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A reconfigurable dual port antenna system for underlay/interweave cognitive radio

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ABSTRACT

An antenna system that is reconfigurable in frequency is presented in this paper as a novel dual port design that serves both undelay and interweave cognitive radio. This 25×40×0.8 mm3 system is composed of two wide slot antennas: the first is designed as an ultra-wideband (UWB) antenna with controllable band rejection capabilities, while the second antenna is reconfigurable for communication purposes. Three slots are etched into the patch of the UWB antenna to obtain band notching in wireless local area network/Xband/International Telecommunication Union bands (WLAN/Xband/ITU) bands which can be controlled by a positive-intrinsic-negative (PIN) diode across each slot. The configuration states of these three diodes are all useable that produces seven band rejection modes plus the UWB operation mode. The second antenna is configured by five PIN diodes to operate either in Cband, WLAN or Xband regions which results in three interweave modes when setting the first antenna for UWB sensing. The design is simulated by computer simulation technology (CST) v.10. S21 results shows good isolation while input reflection coefficient and realized gain results prove system's scanning, filtering and communication capabilities. This system is new that it gathers the undelay/interweave operation in a single design and when considering its large number of operation modes it looks adequate for many cognitive radio applications.

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1. INTRODUCTION

Since 2002, the year when the (3.1-10.3 GHZ) range is declared for ultra-wideband (UWB) by Federal Communications Commission (FCC) [1], this range has gained a growing interest in the world of wireless communications. Features of this range including depressed consumption of power, broad operation band and high throughput [2] made it so favorable for a verity of applications in wireless communications including internet of things (IoT), radar, and medical imaging [3], [4]. Despite of its merits, the main challenge for those want to utilize this wide range is the congestion with many coexist wireless technologies that has been already licensed within the borders of the UWB rang like WiMax (3.3-3.6 GHz), C-band (3.7-4.2 GHz), wireless local area network (WLAN) (5.15-5.825 GHz), Xband (7.25-7.75 GHz) and International Telecommunication Union (ITU) (8.02-8.4 GHz) [5].

Fortunately, cognitive radio, offers a good solution to this problem. This technology which is capable to reduce or eliminate interference effect of wireless technologies that share or use the same frequencies has two directions to address the problem; underlay and interweave [6]. The interweave approach aims to make use of unutilized regions of licensed bands within the UWB spectrum. This can be realized first by scanning the wide range then transmit in unused targeted regions. Whereas the underlay approach avoids transmission in the interfered regions within the UWB by excluding them from the radiation of the underlay system.

For interweave cognitive radio, the designs surveyed in this work share in having a sensing antenna for scanning the UWB range and reconfigurable antenna for communication purposes. The monopole communication antenna of [7] can be tuned into ten narrow bands within the C-band and WLAN frequencies by means of a positive-intrinsic-negative (PIN) diode and a varactor diode inserted into its radiating stub. Two PIN diodes are used to reconfigure the modified triangular monopole of [8] into one of four communication bands that lies in the WLAN range. The reconfigurable antenna of [9] use three PIN diodes to attain four communication states where two of them targeting the WiMax and WLAN spectrum within the UWB. A multifunctional dual port antenna system is presented in [10] where its frequency reconfigurable section can be adjusted into five cases depending on the configuration of its five PIN diodes. The system in [11] can be tuned by a varactor diode placed across its patch slot into one of three bands within WLAN frequencies. The half elliptical monopole of the scanning antenna in [12] is used as a ground plane for its communication slot antenna that can be set by a varactor diode and a PIN diode to operate in one of eight bands within the range (0.8-2.9 GHz). The design of [13] that also uses the UWB antenna as aground for the communication antenna has a varactor diode inserted into the circular slot of its patch in order to tune the communication antenna in six resonance frequencies within the WLAN range.

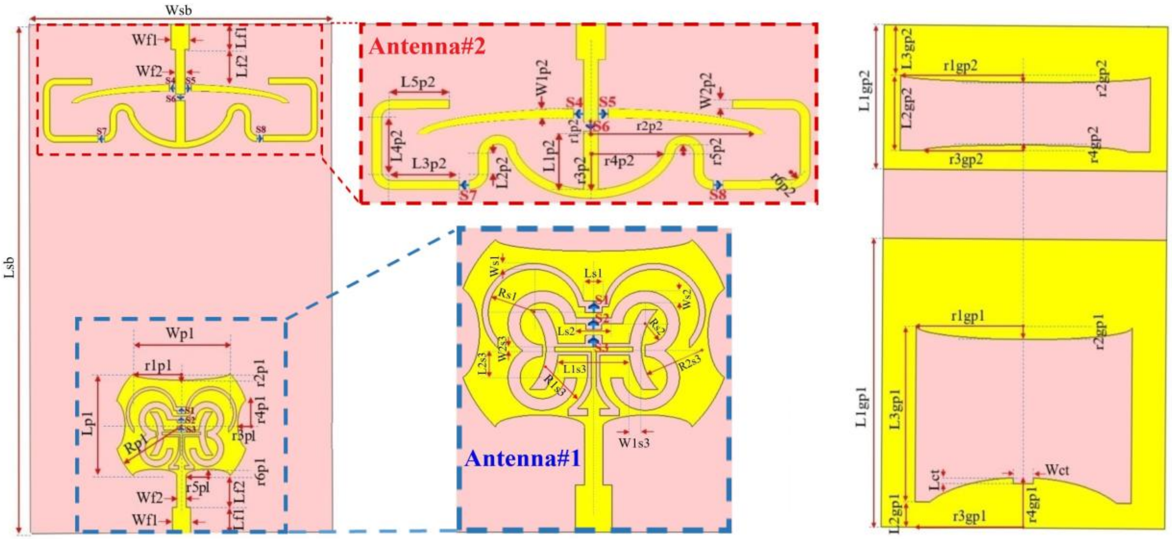
On the other hand, this paper surveys works related underlay, the second approach of cognitive radio. The antennas of these works are designed to cover the UWB with controllable notching of interfered band(s). In [14], on demand exclusion of WLAN from the UWB radiation is implemented by a PIN diode in the U-slot of the feedline of the antenna. The same goal is achieved in [15] by the PIN diode used to join/disjoin the two halves of its modified circular patch. Single/dual band notching is attained in the designs of [16], [17]. The antenna of [16] presents a quad mode reconfigurable fork shaped monopole that has two PIN diodes used for WiMax/WLAN exclusion. Four operation modes are also provided in [17] that notches WLAN/Xband by two pairs of PIN diodes that links/dislinks the resonating stubs in the ground slot. Two PIN diodes are used in the H-shape resonating element at the backside of [18] to mask WLAN/ITU from UWB range. Another single/dual notching effect is obtained by two slots at the feedline and patch of [19] that are controlled by two PIN diodes to prohibit WLAN and/or WiMax regions. Eight operation states excludes upper and lower WLAN regions plus the X-band frequencies resulted from the configuration of the three pairs of PIN diodes in [20].

