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Design of UWB microstrip patch antenna with variable band notched characteristics

M. M. Hasan Mahfuz, Md. Shazzadul Islam, Islam Md. Rafiqul, Mohamed Hadi Habaebi, Nazmus Sakib
Department of Electrical and Computer Engineering, International Islamic University Malaysia (IIUM), Malaysia

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ABSTRACT

Recently lower frequency band 4.5 − 5.5 GHz is proposed by the ASEAN countries for 5G cellular application and therefore, it is essential of designing an ultra-wideband (UWB) antenna for the particular band-notched characteristics. In this article, a compact tuning fork shape ultra-wideband (UWB) patch antenna with a variable band-notched characteristic has been proposed for 5G cellular application. The UWB antenna has been achieved by using a tuning fork shape with a simple partial ground plane. A pair of ring shape slits (RSS) on the ground plane has been added to achieve the band-notched characteristic. The proposed antenna has achieved a large −10 dB bandwidth of 7.8 GHz (2.9 − 11 GHz) and the VSWR value is less than 2 for the entire bandwidth excepted for notched frequency bands of lower 5G bands (4.5 − 5.5 GHz). Moreover, the antenna has a peak radiation efficiency of more than 87% for UWB and less than 27% for the notched frequency band. The notched-band is shifted with the change in the position of RSS's within the vertical axis and thus, the variable band-notched characteristics have been achieved. Besides, the proposed antenna is compact with the dimension of 45 × 34 mm^2 that makes it suitable for the lower band of 5G application.

Corresponding Author:

Islam Md. Rafiqul
Department of Electrical and Computer Engineering
International Islamic University Malaysia (IIUM)
Jalan Gombak 53100 Kuala Lumpur, Malaysia
Email: rafiq@iium.edu.my

1. INTRODUCTION

Many researchers are working on the development of the wireless communication applications for the past few decades and therefore, ultra-wideband (UWB) has become more suitable as it can transfer a large amount of data with large bandwidth, lower cost of fabrication and so on so forth. In 2002, the Federal Communication Commission (FCC) has assigned 3.1− 10.6 GHz bandwidth for UWB application for commercial usage [1]. And since then, UWB has become more popular and widely accepted for short-range wireless communications. Usually, UWB is performing with wide operating bandwidth, while designing a UWB antenna has some challenges like achieving large impedance bandwidth, low reflection coefficient, significant radiation pattern and space limitations. There are several narrowband applications within the UWB [2-6] like 3.3 GHz to 3.7 GHz of WiMAX [7], 3.3 to 3.8 GHz of C-band for ASEAN [8], lower frequency band (4.5 − 5.5 GHz) for 5G (fifth generation) applications [9], 5.15 GHz to 5.35 GHz and 5.725 to 5.825 GHz of WLAN [10], 7.25 to 7.75 GHz of satellite downlink communication for International Telecommunication Union (ITU) [11], 7.725 to 8.275 GHz of X-band [12] and so on. To improve the performance of a planar UWB antenna, several methods can be applied like different patch shapes, partial ground, inset-fed, defected ground structure (DGS), coplanar waveguide (CPW) and various type of slots on the radiating patch [12, 13-19]. It is found from the literature that in most of the cases, the band-notched characteristics have been achieved by different slots on the radiating patch and ground plane [15], while, it is easy to achieve UWB with partial ground plane [20, 21]. Recently, many research works have been proposed regarding band-notched characteristics for various applications.

A CPW-fed UWB antenna with dual split-ring resonators (SRRs) has been proposed for dual notched-bands function in [20]. The UWB antenna operates from 3.0 to 10.6 GHz with two rejection bands ($5.0 - 5.8$ and $7.5 - 8.5$ GHz). The proposal antenna has achieved 50×50 mm^2 dimensions in the area. To achieve first notched-band, a pair of dual SRRs (DF-DSRR) have been designed on the middle of the ground plane, while the second notched-band has been achieved with a pair of dual SRRs (WB-DSRR) on the downside of the ground plane. In [22] a Vivaldi UWB antenna with switchable and tunable band-notch characteristics has been proposed. The band-notched characteristic has achieved with a stepped-impedance resonator (SIR) and the varactor diode gives tunable band-notched function. The proposal antenna operates from 3.1 to 10.6 GHz for UWB. The geometrical dimension of the antenna is 50×40 mm^2 with tunable band-notched bandwidth from $3.1 - 6.8$ GHz and the VSWR value is < 2 for the entire bandwidth except across the band rejection frequencies. The antenna efficiency is more than 80% for the entire bandwidth, while less than 38% in the band-notched frequency bandwidth. A multiple band-notched UWB antenna with DGS has been proposed in [21] with a circular shape radiating patch and the dimension is 80×70 mm^2 in the area. VSWR of the proposal UWB antenna is less than 2, except at the band rejection bandwidth and it has four rejection bands.

