SEMIRCULAR SLOT BASED UWB MICROSTRIP PATCH ANTENNA FOR VARIABLE BAND NOTCHED APPLICATIONS

M.M. Hasan Mahfuz, Md Rafiul Islam*, Mohamed Hadi Habaebi, Norun Abdul Malek

Department of Electrical and Computer Engineering, International Islamic University Malaysia (IIUM), Jalan Gombak 53100, Selangor, Kuala Lumpur, Malaysia

*Corresponding author
rafiq@iium.edu.my

1.0 INTRODUCTION

Demand for wireless connectivity has increased, the demand for higher data rate and hence higher bandwidth and transmission frequencies [1]. The UWB frequency range is specified from (3.1–10.6) GHz according to the Federal Communication Board (FCC) [2], [3]. Although UWB technology offers numerous advantages, one challenge is to build an UWB antenna that is small, with appropriate impedance with good radiation stability and efficiency and a reduction of signal interference in the UWB frequency spectrum with achieve narrower bands [3]–[7]. The superimposed lower 5G frequency band (3.4–3.7) GHz [8], Wi-MAX (3.3–3.8) GHz, WLAN (5.15–5.825) GHz, X-band (7.9–8.4) GHz [9], [10] and ITU 8 GHz at (7.725–8.275) GHz operating connections [11]–[15] within the UWB bandwidth. In this article, a UWB antenna will be equipped with a variable band notch function with Wi-MAX (3.3–3.8) GHz and 5G lower band (3.4–4) GHz applications. The follows briefly review the literature for the shortcomings of past works.

In [13], [16] a UWB antenna designed by using the FR-4 substrate with a single-band notched antenna was developed. A U-shaped slot is inserted into the circular patch for band notched in the Wi-MAX band. S11 result shows that the band entry created for the Wi-MAX application (2.3–3.8) GHz is (2.9–3) GHz to 4.0 GHz, but the effective band entry is (3.3–3.8) GHz. Moreover, (2.8–4.8) GHz is achieved by VSWR. Some essential parameters for the results are not presented in this study, such as radiation efficiency and gain plot. To conclude, the antenna does not supply band notched in Wi-MAX frequency band (3.3–3.8) GHz according to two important result parameters,

Keywords: UWB antenna, Semicircular slot, Variable band notched, 5G lower band, Wi-MAX

© 2022 Penerbit UTM Press. All rights reserved
namely: $S_{11}$ and VSWR. In other works [17], [18] a single band notched (3.3–3.8) GHz antenna’s designed to be centered on the FR-4 element. The band notched criteria obtained with the EBG structure and inserted in feed line. This antenna is large, and the construction of antenna is complicated enough to make it suitable for Wi-MAX frequency band effective. A new UWB hybrid dielectric resonator antenna is built, with a single-band rejection of (3.2–3.8) GHz in [16]–[18] antenna constructed using FR-4 low cost substrate element with height $h=1.64$ mm. It was found that the band notched frequency’s radiation is not adequately received in the UWB frequency band after band stop. This antenna is simple system to build. An integrated electrically reconfigurable wireless microstrip antenna [16] which is a low-profile reconfigurable Wi-MAX band notched dual port MIMO antenna configuration for wireless communications has been presented. Although the antenna proposed shows good efficiency, the geometry of the antenna is complex. The complicated design of the antenna makes it very difficult to produce and commercially available. A half elliptical shape placed on V-shape slit provide UWB (2.7–14.7) GHz bandwidth and band stop functions for WLAN (5.15–5.825) GHz and 5G lower band (3.4–3.7) GHz [8]. FR-4 has been used for design simulated and fabricated purpose. Slot techniques [8], [11], [19] inspire to design a new UWB antenna which have excellent performance such as compact size, UWB bandwidth, gain, radiation efficiency, surface current and so on compare to the existing research work. Overall, this research work is compact size and size reduction almost 11% [12], maximum gain has been achieved 5 dBi which is comparatively [11] better performance. After this proposed antenna has been achieved variable band notched function. Wa= 12 mm has been performed (3.4–4) GHz notched bandwidth for 5G lower band application and Wa= 15 mm creates (3.25–3.8) GHz band notched bandwidth for Wi-MAX wireless communication purpose [20].