Gathering the functionality of both underlay/interweave systems is the main goal of the antenna system in this design. To our best knowledge, this is the first design that has the capability to work as an UWB system for scanning, communicate in specific bands and prohibit specific regions within the UWB range. In this paper, a dual-port antenna system that serves both underlay/interweave cognitive is presented. The system composed of an UWB antenna that is used for scanning purposes. This antenna is modified by etching three slots to notch (WLAN/Xband/ITU). Three PIN diodes in these slots enables the reconfiguration of this antenna to work in single/dual/ triple notching modes. The second antenna is used as communication antenna in the interweave mode. The radiating stub length of this antenna can be controlled by five PIN diodes that enables the antenna to radiate in Cband/WLAN/Xband regions. Simulation of the proposed system is carried out using CST v.10 where input reflection coefficient, realized gain and mutual coupling all evidence the functionality of the system as an underlay/interweave multimode cognitive radio antenna system.

2. SYSTEM DESIGN

The design in this work is constructed over a two-sided 0.8 mm Rogers RT/Duroid 5880 substrate. It occupies a 40×25 mm^2 of this substrate that has a relative permittivity of 2.3 and tangential loss of 0.0009. Final geometry of this dual port system, that is illustrated in Figure 1(a) for the front plane and Figure 1(b) for the back plane, is mainly carried out through a four-step procedure. The first step is to design the UWB antenna named Antenna#1 for UWB scanning. The next is to etch the slots responsible of rejecting undesired bands into the patch of this antenna. The third step is to design the second antenna named Antenna#2 accountable for communication in the coveted frequency bands and finally controlling the operation of the system by proper configuration of its switching elements.

The proposed design is optimized and its final parameters in mm are: Substrate: Lsb=40, Wsb=25; feeds: Lf1=2, Lf2=2.5, Wf1=1.5, Wf2=0.75; Antenna#1 Patch: Lp1=8, Wp1=8, Rp1=5.6, r1p1=0.5, r2p1=4, r3p1=1, r4p1=4, r5p1=1, r6p1=1.8, Ls1=0.8, Ws1=0.25, Rs1=1.85, Ls2=1.45, Ws2=0.5, Rs2=0.9, L1s3=2.9, L2s3=1.55, W1s3=0.5, W2s3=0.2, R1s3=1.85, R2s3=2.5; Antenna#2 patch: L1p2=3.25, L2p2=1, L3p2=3.5, L4p2=3, L5p2=3, W1p2=0.5, W2p2=0.5, r1p2=1.5, r2p2=8.5, r3p2=3, r4p2=3, r5p2=0.5; ground plane: L1gp1=23, L2gp1=2, L3gp1=14, Lct=0.5, Wct=1.75, r1gp1=9.5, r2gp1=1, r3gp1=9.5, r4gp1=4, L1gp2=11.5, L2gp2=6, L3gp2=9, r1gp2=11, r2gp2=0.5, r3gp2=9, r4gp2=0.5.



(a) (b)

Figure 1. Antenna system geometry (a) front plane and (b) back plane

2.1. UWB antenna

For both underlay and interweave systems, the UWB antenna is the corner stone. This design depends a wide slot antenna with a rectangular radiating stub that pass through many progressive modifications to achieve the goal of scanning the 7.5 GHz allocated for UWB range. For this antenna named Antenna#1, the main modifications with the corresponding input reflection coefficient are shown in Figure 2.

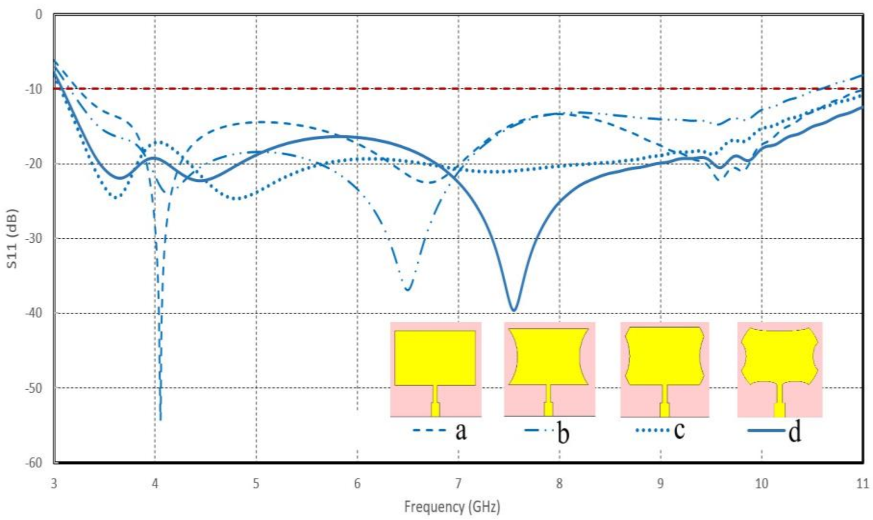


Figure 2. S11 of Antenna#1 as an UWB antenna

2.2. Notch creation

For underlay CR, interference bands have to be excluded from the UWB radiation. To accomplish this objective, three slots are etched symmetrically along the longitudinal axis Antenna#1 radiating stub.

These openings are implemented as $\lambda_g/2$ slots [21], where the length of slot (L_{slt}) basically determines the notched frequency (f_n).