The antenna has achieved a bandwidth of UWB antenna ($1.5 - 12$ GHz) and four rejected bands are $2.15 - 2.65$ GHz, $3.0 - 3.7$ GHz, $5.45 - 5.98$ GHz and $8 - 8.68$ GHz. Two meander shape DGS of upper slot creates the dual notched-bands of $2.15 - 2.65$ GHz and $3.0 - 3.7$ GHz, while lower slot creates another two notched-bands of $5.45 - 5.98$ GHz and $8.0 - 8.68$ GHz. A UWB antenna with triple band-notched characteristics from 3.3 to 3.8 GHz, 5.15 to 5.825 GHz and 7.1 to 7.9 GHz with 3.1 to 10.6 GHz of -10 dB bandwidth has been proposed in [16] that has achieved 50×42 mm^2 geometrical dimensions. A unipolar EBG structure has connected with the ground plane that helps to achieve the band rejection functions and a disc shape radiating patch gives the unique design of this antenna. The achieved notched-bands with the EBG structure are 3.3 to 3.8 GHz of WiMAX, 5.15 to 5.825 GHz of WLAN and 7.1 to 7.9 GHz of X-band for satellite communication. Moreover, it has low radiation efficiency in the stop frequency bands. On the other hand, a UWB antenna with three rejected bands with a dimension of 50×40 mm^2 has been proposed in [17]. The proposed antenna has a wide -10 dB bandwidth of 11.7 GHz (2-13.7 GHz) for UWB application with the three notched-bands of 2.69 to 4.5 GHz, 5.49 to 6.37 GHz and 8.15 to 9.61 GHz.

It is seen from the literature that in most of the works, either the antennas are without tunable band-notched characteristics or the band notched tunability have been achieved by employing active elements like PIN diode, varactor and/or capacitor. Antenna with an active element can suffer from a fabrication process that can be overcome by proposing tunability with a passive structure. Besides, the proposed antennas mentioned above are with large dimension, limitation in continuous tuning and an appropriate tuned band that demands to be overcome. Also, best in our knowledge, there is a limitation in proposing UWB antenna with band-notched characteristic for particular 5G cellular band. The main importance of proposing tunable band-notched antenna is to achieve interfering bands that might slightly differ in terms of different countries.

In this paper, a tuning fork shape (TFS) planner monopole UWB antenna has been proposed with the partial ground (PG) and a pair of ring shape slits (RSS) in the ground plane for the lower band ($4.5 - 5.5$ GHz) 5G applications. The hierarchical process of the proposed antenna synthesis has been discussed in the coming section. Section 3 discusses the performance and its analysis with corresponding figures and table with a benchmark table for performance evaluation. The paper ends at section 4 with a conclusion.

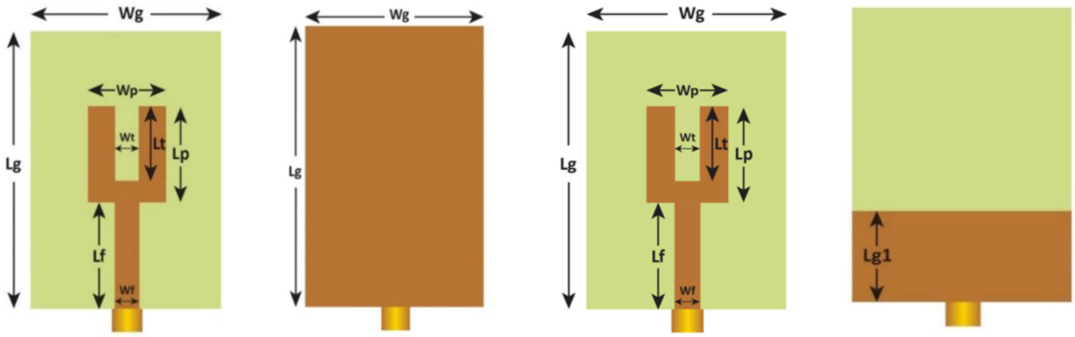
2. ANTENNA SYNTHESIS

2.1. Design of UWB antenna

The antenna has been designed based on the PCB-printed circuit board technology. The reason behind choosing PCB technology is the design simple and easy of fabrication. Besides, it is easy to optimize the design to achieve desire performances [23]. The hierarchical process of the design of UWB antenna has been illustrated in Figure 1. And the final optimized dimensions are presented in Table 1.

