Bulletin of Electrical Engineering and Informatics
Vol. 14, No. 1, February 2025, pp. 216~223
ISSN: 2302-9285, DOI: 10.11591/eei.v14i1.7568

Metamaterial inspired miniaturized ultra-wideband monopole hexagonal antenna with triple band-filter functions

Mourad Elhabchi, Mohamed Bour, Issam Atouf, Abdelmoghit Zaarane
LTI Laboratory, Department of Physics Ben Msick, Faculty of Sciences, Hassan II University of Casablanca, Casablanca, Morocco

Article Info

Article history:

Received Sep 17, 2023
Revised Sep 7, 2024
Accepted Sep 28, 2024

Keywords:

5G band
Hexagonal antenna
Metamaterial
Rejected band
Wireless local area network band

ABSTRACT

In this letter, a new technique to the design of an ultra-wideband (UWB) monopole hexagonal antenna with triple band-rejected functions and to restrict the interferences with the exist bands is proposed, the design has the form of a hexagonal patch and a ground plane having rectangular shaped etched in the back side of the substrate to achieve the UWB behavior. The triple-band filter feature is generated by inserting a metamaterial (MTM) as a split ring resonator slots (SRRs) and a complementary split ring resonators (CSRRs) strip, thus no extra size is needed. The triple band-elimination is for 3.3-3.9 GHz centered at 3.5 GHz for 5G band, 4.99-5.4 GHz centered at 5.2 GHz for wireless local area network (WLAN) band, and 6.2-6.8 GHz centered at 6.5 GHz for IEEE INSAT/Supra-extended C-band. The antenna dimension has a compact size of 20×25×1.6 mm^3. Current distribution on the antenna is used to analyze the effect of MTMs on the antenna operations. The simple structure and small size of the antenna makes it suitable for most of the wireless communication systems.

Corresponding Author:

Mourad Elhabchi
LTI Laboratory, Department of Physics Ben Msick, Faculty of Sciences
Hassan II University of Casablanca
Casablanca, Morocco
Email: mouradelhabchi@gmail.com

1. INTRODUCTION

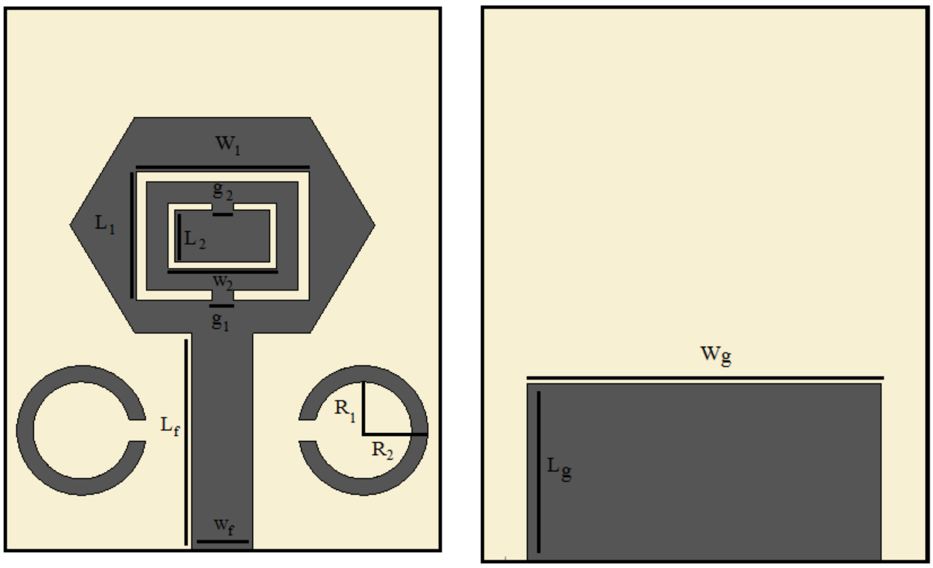
As the development research and the evolution of information and communication technologies during recent few years, various electronic metamaterial (MTM) devices using wireless technologies are being fabricated and manufactured to cover several range frequency spectrums [1]. For the attractive characteristics such as uses in single chip, good radiation efficiency, easy manufacture, high processing gain and omnidirectional radiation pattern, and so on [2], MTM antennas are a fascinating and innovative area of research in the field of electromagnetic waves and antenna technology [3]. The properties of engineered MTMs are designed not to find in naturally occurring materials [4]. The arrangement of subwavelength-sized in ordered or a periodic construct these materials elements MTM antennas [5]. The arrangement of subwavelength-sized in ordered or a periodic construct these materials elements MTM antennas utilize these unique properties to control and manipulate electromagnetic waves in novel ways [6].