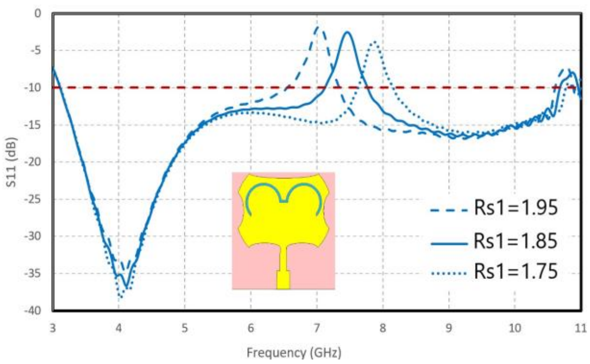
$$L_{slt} \approx \frac{\lambda_g}{2} \tag{1}$$

$$f_n = \frac{c}{\lambda_g \sqrt{\varepsilon_e}} \tag{2}$$

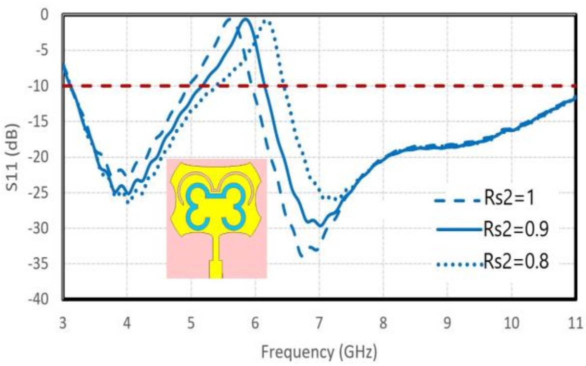
$$\varepsilon_e \approx \frac{\varepsilon_r + 1}{2} \tag{3}$$

Where λ_g: guided wavelength, *c*: velocity of light, ε_e: effective permittivity, and ε_r: relative permittivity.

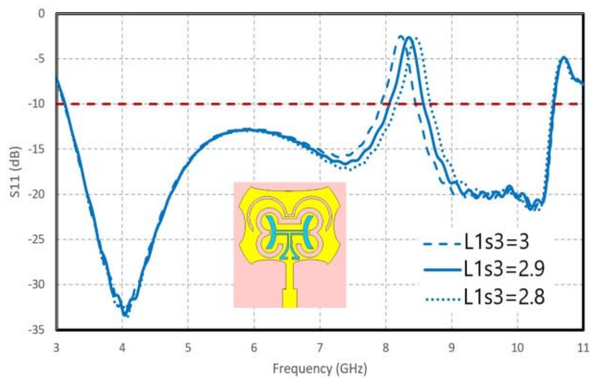
The first slot takes the shape of an inverted (3) and used to exclude X-band. Two face-to-face 3-shaped slots are linked to get a total slot length that causes prohibiting the WLAN frequencies. The third slot is formed by joining an inverted Y and H shape slots and results in blocking the ITU spectrum. The effect these slots produce on S11 response of Antenna#1 when changing a specific parameter in each slot is shown in Figure 3. This effect is illustrated for parameters Rs1, Rs2 and Ls1 in Figure 3(a), 3(b) and 3(c) respectively.



(a)



(b)

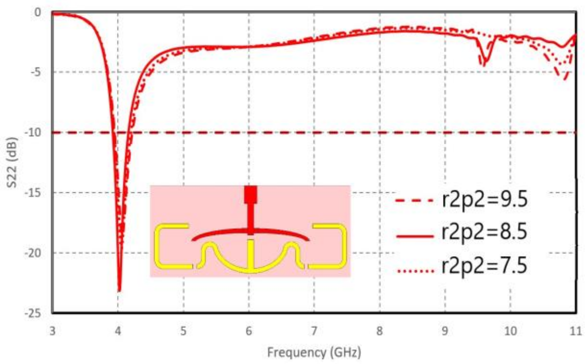


(c)

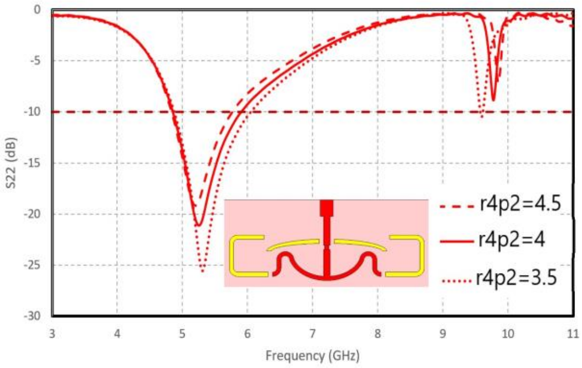
Figure 3. S11 of Antenna#1 as an UWB antenna with band rejection: (a) Xband, (b) WLAN, and (c) ITU

2.3. Communication antenna

As an interweave system, another antenna has to be built for communication purposes. This antenna -named Antenna#2- is designed as reconfigurable slot antenna. This antenna composed of several sections that when joined/disjoined result in changing radiator length and thus affecting the resonance frequency. This antenna can be configured to radiate in C-band, WLAN or Xband regions. Altering the parameters regarding the sections of this antenna affects its operation as shown in Figure 4. The parameters that are selected here are r2p2, r4p2 and L5p2 and their effect on S11 is illustrated in Figures 4(a), 4(b) and 4(c) respectively.



(a)



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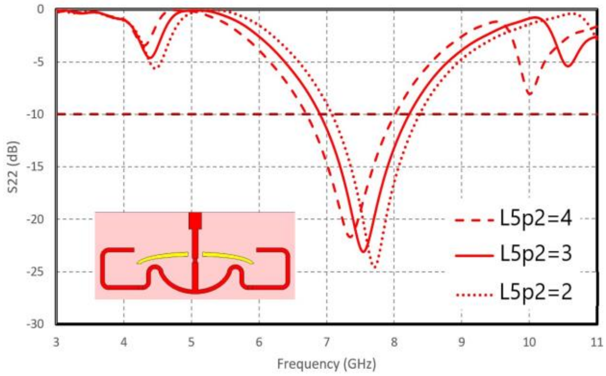


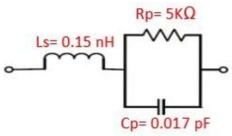
(c)

Figure 4. S22 for Antenna#2 as a communication antenna at (a) Cband, (b) WLAN, and (c) Xband

2.4. System configuration

All modes underlay or interweave operation modes of the proposed system have to be controllable. The system is controlled by switches that can be configured to decide its operation mode. PIN diodes are among the most commonly used elements for switching purposes in reconfigurable antennas [22]. HPND-4005 PIN diodes [23], [24] are utilized for the eight switches of this design. These diodes can be configured to act as short/open circuit due to the values of Rs/Cp of their forward/reverse biasing equivalent circuits illustrated in ON/OFF states as illustrated in Figures 5(a) and 5(b). All operation modes of this antenna with the related switch configuration and targeted bands are tabulated in Tables 1 and 2.