First, a TFS rectangular patch antenna (RPA-TFS) has been designed and realized on FR-4 substrate with dielectric height, $h = 1.6$ mm, permittivity, $\varepsilon_r = 4.4$, loss tangent, $\delta = 0.025$ and trace thickness, $t = 0.035$ mm. After being designed and simulated in CST MWS 2019, the antenna has achieved a narrow bandwidth. Therefore, the bandwidth has been increased by employing the partial ground technique. And thus, the partial ground-based RPA-TFS, (PG-RPA-TFS) UWB antenna has been proposed. The proposed PG-RPA-TFS has achieved a wide -10 dB bandwidth of 8.05 GHz $(2.95 - 11$ GHz).

After being simulated in CST MWS 2019, the return loss (S_{11}) and VSWR of the RPA-TFS, PG-RPA-TFS have been compared that are shown in Figures 2 and 3 respectively. It is seen from Figure 2 that RPA-TFS has a narrow bandwidth, while the bandwidth of the PG-RPA-TFS has been achieved with a partial ground. The minimum VSWR value is as low as less than 1.2 for the UWB as seen in Figure 3. A parametric study has been carried out the effects of the partial ground by changing its length, Lg1=9 mm gives the best performance and it has been selected for the final design.



(a) (b)

Figure 1. The antenna geometry; (a) RPA-TFS (b) PG-RPA-TFS

Table 1. Dimensions of the UWB antenna

Measurement	Value								
Parameters	L_g	W_g	L_g1	L_f	W_f	L_p	W_p	L_t	W_t
Dimension (mm)	45	34	13.5	3	7.5	15	12	10.5	3

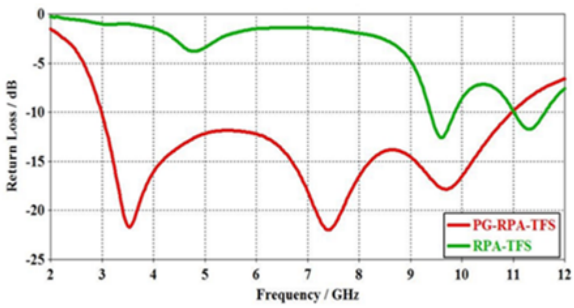


Figure 2. The return loss of RPA-TFS and PG-RPA-TFS

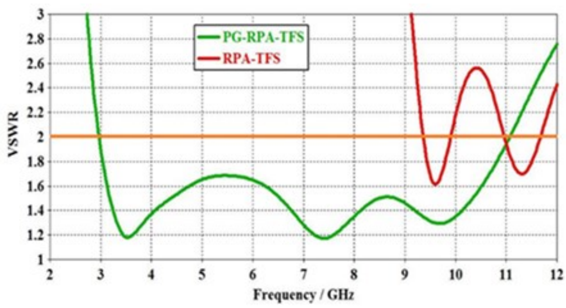


Figure 3. VSWR of RPA-TFS and PG-RPA-TFS

2.2. Variable band-notched UWB antenna

The proposed variable band-notched ultra-wideband antenna (VBN-UWB) contains a tuning fork shape radiating patch and two symmetric RSS behind the patch on the ground plane. For achieving the notched-band, 4.5 to 5.5 GHz has been defined that is proposed to be used for future 5G application in ASEAN countries [4]. Figure 4 illustrates the geometry of the proposed antenna. The proposed antenna has been designed and simulated in CST MWS. Some parameters have been optimized in CST to achieve the desired performances that have been presented in Table 2.

The achieved return loss of the proposed antenna has been comprised in Figure 5. It can be seen from the figure that the antenna has achieved a notched-band of 4.5 GHz to 5.5 GHz with the RSS. The inner and outer radius of the RSS is r and R respectively as shown in Figure 4. The inner radius of RSS is $r = 2.2$ mm and outer radius $R = 6.7$ mm. The optimum coordinate positions of the RSS pairs along to the X-axis are $X1 = +6, X2 = -6$ and along to the Y-axis, $Y = +2$ for both the RSS by considering zero (0) as the middle of the antenna.The geometrical position of the RSS's has a greater impact on the antenna notched-band, especially, changes position along the Y-axis. In fact, the variable band-notched characteristics have been achieved with a change in the RSS's position in Y-axis. The parametric study of the changes in the RSS's position has been performed to show the shifted notched-band. The parametric study of the return loss of the proposed VBN-UWB has been illustrated in Figure 6.