Ultra-wideband (UWB) technology is known for its wide frequency range and high data rates, but interference with other licensed bands like 5G, wireless local area network (WLAN), X-band, and IEEE INSAT/Supra-extended C-band is still a challenge can be a concern to conceptualize an efficient and small UWB antenna [7]-[9]. To mitigate this interference, UWB antennas with band-filter features are often designed [10], [11]. Gong *et al.* [12] uses a regular hexagonal the worldwide interoperability for microwave access (WiMAX) lower and upper bands and a double symmetry inverted T-shaped loaded in the ground plane at the upper edge to filter downlink of X-band signals. Hammache *et al.* [13] inspired in the hexagonal part of the radiating shaped with a a three slot in the C-shaped forms to suppress a triple band features. Several other techniques have been investigated to generate an UWB behavior with filters features such as the use of double inverted S-shaped slots [14], UWB antenna loaded with modified H-shaped resonator [15], using three C-shaped slots [16].

In this letter, we propose to investigate an UWB monopole hexagonal antenna for triple band suppression with a MTMs as a split ring resonator slot (SRRs) has been inspired in the hexagonal radiation patch to reject existing licensed 5G (3.3-3.9 GHz) bands and IEEE INSAT/Supra-extended C-band (6.2-6.8 GHz). In order to restrict the problem of interference with the exist WLAN band (4.99-5.4 GHz) a complementary split ring resonators (CSRRs) strips has been loaded in the substrate. The simulated results both on CST Mw and Ansoft HFSS show that this proposed hexagonal MTM UWB antenna can offer an operating frequency range from 3-10.04 GHz with 10 dB S-parameters bandwidth, except the mentioned three eliminated bands. S-parameter bandwidth, except the mentioned three eliminated bands. The simulated results are in quasi consistent. The proposed MTM antenna can be a good candidate to fulfils the recent developments in wireless UWB applications.

2. METHOD

The configurations of the studied MTM hexagonal monopole antenna together with its overall dimensions are shown in Figures 1(a) and (b). The proposed 50 fed design has microstrip line with W_f=2.8 mm and L_f=10 mm and fabricated on an FR4 substrate with ε_r=4.3 (permittivity), and loss tangent of 0.025 (loss tangent). The presented structure has a very small area of 20×25×1.6 mm^3. The antenna dimensions are displayed in the Table 1.



(a) (b)

Figure 1. Proposed MTM antenna configuration (mm); (a) top view and (b) bottom view

Table 1. MTM antenna dimensions

Parameters	Dimensions (mm)	Parameters	Dimensions (mm)
W_1	9.5	g_1	1
L_1	5.5	g_1	2
W_2	5.25	R_1	2.25
L_2	2.25	R_2	3.25
W_g	16	L_g	8

The MTM antenna optimization procedure steps are presented in the Figure 2. Firstly, a conventional 50-ohm hexagonal UWB antenna is designed and simulated (antenna I). In the second and third steps, a SRRs slot is loaded in the center of the radiating hexagonal antenna with defined position and dimensions (antenna II and III) [17], [18]. Afterwards, a symmetrical CSRRs are placed on the ground plane (antenna VI). Finally, the precedents strips and slots are combined to create a multiple band notched operation. Figure 3 depicts the reflection coefficient plots for the mentioned MTM structures. From this traces we can observe that the initial reference antenna (AntI) can radiate in a UWB band characteristics and the antenna II shows that the 5G centred at 3.5 GHz is rejected with the addition of a single SRR slot only into the hexagonal antenna, while antennas III presents the design with a double SRR slot to eliminate the frequency centered at 6.5 GHz for IEEE INSAT/Supra-extended C-band band. The 5.2 GHz is rejected with the addition of (CSRRs) [19].