By inserting semicircular slots (SCS) in the radiating patch, the band rejection function is achieved. A compact size of proposed antenna $42\times26 = 1092 \text{mm}^2$ with $W_p= 15$ mm, $L_p= 15$ mm, $L_f= 7.5$ mm, $W_f= 3$ mm, $a=0.6$ mm, $b= 2.5$ mm and $c= 2.23$ mm. Which is the compact size compare to recent research work, [11] 1221 mm$^2$, [12] 2100 mm$^2$ and [13] 2000 mm$^2$. Figure 1(a, b) shows the physical layout of the proposed VBN-UWB antenna with surface current. Due to SCS a huge amount of surface current i.e. 204 A/m accumulated. It is justified, due to the SCS top on the radiation patch, that band notched features are achieved. The certain parameters that are tailored to achieve the desired output by using CST MWS. It is noteworthy from Figure 1(d) that the (3.25–3.8) GHz antenna was rejected with $S_{11}$ parameter notched value near to -1.8 dB. The band rejection bandwidth can vary from (2.95–4) GHz i.e. lower frequency to upper cut off frequency by changing “Wa” functions and “Wa” values from (8–18) mm, it notable that all cases “Wa” values satisface the UWB bandwidth with band notched function. Thus, Wa=15 mm, 12 mm are optimized value that encompasses UWB bandwidth as well as Wi-MAX and 5G lower band applications. All “Wa” values are shown in Table 1 for a UWB bandwidth and $S_{11}$ study in Figure 1(e). Figure 1(f) illustrated the $S_{11}$ comparison between SCS and without SCS. From this $S_{11}$ comparison it’s clear that SCS creates a band stop function for avoiding the single interference.

2.0 VARIABLE BAND NOTCHED (VBN-UWB)

A rectangular patch antenna (RPA) is constructed using the PCB-printed circuit board system, where FR-4 is used as a substrate and copper as a conductive patch layer comprising patch and ground thickness $t=0.035$ mm. FR-4 substrate height $h=1.6$ mm, relative permittivity $\varepsilon_r=4.4$, a loss tangent of $\delta=0.025$. The width and length of the radiating patch $W_p= 12.5$ mm, $L_p= 15$ mm respectively. This antenna connected by a quarter-wave ($\lambda/4$) microstrip feedline with $W_f$ width and length $L_f$. It is noteworthy that this traditional patch antenna has a narrow bandwidth of UWB and the ground length is reduced to $L_g1=13$ mm for obtaining a full UWB frequency range. The partial ground (PG) method UWB antenna achieved (2.7–13) GHz.
Table 1 Notched bandwidth performance with respect to different Wa values [20]

| Wa (mm) | Notched Bandwidth (GHz) | UWB bandwidth (GHz) |
|---------|-------------------------|---------------------|
| 8       | 3.95–4.40               | 3.10–13.30          |
| 9       | 3.80–4.40               | 3.07–13.50          |
| 10      | 3.70–4.30               | 3.04–13.70          |
| 11      | 3.50–4.20               | 2.97–13.62          |
| 12      | 3.40–4.00               | 2.92–13.50          |
| 13      | 3.20–3.90               | 2.90–13.40          |
| 14      | 3.00–3.80               | 2.76–13.20          |
| 15      | 3.25–3.80               | 2.70–13.00          |
| 16      | 3.10–3.80               | 2.60–12.80          |
| 17      | 2.95–3.80               | 2.50–12.50          |
| 18      | 2.75–3.90               | 2.40–12.25          |

3.0 EXPERIMENTAL VALIDATION

Figure 2(a, b) shows the photography of testing antenna for Wa=15 mm. Figure 2(c,d,e) illustrated the comparison between simulated and measured $S_{11}$ of PG-RPA (partial ground-rectangular patch antenna), $S_{11}$ and VWSR of VBN-UWB antenna. The VSWR is found at less than 2, for the entire UWB (2.7–13) GHz and a higher than two at the notched frequency (3.25–3.8) GHz. Measured 2-D polar pattern illustrated in Figure 2(f). Usually, the antenna proposed is the h-field of the monopole antenna provided by an omnidirectional radiation pattern. So, the 2-D polar pattern, excluding the band notch frequency is more appropriate. Figure 2(g) illustrated the tested gain of the proposed VBN-UWB antenna. The maximum gain 5 dBi at 10 GHz and minimum gain near to 0 dBi at 3.5 GHz. Moreover, new research efforts have been used to compare the proposed VBN-UWB antenna’s performance to previous work in Table 2.

