHz, Xband
[28]	70×60×1.58	2	2	Interweave	5	No	-	LTE bands 7/38/40/41
[29]	88×88×1.6	4	-	Interweave	8	No	-	WLAN, WiMax
[30]	32×24×5	3	1	Interweave	8	No	-	WLAN
Prop.	25×30×0.8	6	-	Underlay/Interweave	8	Yes	WiMax, Cband, WLAN, Xband	WiMax, Cband, WLAN, Xband, ITU

4. CONCLUSION

This paper presents a single port antenna system that can be configured for working as an UWB antenna, filtering WiMax/Cband/WLAN or Xband from the UWB radiation, or working in dual band modes covering WiMax/Cband, Cband/WLAN and Xband/ITU frequencies. This design is reconfigurable via six PIN diodes that connects/disconnects specific antenna sections that in turn decides the mode of operation. Configuration states results in eight operation modes including one UWB mode, four band-notch modes and three communication modes. This design is unique and novel as compared to previous designs where its novelty based on gathering underlay and interweave cognitive radio in a single port design. Input reflection coefficient, realized gain and VSWR results beside the compact size and ease to choose or reject the regions of operation all support the feasibility of the proposed system as a multifunction cognitive radio system.

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