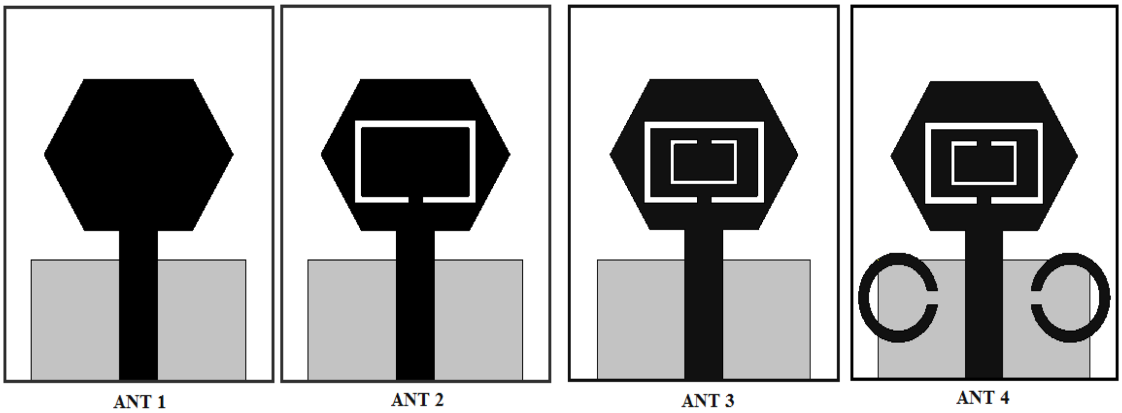


Figure 2. Evolution process steps of the presented MTM antenna

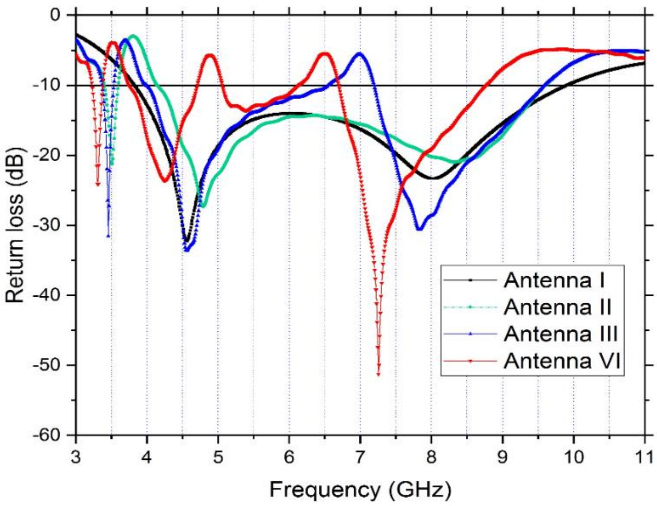
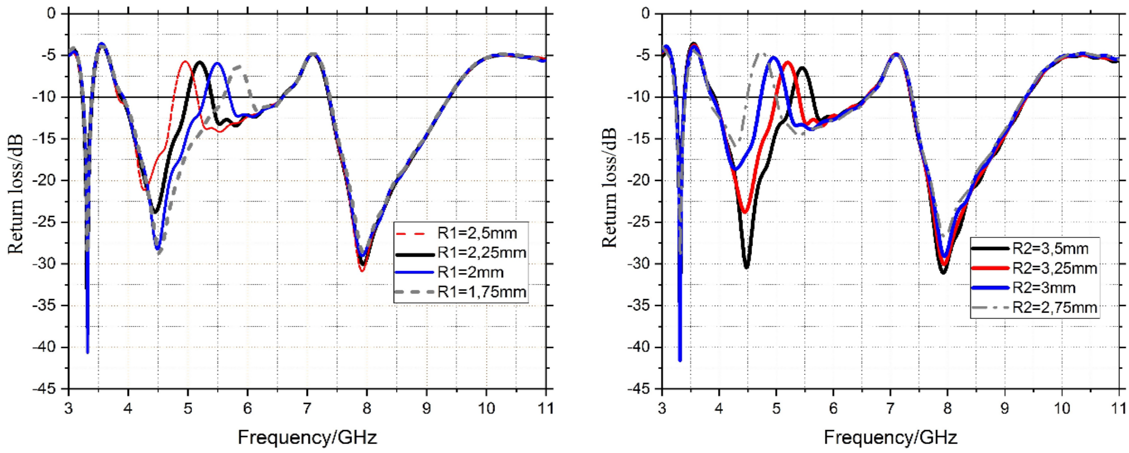