Figure 1 Proposed VBN-UWB antenna layout (a,b), surface current at .5 GHz (c), $S_{11}$ for Wa= 15 mm (d), parametric study $S_{11}$ of different Wa values (e) and comparison $S_{11}$ between with SCS and without SCS (f) [20]
Figure 2 Testing of fabricated antenna (a, b), comparison between the simulated and measured $S_{11}$ of partial ground rectangular patch antenna (PG-RPA) UWB antenna (c), $S_{11}$, VSWR (d, e), measured 2-D polar pattern at 3.5 GHz (f) and gain (g) of proposed VBN-UWB antenna

Table 2 Performance comparison of the proposed antennas with others recent research works [20]

| Ref. | Dimension (L×W), mm$^2$ | UWB Bandwidth (GHz) | Band-Notched (GHz) | Variable Characteristic |
|------|------------------------|---------------------|-------------------|-----------------------|
| 6    | 75 × 10                | 2.70 – 14.70        | 5.15 – 5.83, 3.40–3.70 | No                   |
| 9    | 37 × 33                | 2.87 – 11.48        | 3.20 – 3.80        | No                   |
| 10   | 42 × 50                | 2.00 – 12.00        | 3.30 – 6.00        | No                   |
| 11   | 50 × 40                | 2.30 – 12.00        | 3.30 – 3.80        | No                   |
| 14   | 14 × 30                | 3.00 – 12.00        | 3.20 – 3.80        | No                   |
| Our Work | 42 × 26            | 2.70 – 13.00        | 3.25 – 3.80, 3.40 – 4.00 | Yes                 |

4.0 CONCLUSION

A UWB antenna has been suggested, designed, validated the simulated and measured results with variable band-notched function. The proposed antenna was designed on FR-4 substrate. A SCS produces band notched that can be used for Wi-MAX and 5G lower band wireless applications. The bandwidth can be changed by changing “Wa” and notched bandwidth moves lower cut of frequency to upper cut frequency, which is (2.95–4.4) GHz. With its basic configuration the antenna is best suited for Wi-MAX and 5G lower band notched applications.

Acknowledgement

Authors are grateful Research Management Centre, International Islamic University Malaysia to support this research. They are also thankful to the Microwave Lab at International Islamic University Malaysia, RF and Microwave Lab at Universiti Teknikal Melaka (UTeM), Malaysia of Dr. A.K.M. Zakir Hossain providing the support for antenna testing.

References

[1] R. A. Pandhare, M. P. Abegaonkar, and C. Dhole, 2022, “High gain wideband and multi-band on-demand reconfigurable antenna for modern wireless application,” International Journal of Microwave and Wireless Technologies, 1-16. doi: 10.1017/S1759078722000630.
[2] F. C. Commission, 2002, “First Report and Order in The Matter of Revision of Part 15 of the Commission’s Rules Regarding Ultra-Wideband Transmission Systems,” ET-Docket 98-153, FCC 02-48, Accessed: Dec. 24, 2019. [Online]. Available: https://ci.nii.ac.jp/naid/10029633643/
[3] G. R. Sri, A. J. Rani, and V. Saritha, 2020, “Design And Implementation Of A Very Compact Mimo Antenna Providing Dual Notches At Wlan And Xband,” PIER C, 104: 241–252, doi: 10.2528/PIERC20062702.
[4] M. M. H. Mahfuz, M. R. Islam, N. A. Malek, Md. S. Islam, and G. M. Asadullah, 2020, "Design of dual band notched ultra wideband microstrip patch antenna for 5G lower bands application," AIP Conference Proceedings, 2306(1): 020009. doi: 10.1063/5.0032481.

[5] S. Modak, T. Khan, T. A. Denidni, and Y. M. M. Antar, 2022, “Miniaturized self-isolated UWB MIMO planar/cuboidal antenna with dual X-band interference rejection,” AEU - International Journal of Electronics and Communications, 143: 154020. doi: 10.1016/j.aeue.2021.154020.

[6] O. P. Kumar, P. Kumar, T. Ali, P. Kumar, and S. Vincent, 2022, "Ultrawideband Antennas: Growth and Evolution," Micromachines, 13(1): Art 1. doi: 10.3390/mi13010060.

[7] Y. Ibnatta, M. Khaldoun, and M. Sadik, 2021, "Indoor Localization Techniques Based on UWB Technology," in Ubiquitous Networking, Cham. 3–15. doi: 10.1007/978-3-030-86356-2_1.