(a)



(b)

Figure 5. HPND-4005 equivalent circuits at (a) ON-state and (b) OFF-state

Table 1. Underlay operation modes

Mode	S1	S2	S3	Rejected bands	Rejection state
U#1	1	1	1	UWB (No band rejection)	No-band rejection
U#2	0	1	1	Xband	
U#3	1	0	1	WLAN	Single-band rejection
U#4	1	1	0	ITU	
U#5	0	0	1	WLAN+Xband	
U#6	0	1	0	Xband+ITU	Dual-band rejection
U#7	1	0	0	WLAN+ITU	
U#8	0	0	0	WLAN+ Xband +ITU	Triple-band rejection

Table 2. Interweave operation modes

Mode	S1	S2	S3	S4	S5	S6	S7	S8	Comm. band	Scan. band
I#1	1	1	1	1	1	0	0	0	Cband	UWB
I#2	1	1	1	0	0	1	0	0	WLAN	UWB
I#3	1	1	1	0	0	1	1	1	Xband	UWB

3. RESULTS AND DISCUSSION

The design is capable to handle both undelay and interweave functionality that is evidenced by input reflection coefficient results of this antenna system. Working in the undelay modes, only Antenna#1 is considered, here good S11 response that covers the whole UWB is seen in Figure 6(a) where the all-PIN diodes are enabled. A large operation bandwidth is shown in each of the curves of Figure 6(b) with a complete exclusion of the targeted interfered band (WLAN, Xband or Cband) from the UWB by disabling the intended switch (S1, S2, or S3). Dual-band notch can be obtained by reverse biasing any two diodes in Antenna#1 that results in one of the curves of Figure 6(c) where each show two notches that almost blocks the frequencies of two of the three targeted bands. Finally, when all switches act as open circuits, Figure 6(d) shows that S11 at the WLAN, Xband and ITU regions is above the -10 dB line that leads to the triple band rejection mode.

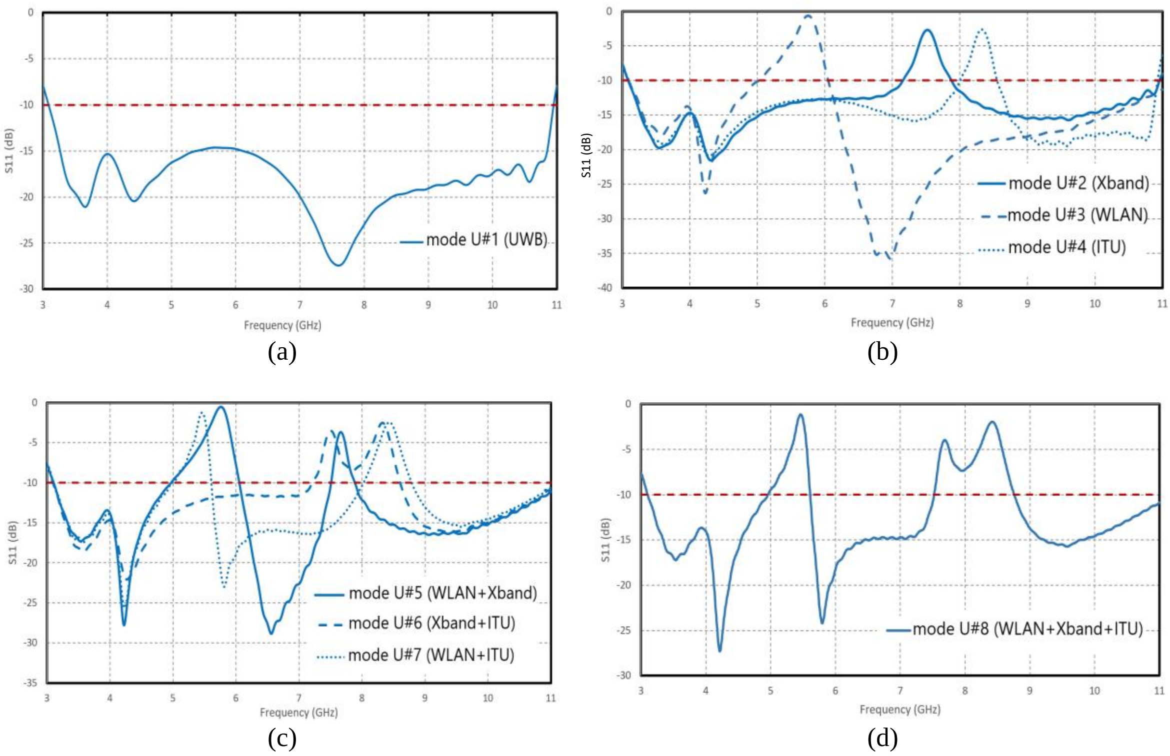


Figure 6. S11 of Antenna#1 at (a) UWB mode, (b) single-band rejection modes, (c) dual-band rejection modes, and (d) triple-band rejection mode

On the other hand, to enable interweave operation, both antennas of this dual port antenna system have to be considered. All interweave modes requires enabling the three diodes of Antenna#1 in order to achieve the scanning functionality. Antenna#2 input reflection coefficient curves in Figure 7 show an S22 response below the -10 dB line for C-band when the switch pair S4 and S5 is enabled. While having only S6 in the ON state causes the antenna to act as WLAN antenna. Moreover, having S6 in ON state while enabling the pair S7 and S8 shift the operation region to the Xband.

Figure 8 presents the outcomes related the realized gain of the antenna system in its underlay operation. It exhibits nearly a flat gain in the UWB mode with a peak value exceeds the 4 dB value as illustrated in Figure 8(a). A single sharp and sudden decrease is observed in the value of the gain in each of the single-band notched modes especially in WLAN region where the value is nearly -12 dB as shown in

Figure 8(b). Each curve in Figure 8(c) has two reductions in the targeted notched bands of its dual-band rejection modes. Finally, the value of the realized gain is lowered to negative values at WLAN, Xband and ITU regions in the triple-band rejection curve of Figure 8(d).