Figure 3. Comparison of return loss features for the four MTM antenna structures

3. RESULTS AND DISCUSSION

3.1. Parametric studies of the rejected bands

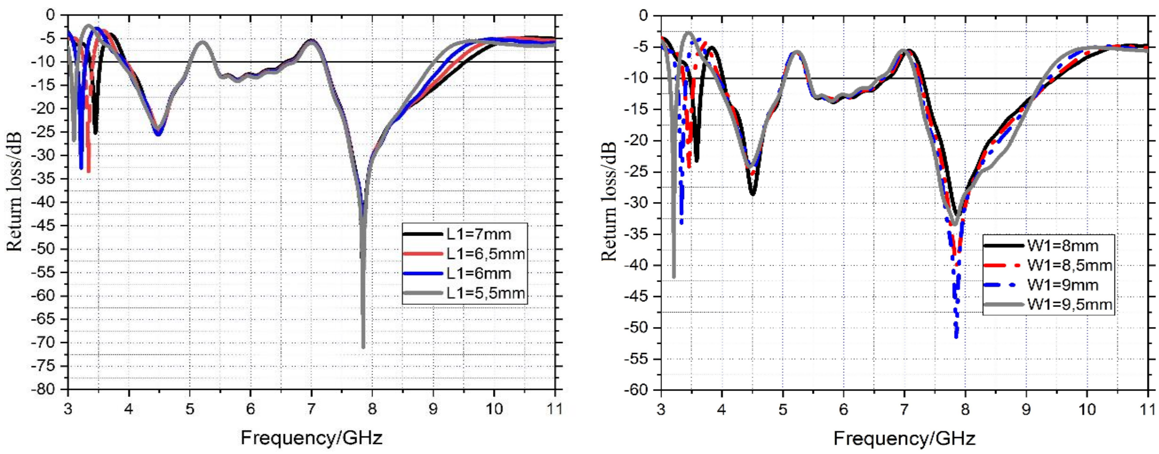
Figure 4(a) depicts the optimized return loss for different CSRRs inner radius R_1 values. It is clearly shown that the WLAN band centred at (5.2 GHz), is highly affected by decreasing the R_1 from 2.5 to 1.75 mm without an observed effect of the other bands due to the couplage between the resonator and the other antenna parameters. The S_{11} for the different outer radius R_2 values of CSRRs is illuminated in Figure 4(b). It can be noted that by decreasing the R_2 from 3.5 to 2.75 mm by a step of 0.25 mm, resonance at 5.2 GHz band is much influenced and shifted towards the lower frequency while the other resonance signals are almost not affected. The interpretation mentioned above confirms that the CSRRs predominantly affects for the resonance at lower WLAN band rejection [20], [21].



(a) (b)

Figure 4. S_{11} parameters for different radius of CSRRs; (a) inner radius R_1 and (b) outer radius R_2

Figure 5(a) shows the simulated coefficient reflection for the outer SRR slot L_1 length value. It can be observed that by changing the L_1 from 7 to 5.5 mm values without affecting the other antenna parameters, the WLAN (3.5 GHz) resonance is strongly influenced while the other resonances are slightly affected. The design performance corresponds to different width of outer SRR slot W_1 is illuminated in Figure 5(b). As seen as the WLAN (3.5 GHz) resonance frequency is affected similarly to the other by changing W_1, it is demonstrated that the WLAN resonance is tuned towards the lower frequency by decreasing the width values from 7 to 5.5 mm and vice a versa. It is noted that the antenna performance is obtained at W_1=9.5 mm and L_1=5.5 mm.



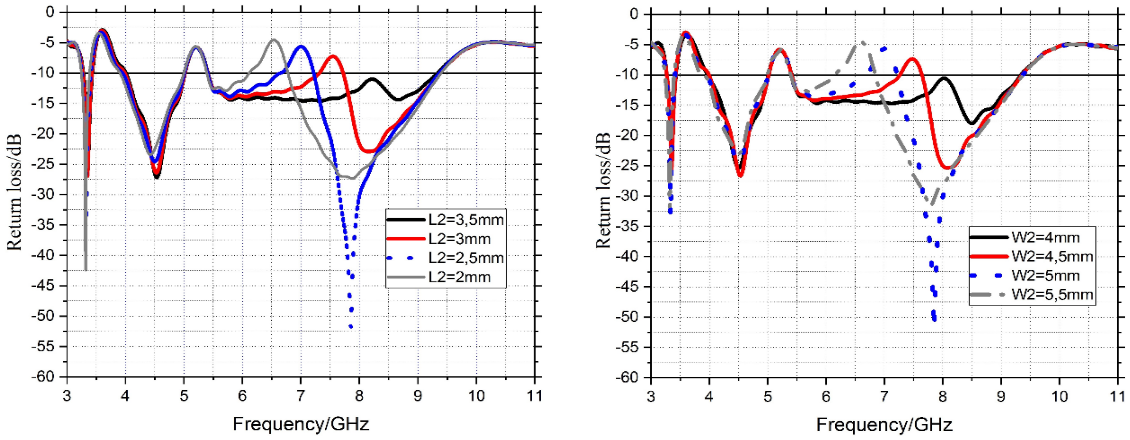
(a) (b)