It is seen from Figure 6 that the antenna notched-band shifted because of the changes in the RSS's position in the Y-axis. The more it shifted towards the positive side of the Y-axis, the more notched -band has shifted from lower to higher frequencies.Therefore, the optimized position has been considered to obtain the notched-band from 4.5 GHz to 5.5 GHz. The effects of the changes in the performance on the notched-band and entire bandwidth of the antenna have been reported in Table 3. It can be observed from the table that the RSS's position has slight impacts on the overall bandwidth that is negligible as the bandwidth of UWB is still within the bandwidth.

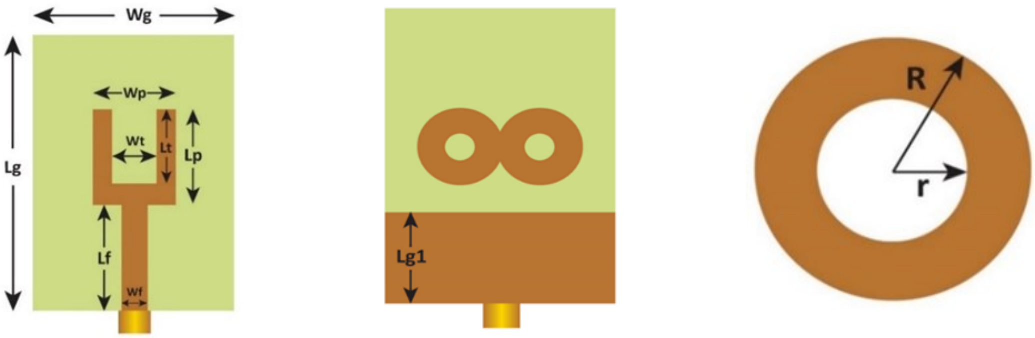


Figure 4. Antenna geometry of proposed VBN-UWB

Table 2. Dimensions of the VBN-UWB antenna

Measurement	Value						
Parameters	Wp	Lp	Wg	Lg	Lf	Wt	Lt
Dimension (mm)	12.5	16.8	34	45	7	5.9	13.5

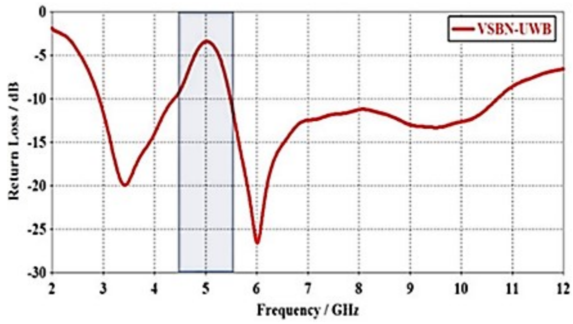


Figure 5. The return loss of VBN-UWB

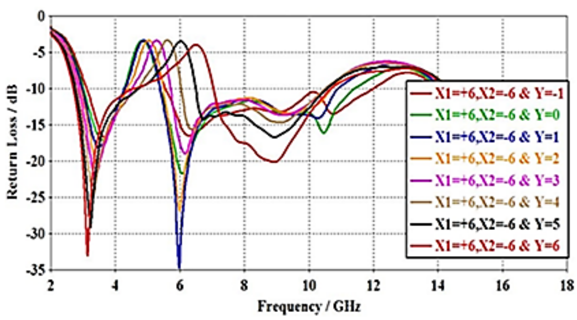


Figure 6. Parametric study of the VBN-UWB

Table 3. Notched bandwidth performance due to different Y values

Values of Y in (mm)	Shifting notched bandwidth (GHz)	UWB bandwidth (GHz)
-1	4.3– 5.6	3.1– 12.32
0	4.3– 5.4	3.0– 11.5
1	4.4– 5.4	2.9– 10.9
2	4.5– 5.5	2.9– 10.7
3	4.6– 5.7	2.9– 10.7
4	4.7– 6	2.8– 10.5
5	4.7– 6.5	2.7– 10.6
6	4.6– 7	2.7– 10.7