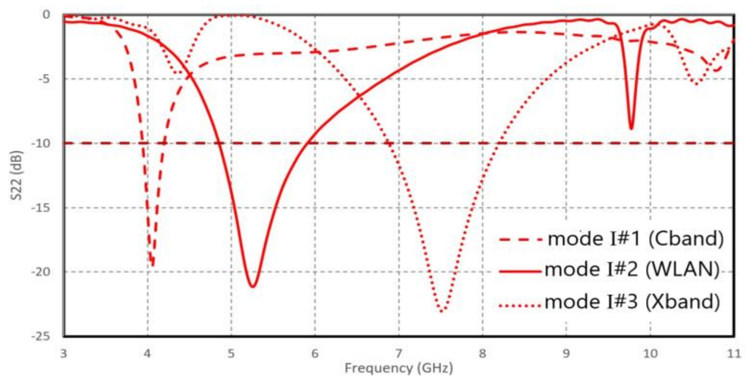


Figure 7. S22 for Antenna#2 interweave modes

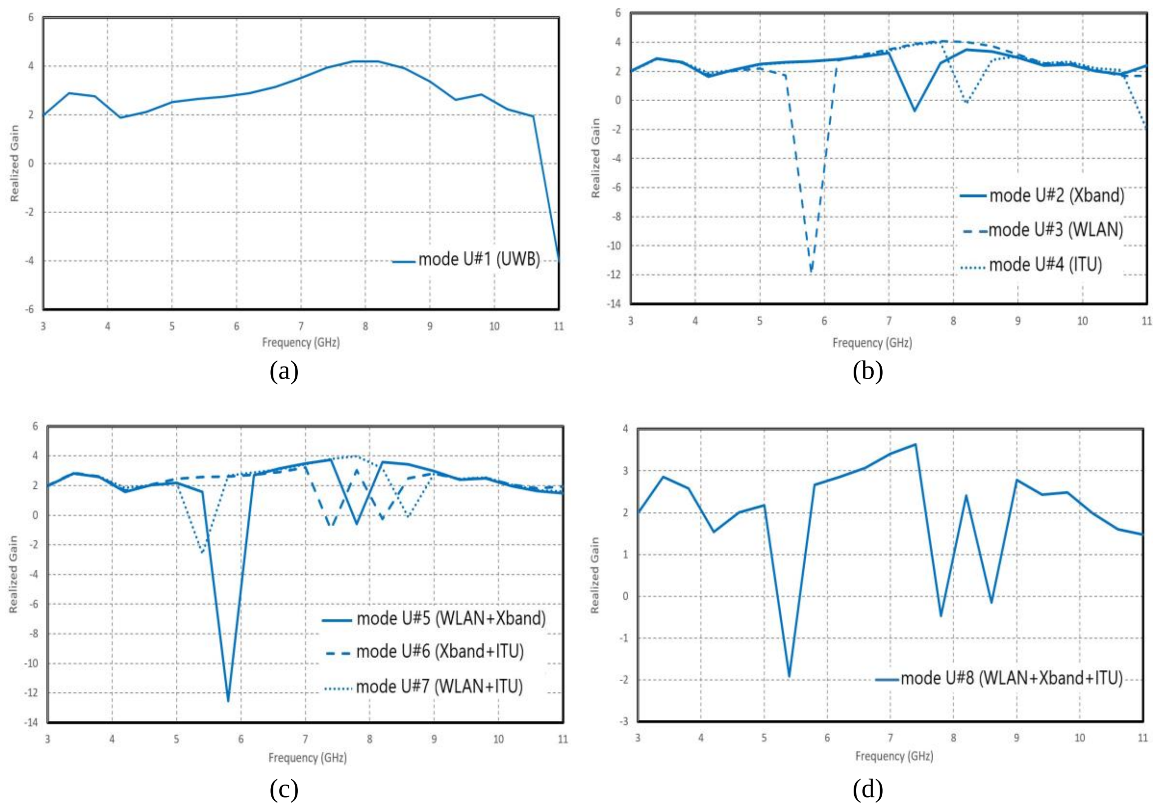
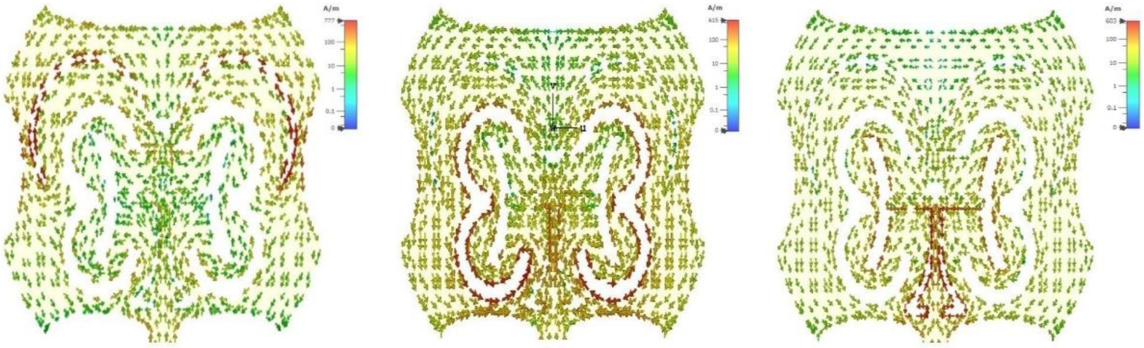