Figure 5. S_{11} parameters for different outer SRRs slot: (a) length L_1 and (b) width W_1

Figures 6(a) and (b) illuminate the inner SRRs dimension effects on S_{11} versus frequency plot. It is shown that as the length L_2 value decreases from 3.5 to 2 mm, the notched signal shifted from 8.5 to 6.5 GHz, The reject in IEEE INSAT/Supra-extended C-band spectrums is centred at 6.5 GHz with a reflection coefficient value -5 dB Figure 6(a). Finally, for a good 6.5 GHz signal suppressions, the reflection coefficient value enhances from 10 dB to 4 dB when varying the width L_2 of the inner SRR from 4 to 5.5 mm with a step of 0.5 mm Figure 6(b).

3.2. Simulated current distribution, realized gain, radiated efficiency, and S_{11} parameters

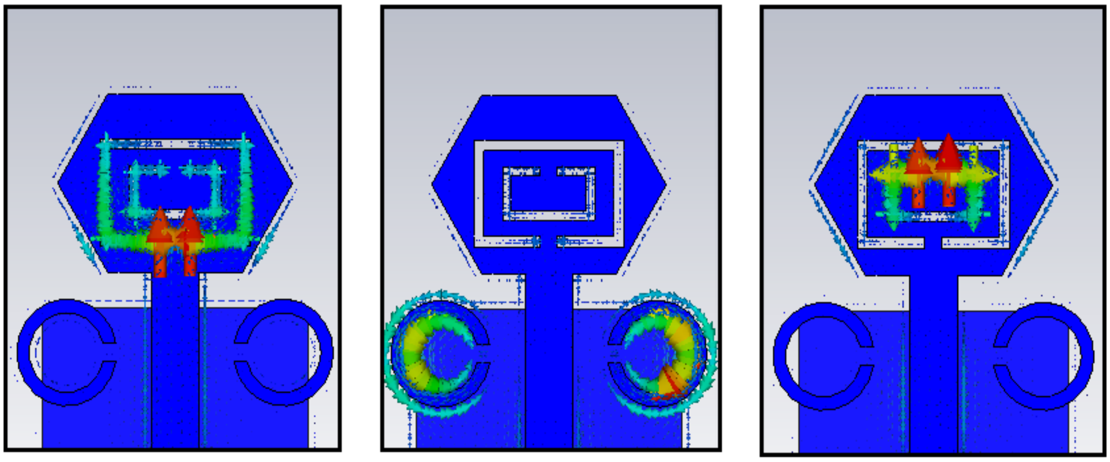
To provide an explanation for the generation of filter band frequencies. The surface current distribution density of the proposed MTM hexagonal triple band rejected at 3.5, 5.2, and 6.5 GHz can be seen in Figure 7. In the 3.5 GHz frequency band, a high current density is concentrated around the outer SRR slot to reject the 5G band whereas a small stream circulates around the other parts of the structure Figure 7(a).



(a) (b)

Figure 6. S_{11} parameters for different inner SRRs slot: (a) length L_2 and (b) width W_2

The current distributions at the second notched band (5.2 GHz) are mostly directed around the dual symmetrical CSRRs strips to filter the WLAN signals Figure 7(b). Therefore, its density is highly in the inner SRR slot to filter the third band (6.5 GHz) (Figure 7(c)). Thus, these SRRs slot and CSRRs strip proves that the production of rejected wave is caused by resonating at the filtered frequencies [22], [23].



(a) (b) (c)

Figure 7. Current distributions at; (a) 3.5 GHz, (b) 5.2 GHz, and (c) 6.5 GHz

Figure 8(a) presents the simulated realized gain and radiated efficiency of the triple band rejected of MTM antenna. Stable and positive achieved gain and radiated efficiency are in the UWB range with a maximum gain value of 3 dB except in the notched frequency spectra. The radiated efficiency and gain value have been reduced to negative.

Simulated S_{11} parameters of proposed MTM notched band antenna are presented in Figure 8(b) both in CST Mw and Ansoft HFSS to validate against the simulated results. The showed results are in quasi consistent with the simulated ones. A little shift was seen between the optimized results is due to the method of calculation between CST Mw which based on the time method the finite difference time domain (FDTD) and Ansoft HFSS which use a spatial method the finite element method (FEM) [24], [25].