[8] H.-U. Bong, M. Jeong, N. Hussain, S.-Y. Rhee, S.-K. Gil, and N. Kim, 2019, "Design of an UWB antenna with two slits for 5G/WLAN-notched bands," Microwave and Optical Technology Letters, 61(5): 1295–1300. doi: 10.1002/mop.31670.

[9] D. Jang, T. H. Lim, D. Kim, S. Wang, and H. Choo, 2022, "Design of a High-Durability X-Band Patch Antenna with a CPW Feeding Network Based on a Durability Evaluation Analysis," Electronics, 11(4): Art 4. doi: 10.3390/electronics11040553.

[10] B. A. Babu, B. T. P. Madhav, K. Srilatha, B. M. S. Siriram, and A. V. Hemanth, 2022 "A Compact Dual-Band Self-Diplexing MIMO Patch Antenna for ISM and X-Band Communications," Journal of Microwaves, Optoelectronics and Electromagnetic Applications, 21(2): 319–327. doi: 10.1590/2179-10742022v21i2259539.

[11] M. M. S. Ahmed, R. Islam, and S. Khan, Design of Dual Band Notched Ultra Wideband Antenna Using (u-W) Shaped Slots.

[12] Qurratulain and N. Chattoraj, 2017, “Study of effects of a single wide band notch for WLAN on UWB antenna for wireless communication,” in 2017 International Conference on Intelligent Computing and Control (IC2C): 1–5. doi: 10.1109/IC2C.2017.8321948.

[13] D. Sarkar, K. V. Srivastava, and K. Saurav, 2014 "A Compact Microstrip-Fed Triple Band-Notched UWB Monopole Antenna," IEEE Antennas and Wireless Propagation Letters, 13: 396–399. doi: 10.1109/LAWP.2014.2306812.

[14] N. Taher, A. Zakriti, N. Amar Touhami, and F. Rahmani, 2022 "Circular ring UWB antenna with reconfigurable notch band at WLAN/sub 6 GHz 5G mobile communication," Microsystem Technologies 28(1):1-8. doi: 10.1007/s00542-021-05246-9.

[15] R. K. Maurya, B. K. Kannaujia, A. K. Maurya, and R. Prakash, 2022, “Design of DGS Compact UWB Antenna for C-, X-, Ku-, and Ka-Band Applications Using ANN and ANFIS Optimization Techniques,” in Proceedings of First International Conference on Computational Electronics for Wireless Communications, Singapore. 1–11. doi: 10.1007/978-981-16-6246-1_1.

[16] K. J. Singh and R. Mishra, “2017, Design of A Circular Microstrip Patch Antenna with Single Band Notch Characteristic for UWB Applications,” in 2017 IEEE International WIE Conference on Electrical and Computer Engineering (WIECON-ECE), Dec: 262–265. doi: 10.1109/WIECON-ECE.2017.8468902.

[17] R. Azim, M. T. Islam, and A. T. Mobashsher, 2014, "Dual Band-Notch UWB Antenna With Single Tri-Arm Resonator," IEEE Antennas and Wireless Propagation Letters, 13: 670–673. doi: 10.1109/LAWP.2014.2314486.

[18] N. Jaglan, S. D. Gupta, B. K. Kanaujia, and S. Srivastava, 2018 "Band notched UWB circular monopole antenna with inductance enhanced modified mushroom EBG structures," Wireless Netw, 24(2): 383–393, Feb., doi: 10.1007/s11276-016-1343-7.

[19] S. Y. A. Fatah, E. K. I. K. I. Hamad, W. Swelam, A. M. M. A. Al lam, M. F. Abo Sree, and H. A. Mohamed, 2021, "Design and Implementation of UWB Slot-Loaded Printed Antenna for Microwave and Millimeter Wave Applications," IEEE Access, 9: 29555–29564. doi: 10.1109/ACCESS.2021.3057941.

[20] M. M. Hasan Mahfuz, M. M. Soliman, M. R. Islam, M. H. Habaebi, N. Sakib, and N. A. Malek, 2020, "Design of UWB Microstrip Patch Antenna with Variable Band Notched Characteristic for Wi-MAX Application," in 2020 IEEE Student Conference on Research and Development (SCoReD), Sep: 50–54. doi: 10.1109/SCoReD50371.2020.9250947.