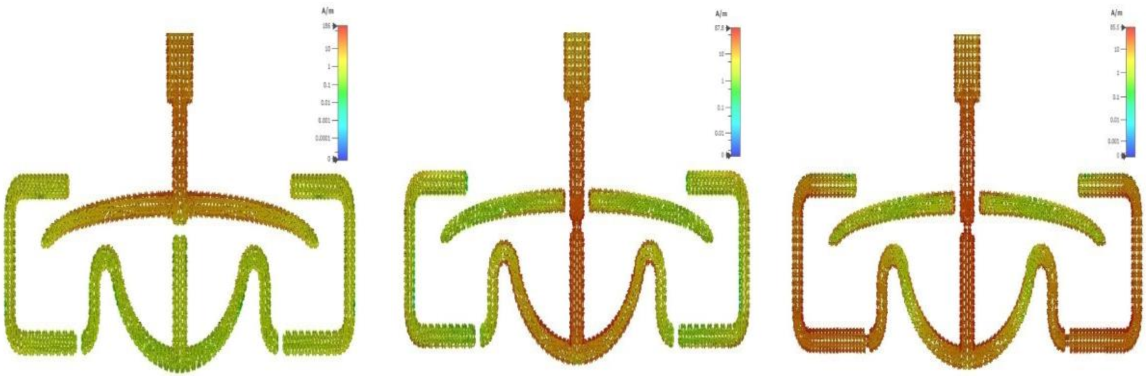
Figure 8. Realized gain of Antenna#1 at (a) UWB mode, (b) single-band rejection modes, (c) dual-band rejection modes, and (d) triple-band rejection mode

Surface current distribution can interpret the operation of this dual port system both in underlay or interweave modes of operation. Figures 9(a), 9(b) and 9(c) show how current is concentrated around the $\lambda_g/2$ slot at modes U#2, U#3 and U#4 respectively. Switching OFF the PIN diode across the slot in each of these modes causes the cancellation of radiation at the intended band. On the other hand, current distribution is very high in specific sections of Antenna#2 in each of the interweave modes I#1, I#2 and I#3 as clarified in Figures 10(a), 10(b) and 10(c) respectively. These sections, which affect the effective length of the patch, are responsible to configure this antenna to radiate in the desired communication band.



(a) (b) (c)

Figure 9. Surface current at Antennna#1 in (a) mode U#2 at 7.5 GHz, (b) mode U#3 at 5.7 GHz, and (c) mode U#4 at 8.3 GHz



(a) (b) (c)

Figure 10. Surface current at Antenna#2 in (a) mode I#1 at 4 GHz, (b) mode I#2 at 5.3 GHz, and (c) mode I#3 at 7.5 GHz

In multi-port antenna systems, the interaction between the antennas or how to affect each other is important to judge its proper operation. An indication to that is the mutual coupling usually expressed by the value of the forward or reverse reflection coefficients. The antenna in this design exhibits low levels of coupling which is indicated by S21 curves of Figure 11. S21 value in those curves is generally below -15 dB along the UWB range and for all interweave modes except mode I#1 at which S21 rises to -10 dB at 3.9 GHz.

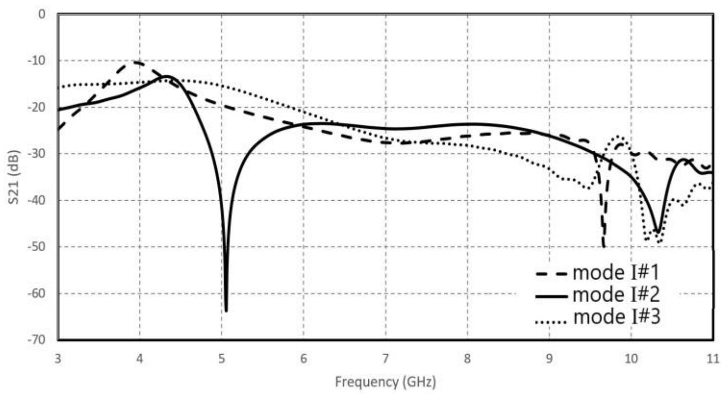


Figure 11. S21 the antenna system at interweaves modes

The design is compared to recent works, but it should be mentioned that none of them combines underlay and interweave operation in a single system. So, two distinct comparisons are considered for the designs in the two directions of cognitive radio. Table 3 compares the proposed design to recent works as an undelay system considering the size of the antenna, the number of PIN diodes in the design, its modes of operation, the notched bands, and the rejection states. Then, as an interweave system, Table 4 lists the main comparison topics which again take the size and the number of configuration elements (PIN diodes for switching and varactor diodes for tuning) but focuses on communication instead of rejected bands. Thus, beside the capability of this design to work as an underlay/interweave system which is a novel aspect when compared to previous cognitive radio systems, it provides a large number of operation modes with high flexibility to choose the rejection or communication bands where it all comes in a simple and compact construction.

Table 3. Comparison to underlay cognitive radio systems

Ref.	Size (mm^3)	PIN diodes	Operation modes	Notched bands	Rejection states
[14]	30×40×0.787	1	2	WLAN	S
[15]	17×19.5×1.6	1	2	WLAN	S
[16]	20×20×0.8	2	4	WiMax, WLAN	S/D
[17]	26×28×0.8	4	4	WLAN, Xband	S/D
[18]	22×30×0.76	2	2	WLAN, ITU	S/D
[19]	25×35×0.78	2	4	WiMax, WLAN	S/D
[20]	26×40×0.787	6	8	WLAN,Xband	S/D/T
[25]	36×32×1.6	3	4	WiMax, WLAN	S/D
[26]	25×29×1	3	8	WiMax,WLAN,ITU	S/D/T
[27]	35×41×1.5	5	3	WiMax,WLAN	S
[28]	28×28×0.8	3	5	WiMax,WLAN,ITU	S/T
[29]	27×32×1.6	3	4	WiMax,WLAN	S/D
[30]	38×40×1.59	4	7	WiMax,WLAN,Xband	S/D/T
[31]	26×38×1.5	3	4	WiMax, WLAN	S/D
[32]	30×40×0.78	1	2	WiMax	S
[33]	38.7×27.1×1.6	6	4	WiMax, WLAN	S/D
[34]	46×36×1.6	4	4	Cband, WLAN	S/D
[35]	40×30×0.787	2	4	WiMax,WLAN	S/D
Proposed	25×40×0.8	3	8	WLAN, Xband, ITU	S/D/T

S: Single, D: Dual, T: Triple

Table 4. Comparison to interweave cognitive radio systems

Ref.	Size (mm^3)	Switching Elements		Communication modes			Targeted bands
		PIN diodes	Varactor diodes	switchable	tunable	Total	
[7]	36×60×1.6	1	1	2	5	10	Cband, WLAN
[8]	30×50×0.8	2	-	4	-	4	WLAN
[9]	66×76×1.6	3	-	4	-	4	WLAN, WiMax
[10]	85×85×1.6	5	-	5	-	5	WiFi, WiMax
[11]	26×40×0.8	-	1	-	3	3	WLAN
[13]	36×40×1.6	-	1	-	6	6	WLAN
Proposed	25×40×0.8	5	-	3	-	3	Cband, WLAN, Xband