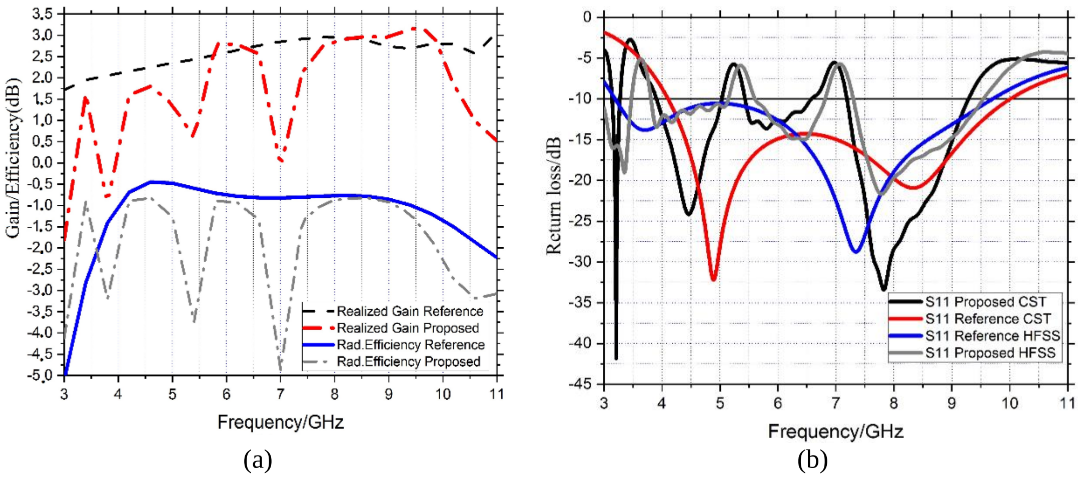


Figure 8. Comparison of performance: (a) realized gain and efficiency without and with three notched bands and (b) S_{11} parameters without and with three notched bands

3.3. Comparison with recently published works

Table 2 shows the comparison between this work and other recent publications in terms of bandwidth, total area, gain, and rejected band numbers. We can see from this comparison that the submitted structure has a very compact size of 500 mm^2, cover the entire FCC band with acceptable gain characteristics with a maximum value of 3 dB relative to other similar antennas.

Table 2. MTM antenna dimensions

Antennas	Bandwidth (GHz)	Dimension (mm^2)	Total area (mm^2)	Gain (dB)	Number of bands
Ref. [2]	3-12	42×50	2100	About 4	3
Ref. [12]	3-11	31×40	1240	1.5-6.5	3
Ref. [13]	2.95-12	30×30	900	1.5-5.37	3
Ref. [14]	3-11	35×30	1050	About 3	2
Ref. [15]	2.5-10.6	25×33	825	2-5	3
Ref. [17]	2.7-14.6	75×10	750	About 2	1
Ref. [19]	3.1-11	24×35	840	3-6	3
Ref. [20]	3-10.6	35×35	1225	2.5-3.5	3
Ref. [21]	3.1-10.6	24×34	830	2-4	3
Ref. [23]	3-10	28×28	798	2-3	3
This paper	3-9.5	20×25	500	2.5-3.1	3

4. CONCLUSION

In this letter, we have proposed a new compact triple band MTM antenna with controllable hexagonal band rejected with three slots of different shape and strips of MTMs. We have added a double SRRs slot and a dual symmetrical CSRR slit to create notched signals for three frequency bands in 5G, lower WLAN band, and IEEE INSAT/Supra-extended C-band. Simulated results have proven that the MTM is responsible for the frequency of filtering to the desired bands, in the notched band range, gain and efficiency values are decreased. Finally, the presented filtered MTM hexagonal antenna is formed to reject interference, with these characteristic, the objective of resolving interference between UWB and the existing 5G, WLAN, and INSAT bands has been achieved successfully. The design analysis shows that a very compact volume as an added advantage and it is applicable in miniature devices for the latest state-of-the-art technology.