3. RESULTS AND DISCUSSION

The VSWR of the proposed VBN-UWB has been shown in Figure 7. It can be noticed that the VSWR value for the operating bandwidth of the VBN-UWB antenna is less than 2.0, which means it has a good impedance matching between the radiating patch and the feedline. While the VSWR value is higher than 2.0 within the rejected frequency band. The proposed VBN-UWB antenna's surface current distribution has been presented in Figure 8 at four frequencies. It can be observed from Figure 8 (a) that at the middle of the notched-band frequency of 5 GHz, a greater amount of current has accumulated due to the RSS that is above 120 A/m, while, only 46.5 A/m current has accumulated on the radiating patch without RSS as shown in Figure 8 (b). The current density of the radiating patch at the notched-band frequency justifies that the band-notched characteristic has achieved with the pair of RSSs on the ground plane. At the middle frequency of UWB of 6.85 and the resonant frequency of 6 GHz of the VBN-UWB have been shown in Figure 8 (c) and Figure 8 (d) respectively and the accumulated current on the patch are 52.6 A/m and 78.2 A/m respectively.

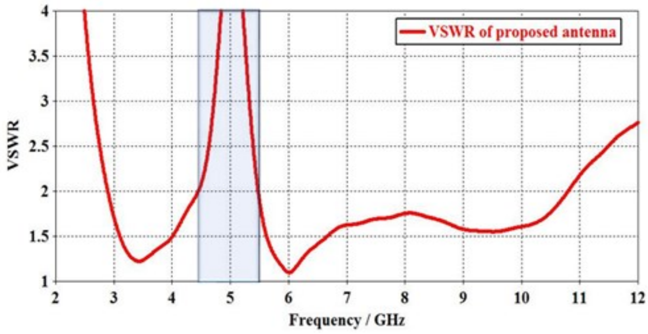
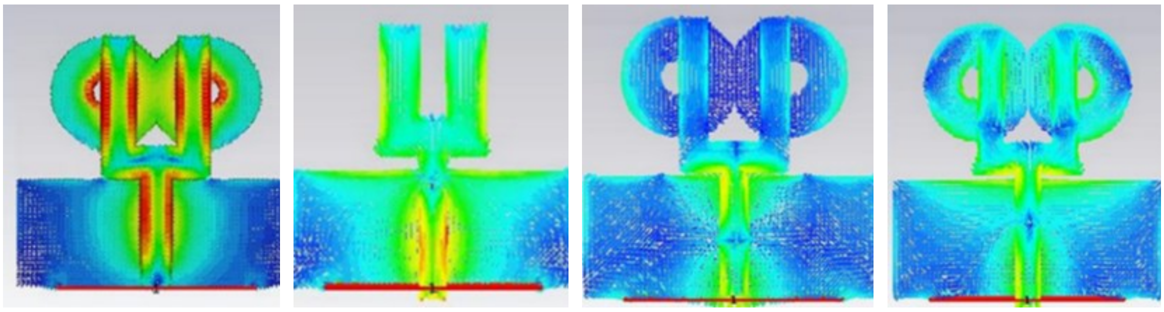


Figure 7. Simulated VSWR of proposed VBN-UWB



(a) (b) (c) (d)

Figure 8. The surface current distribution; (a) VBN-UWB antenna, (b) UWB antenna, (c) at the middle frequency of UWB of the VBN-UWB and (d) at the resonant frequency of the VBN-UWB antenna

The polar radiation pattern of the proposed VBN-UWB antenna has been shown in Figure 9. Usually, for monopole antenna, the omnidirectional radiation pattern generates at the h-field of the antenna that exactly happens for the proposed antenna. Therefore, the radiation patterns are more considerable except for the notched-band frequency. The increasing amount of the surface current at the radiating patch of the VBN-UWB antenna leads an increase in the antenna radiating efficiency. The radiation efficiency of the proposed antenna has been shown in Figure 10. The maximum radiation efficiency of the proposed UWB antenna is 89% with an average efficiency of 75%. While at the rejected band frequencies, the radiation efficiency less than 28%, which means its performance is very poor or does not perform. The proposed VBN-UWB antenna performances have been benchmarked with some new research activities as presented in Table 4. It is seen from the table that the antenna has achieved a compact dimension compare to the other proposed antennas, while the UWB frequency band is within the -10 dB bandwidth and has obtained notched-band characteristic of the lower band for 5G cellular application. It is to note that the proposed antenna has achieved the exact notched-bandwidth ($4.5 - 5.5$ GHz) of lower 5G frequencies proposed in ASEAN that resonates at 5 GHz which is the middle frequency of the band and the tunable characteristic of the notched-band has achieved with a passive structure on the ground plane of the antenna.