4. CONCLUSION

This paper presents a dual port antenna system that is applicable for cognitive radio. The two antennas of this compact design are reconfigurable in terms of band rejection for the first and selecting band of operation in the second. Antenna#1 can work an UWB antenna or can be used for band rejection by three PIN diodes controlling the notching slots etched into its patch. The ON/OFF state of these diodes leads to cancel/achieve notching effects that results in a no-rejection mode covers the whole UWB plus seven single/dual/triple band rejection modes to block WLAN, Xband and/or ITU regions. On the other hand, having Antenna#1 with no band rejection to scan the UWB, Antenna#2 can be reconfigured by five PIN diodes to radiate in either Cband, WLAN or Xband. The results regarded S11, S22 and realized gain ensures good performance of the antenna system to work as UWB antenna, notch the desired bands or to communicate in the intended bands. Moreover, S21 results ensures the feasibility as dual port system by low coupling values. This system that can choose between eleven operation modes looks promising to fill the requirements of cognitive radio as compared to recent designs especially when considering its novelty of gathering underlay and interweave functionality in a single design.

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REFERENCES

[1] F. Commission, "Revision of Part 15 of the commission's rules regarding ultra-wideband transmission systems," First Report and Order, pp. 02-48, Apr. 2002.

[2] R. Cicchetti, E. Miozzi, and O. Testa, "Wideband and UWB antennas for wireless applications: a comprehensive review," *International Journal of Antennas and Propagation*, pp. 1–45, 2017, doi: 10.1155/2017/2390808.

[3] V. Dhasarathan, M. Sharma, M. Kapil, P. C. Vashist, S. K. Patel, and T. K. Nguyen, "Integrated bluetooth/LTE2600 superwideband monopole antenna with triple notched (WiMAX/WLAN/DSS) band characteristics for UWB/X/Ku band wireless network applications," *Wireless Networks*, vol. 26, no. 4, pp. 2845–2855, May 2020, doi: 10.1007/s11276-019-02230-0.

[4] A. A. Basheer, A. M. Alsahlany, Q. jalil Kadhum, S. A. Abbas, A. A. Qasim, and M. F. L Abdullah, "Design a cylindrical antenna for millimeter-wave applications," in *2020 International Conference on Information Science and Communication Technology (ICISCT)*, Feb. 2020, pp. 1–4. doi: 10.1109/ICISCT49550.2020.9080019.

[5] R. A. Abdulhasan, K. N. Ramli, R. Alias, L. Audah, and A. R. O. Mumin, "Inverted diamond-shaped notched substrate and patch for high-frequency interference on ultra-wideband antenna," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 7, no. 6, pp. 2929–2935, Dec. 2017, doi: 10.11591/ijece.v7i6.pp2929-2935.

[6] Y. Tawk, J. Costantine, and C. Christodoulou, *Antenna design for cognitive radio*. Artech House, 2016.

[7] F. M. Alnahwi, A. A. Abdulhameed, H. L. Swadi, and A. S. Abdullah, "A planar integrated UWB/reconfigurable antenna with continuous and wide frequency tuning range for interweave cognitive radio applications," *Iranian Journal of Science and Technology, Transactions of Electrical Engineering*, vol. 44, no. 2, pp. 729–739, Jun. 2020, doi: 10.1007/s40998-019-00268-6.

[8] A. A. Abdulhameed, F. M. Alnahwi, H. L. Swadi, and A. S. Abdullah, "A compact cognitive radio UWB/reconfigurable antenna system with controllable communicating antenna bandwidth," *Australian Journal of Electrical and Electronics Engineering*, vol. 16, no. 1, pp. 1–11, Jan. 2019, doi: 10.1080/1448837X.2019.1575003.

[9] S. Sharma and C. C. Tripathi, "A wide spectrum sensing and frequency reconfigurable antenna for cognitive radio," *Progress In Electromagnetics Research C*, vol. 67, pp. 11–20, 2016, doi: 10.2528/PIERC16070803.

[10] S. Sharma and C. C. Tripathi, "A novel reconfigurable antenna with separate sensing mechanism for CR system," *Progress In Electromagnetics Research C*, vol. 72, pp. 187–196, 2017, doi: 10.2528/PIERC17010901.

[11] X. Jiao, J. Wang, and Z. Ying, "A compact two-port integrated uwb and frequency reconfigurable antenna system for cognitive radio application," in *2019 IEEE MTT-S International Wireless Symposium (IWS)*, May 2019, pp. 1–3, doi: 10.1109/IEEE-IWS.2019.8804119.

[12] S. Koley, H. Pant, and L. Murmu, "Half-elliptical UWB planar monopole with reconfigurable slot antenna for cognitive radio front-end," *Journal of Circuits, Systems and Computers*, vol. 27, no. 13, Dec. 2018, doi: 10.1142/S0218126618502134.

[13] F. M. Alnahwi, A. Abdulhameed, and A. S. Abdullah, "A compact integrated UWB/reconfigurable microstrip antenna for interweave cognitive radio applications," *International Journal on Communications Antenna and Propagation (IRECAP)*, vol. 8, no. 1, Feb. 2018, doi: 10.15866/irecap.v8i1.13078.

[14] A. Alhegazi, Z. Zakaria, N. A. Shairi, A. Salleh, and S. Ahmed, "Compact UWB filtering-antenna with controllable WLAN band rejection using defected microstrip structure," *Radioengineering*, vol. 27, no. 1, pp. 110–117, Apr. 2018, doi: 10.13164/re.2018.0110.

[15] V. Sharbati, P. Rezaei, and M. M. Fakharian, "Compact planar UWB antenna with enhanced bandwidth and switchable band-notch function for WLAN and DSRC," *IETE Journal of Research*, vol. 63, no. 6, pp. 805–812, Nov. 2017, doi: 10.1080/03772063.2017.1329634.

[16] M. B. Kakhki and P. Rezaei, "Reconfigurable microstrip slot antenna with DGS for UWB applications," *International Journal of Microwave and Wireless Technologies*, vol. 9, no. 7, pp. 1517–1522, Sep. 2017, doi: 10.1017/S1759078717000034.