REFERENCES

[1] Z. Hao and J. Hong, "Ultra wideband filter technologies," *IEEE Microwave Magazine*, vol. 11, p. 56-68, 2010, doi: 10.1109/MMM.2010.936494.
[2] N. Jaglan, B. K. Kanaujia, S. D. Gupta, and S. Srivastava, "Triple band notched UWB antenna design using electromagnetic band gap structures," *Progress In Electromagnetics Research C*, vol. 66, 139–147, 2016, doi: 10.2528/PIERC16052304.
[3] W. Lee, S.-I. Choi, H.-I. Kim, S. Hwang, S. Jeon, and Y.-K. Yoon, "Metamaterial-integrated high-gain rectenna for RF sensing and energy harvesting applications," *Sensors*, vol. 21, p. 6580, 2021, doi: 10.3390/s21196580.
[4] M. T. Islam, A. Hoque, A. F. Almutairi, and N. Amin, "Left-handed metamaterial-inspired unit cell for S-band glucose sensing application," *Sensors*, vol. 19, 2019, doi: 10.3390/s19010169.

[5] M. S. Bakir *et al*., "A comprehensive study on fuel adulteration sensing by using triple ring resonator type metamaterial," *Journal of the Electrochemical Society*, vol. 166, p. 1044-1052, doi: 2018, doi: 10.1149/2.1491912jes.
[6] T. Wanghuang, W. Chen, Y. Huanga, and G. Wen, "Analysis of metamaterial absorber in normal and oblique incidence by using interference theory," *AIP Advances*, vol. 3, 2013, doi: 10.1063/1.4826522.
[7] S. Doddipalli and A. Kothari, "Compact UWB Antenna With Integrated Triple Notch Bands for WBAN Applications," in *IEEE Access*, vol. 7, pp. 183-190, 2019, doi: 10.1109/ACCESS.2018.2885248.
[8] B. Xu, Y. Zhao, L. Gu, and Z. Nie, "Fork-shaped patch printed ultra-wideband slot antenna with dual band-notched characteristics using metamaterial unit cells," *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 29, no. 7, p. e21742, 2019, doi: 10.1002/mmce.21742.
[9] A. Toktas and M. Yerlikaya, "A compact reconfigurable ultra-wideband G-shaped printed antenna with band-notched characteristic," *Microwave and Optical Technology Letters*, vol. 61, no. 1, pp. 745–749, 2019, doi: 10.1002/mop.31516.
[10] R. B. Rani and S. K. Pandey, "A CPW-fed circular patch antenna inspired by reduced ground plane and CSRR slot for UWB applications with notch band," *Microwave and Optical Technology Letters*, vol. 59, no. 4, pp. 745–749, 2017, doi: 10.1002/mop.30386.
[11] M. Elhabchi, M. N. Srifi and R Touahni, "CPW-Fed miniaturized isosceles triangular slot UWB planar antenna with triple band-notched characteristics," *Progress in Electromagnetics Research Letters*, vol. 87, pp. 59-66, 2019.
[12] X. Gong, Y. Tong, B. Tian, and B. Gao, "Design of a microstrip-fed hexagonal shape UWB antenna with triple notched bands," *Progress In Electromagnetics Research C*, vol. 62, 77–87, 2016, doi: 10.2528/PIERC15101701.
[13] B. Hammache, A. Messai, I. Messaoudene, and T. A. Denidni, "A compact ultrawideband antenna with three C-shaped slots for notched band characteristics," *Microwave and Optical Technology Letters*, vol. 61, no. 1, pp. 275-279, 2019, doi: 10.1002/mop.31535.
[14] B. Li, J. Hong, and B. Wang, "Switched Band-Notched UWB/Dual-Band WLAN Slot Antenna With Inverted S-Shaped Slots," in *IEEE Antennas and Wireless Propagation Letters*, vol. 11, pp. 572-575, 2012, doi: 10.1109/LAWP.2012.2200228.
[15] Y. Sung, "Triple Band-Notched UWB Planar Monopole Antenna Using a Modified H-Shaped Resonator," in *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 2, pp. 953-957, Feb. 2013, doi: 10.1109/TAP.2012.2223434.
[16] S. D. Sateaa, M. S. Hussein, Z. G. Faisal, and A. M. Abood, "Design and simulation of dual-band rectangular microstrip patch array antenna for millimeter-wave," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 11, no. 1, pp. 299-309, 2022, doi: 10.11591/eei.v11i1.3336.
[17] M. Elhabchi, M. N. Srifi and R. Touahni, "Bandwidth Enhancement of Trapezoid Antenna Using an Open F-rotated and I-shaped Slots Defected Ground Structures (DGS)," *2019 International Symposium on Advanced Electrical and Communication Technologies (ISAECT)*, pp. 1-4, Nov. 2019.
[18] S. Santhanam and T. S. Palavesam, "Comparative characterization of microstrip patch antenna array with defected ground structure for biomedical application," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 11, no. 1, pp. 346-353, 2022, doi: 10.11591/eei.v11i1.3459
[19] J. Y. Deng, Y.-Z. Yin, Sh.-G. Zhou, and Q.-Zh. Liu, "Compact ultra-wideband antenna with tri-band notched characteristic," *Electronics Letters*, vol. 44, no. 21, pp. 1231–1233, Oct. 2008, doi: 10.1049/el:20081660.
[20] D. Sarkar, K. V. Srivastava, and K. Saurav, "A Compact Microstrip-Fed Triple Band-Notched UWB Monopole Antenna," in *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 396-399, 2014, doi: 10.1109/LAWP.2014.2306812.
[21] M. Sarkar, S. Dwari, and A. Daniel, "Printed monopole antenna for ultra-wideband application with tunable triple band-notched characteristics," *Wireless Personal Communications*, vol. 84, pp. 2943-2954, May 2015, doi: 10.1007/s11277-015-2774-7.
[22] M. S. Rana, T. A. Fahim, B. Ghosh and M. M. Rahman, "Microstrip patch antenna design and simulation for S-band wireless applications operating at 3.5 GHz," *Bulletin of Electrical Engineering and Informatics (BEEI*, vol. 12, no. 6, pp. 3428-3437, 2023, doi: 10.11591/eei.v12i6.5626.
[23] M. Elhabchi, M. N. Srifi and R. Touahni, "A Modified Hexagonal UWB Antenna Loaded with Multiple L-shaped Stubs for GPS Band Integration and Like Y-Shaped Slot for Single Band Rejection," *2019 International Conference on Wireless Technologies, Embedded and Intelligent Systems (WITS)*, Fez, Morocco, 2019, pp. 1-5, doi: 10.1109/WITS.2019.8723735.
[24] M. S. Rana and M. M. R. Smieee, "Design and analysis of microstrip patch antenna for 5G wireless communication systems," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 11, no. 6, pp. 3329–3337, Dec. 2022, doi: 10.11591/eei.v11i6.3955
[25] M.Farhan and A. K. Jassim, "Design and analysis of microstrip antenna with zig-zag feeder for wireless communication applications," *Bulletin of Electrical Engineering and Informatics (BEEI)*, vol. 10, no. 3, pp. 1388-1394, 2021, doi: 10.11591/eei.v10i3.2122.

BIOGRAPHIES OF AUTHORS

Mourad Elhabchi is an accomplished assistant professor in the Faculty of Science Ben M'sick Casablanca, specializing in Electronic Engineering, Telecommunications Engineering, and Communication Engineering. With a wealth of knowledge and expertise in these fields, he has made significant contributions to the academic and research community he published more than 14 papers. Their research and teaching focus on cutting-edge technologies, with a particular emphasis on antennas. His possesses a deep understanding of antenna design, optimization, and performance evaluation, making them a sought-after expert in this area. He can be contacted at email: mouradelhabchi@gmail.com.

Mohamed Bour is an accomplished and highly specialized professor in the Faculty of Science at Ben M'sick Casablanca, with expertise spanning Electronic Engineering, Telecommunications Engineering, and Communication Engineering. It is evident that he has made substantial contributions to the academic and research domains, particularly in the areas of signal processing, telecommunications, and antennas. Their dedication to cutting-edge technologies and commitment to teaching undoubtedly make them a valuable asset to both their students and the broader academic community. His possesses a deep understanding of antenna design, optimization, and performance evaluation, making them a sought-after expert in this area. He can be contacted at email: med11bour@gmail.com.

Issam Atouf has been a professor at Casablanca's Ben M'Sick Faculty of Science since 2004, specializing in electronics, embedded systems electronics, information processing, and artificial neural networks. He has supervised several research projects as part of his theses or final year projects for Master's students. His work has been the subject of some twenty articles published in specialized journals. He can be contacted at: issamatouf@gmail.com.

Prof. Abdelmoghit Zaarane is a distinguished researcher and educator specializing in embedded systems and computer vision. He holds the position of assistant Professor and Researcher at Hassan II University of Casablanca, Faculty of Sciences Ben Msik. He has published extensively in renowned journals and conferences, making significant contributions to fields such as traffic engineering computing, object detection, and image segmentation. His work has earned him recognition as one of the worlds top 2/100 scientists in engineering and technology by the AD Scientific Index in 2023. His dedication to advancing technology and educating future researchers underscores his prominent role in the academic community. He can be contacted at email: z.abdelmoghit@gmail.com.