[17] F. M. Alnahwi, A. A. Abdalhameed, H. L. Swadi, and A. S. Abdullah, "A compact wide-slot UWB antenna with reconfigurable and sharp dual-band notches for underlay cognitive radio applications," *Turkish Journal of Electrical Engineering and Computer Sciences*, vol. 27, no. 1, pp. 94–105, Jan. 2019, doi: 10.3906/elk-1803-63.

[18] D. Yadav, M. P. Abegaonkar, S. K. Koul, V. Tiwari, and D. Bhatnagar, "A monopole antenna with reconfigurable notched characteristics from WLAN-band notched UWB to ITU-band notched UWB antenna," in *Lecture Notes in Electrical Engineering*, Springer Singapore, 2018, pp. 647–654.

[19] J. Li and Y. Sun, "Design of reconfigurable monopole antenna with switchable dual band-notches for UWB applications," *Progress In Electromagnetics Research C*, vol. 96, pp. 97–107, 2019, doi: 10.2528/PIERC19081401.

[20] I. D. Saiful Bahri, Z. Zakaria, N. A. Shairi, and N. Edward, "A novel UWB reconfigurable filtering antenna design with triple band-notched characteristics by using u-shaped coppers," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 14, no. 1, pp. 267–275, Apr. 2019, doi: 10.11591/ijeecs.v14.i1.pp267-275.

[21] M. M. Fakharian, P. Rezaei, and A. Azadi, "A planar UWB Bat-shaped monopole antenna with dual band-notched for WiMAX/WLAN/DSRC," *Wireless Personal Communications*, vol. 81, no. 2, pp. 881–891, Mar. 2015, doi: 10.1007/s11277-014-2162-8.

[22] R. M. C. Cleetus and D. G. J. Bala, "Frequency reconfigurable antennas for cognitive radio applications: a review," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9, no. 5, pp. 3542–3549, Oct. 2019, doi: 10.11591/ijece.v9i5.pp3542-3549.

[23] L. W. Abdullah, M. H. Wali, and A. H. Saloomi, "Twelfth mode on-demand band notch UWB antenna for underlay cognitive radio," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 22, no. 3, pp. 1446–1456, Jun. 2021, doi: 10.11591/ijeecs.v22.i3.pp1446-1456.

[24] M. khadom Mohsen, M. S. M. Isa, Z. Zakaria, A. A. M. Isa, M. K. Abdulhameed, and M. L. Attiah, "Control radiation pattern for half width microstrip leaky wave antenna by using PIN diodes," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 5, pp. 2959–2966, Oct. 2018, doi: 10.11591/ijece.v8i5.pp2959-2966.

[25] M. S. Alam and A. Abbosh, "Reconfigurable band-rejection antenna for ultra-wideband applications," *IET Microwaves, Antennas and Propagation*, vol. 12, no. 2, pp. 195–202, Feb. 2018, doi: 10.1049/iet-map.2017.0442.

[26] C. Luo, J. Hong, M. Amin, and L. Zhong, "Compact UWB antenna with triple notched bands reconfigurable," in *2016 IEEE*

International Conference on Microwave and Millimeter Wave Technology (ICMMT), Jun. 2016, pp. 746–748, doi: 10.1109/ICMMT.2016.7762429.
[27] H. Yang, X. Xi, H. Hou, Y. Zhao, and Y. Yuan, "Design of reconfigurable monopole antenna with switchable dual band-notches for UWB applications," *International Journal of Microwave and Wireless Technologies*, vol. 10, no. 9, pp. 1065–1071, Nov. 2018, doi: 10.1017/S175907871800096X.
[28] E. Nasrabadi and P. Rezaei, "A novel design of reconfigurable monopole antenna with switchable triple band-rejection for UWB applications," *International Journal of Microwave and Wireless Technologies*, vol. 8, no. 8, pp. 1223–1229, Dec. 2016, doi: 10.1017/S1759078715000744.
[29] G. Srivastava, S. Dwari, and B. K. Kanaujia, "A compact UWB antenna with reconfigurable dual notch bands," *Microwave and Optical Technology Letters*, vol. 57, no. 12, pp. 2737–2742, Dec. 2015, doi: 10.1002/mop.29424.
[30] A. S. Kholapure and R. G. Karandikar, "UWB antenna with reconfigurable triple band notched characteristics for cognitive radio," *ICTACT Journal on Communication Technology*, vol. 8, no. 3, pp. 1553–1558, Sep. 2017, doi: 10.21917/ijct.2017.0229.
[31] G. Gao, B. Hu, L. He, S. Wang, and C. Yang, "Investigation of a reconfigurable dual notched UWB antenna by conceptual circuit model and time-domain characteristics," *Microwave and Optical Technology Letters*, vol. 59, no. 6, pp. 1326–1332, Jun. 2017, doi: 10.1002/mop.30535.
[32] N. F. Miswadi and M. T. Ali, "Design of compact reconfigurable UWB antenna with WiMAX and WLAN band rejection," *Indonesian Journal of Electrical Engineering and Computer Science (IJEECS)*, vol. 17, no. 3, pp. 1427–1433, Mar. 2020, doi: 10.11591/ijeecs.v17.i3.pp1427-1433.
[33] P. Mayuri, N. D. Rani, N. B. Subrahmanyam, and B. T. P. Madhav, "Design and analysis of a compact reconfigurable dual band notched UWB antenna," *Progress In Electromagnetics Research C*, vol. 98, pp. 141–153, 2020, doi: 10.2528/PIERC19082903.
[34] A. Yadav, G. Kumar, and R. P. Yadav, "Frequency reconfigurable dual notch UWB antenna," in *2020 International Conference on Wireless Communications Signal Processing and Networking (WiSPNET)*, Aug. 2020, pp. 1–6. doi: 10.1109/WiSPNET48689.2020.9198600.
[35] A. Alhegazi, Z. Zakaria, N. A. Shairi, I. M. Ibrahim, and S. Ahmed, "A novel reconfigurable uwb filtering-antenna with dual sharp band notches using double split ring resonators," *Progress In Electromagnetics Research C*, vol. 79, pp. 185–198, 2017.

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