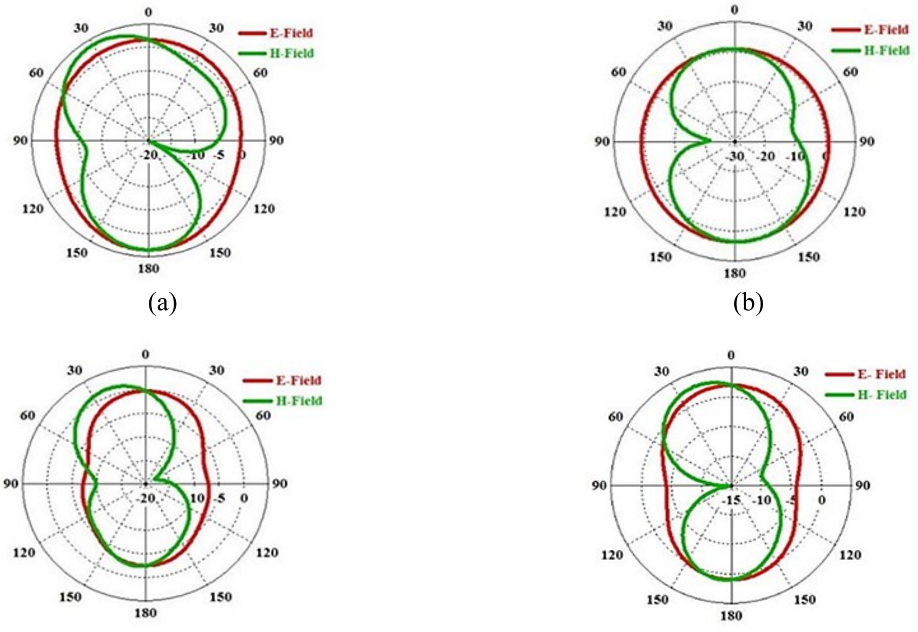


Figure 9. The 2-D polar radiation pattern of VBN-UWB, (a) VBN-UWB antenna, (b) UWB antenna, (c) at the middle frequency of UWB of the VBN-UWB and (d) at the resonant frequency of the VBN-UWB antenna

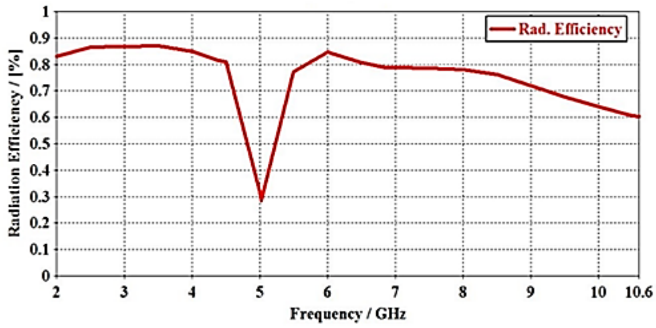


Figure 10. Radiation Efficiency of VBN-UWB

Table 4. Performance comparison of the proposed VBN-UWB antenna with other recent works

Ref.	Dimension (L×W), mm^2	Bandwidth (GHz)	Notched-Band Range (GHz)	Variable Characteristic
[20]	50 × 50	3– 10.6	5 – 5.8 7.5 – 8.5	No
[21]	80 × 70	1.5– 12	2.15 – 2.65 3 – 3.7 5.45 – 5.98 8 – 8.68	No
[22]	50 × 40	3.1– 10.6	3.1 – 6.8	Yes
[24]	50 × 42	3.1– 10.6	3.3 – 3.8 5.15 – 5.825 7.1 – 7.9	No
[25]	50 × 40	2– 13.7	2.69 – 4.5 5.49 – 6.37 8.15 – 9.61	No
This Work	45 × 34	2.9– 10.7	4.5 – 5.5	Yes

4. CONCLUSION

A compact UWB antenna with band-notched characteristics has been designed, simulated and analyzed in this article. The UWB antenna is designed and realized on an FR-4 substrate by using a tuning fork shape with a simple partial ground plane. A pair of ring shape slits (RSS) on the ground plane has been added to achieve the band-notched characteristic from 4.5 to 5.5 GHz that is proposed in ASEAN countries for 5G application. Also, the notched bandwidth is shifting from $4.3-5.6$ to $4.7-6.5$ GHz due to the changes of RSS position in the vertical axis. The tunable characteristic of the proposed antenna makes it capable of achieving the interfering bands if it is slightly varying with the requirement. The proposed antenna has a good performance on UWB frequency with band rejection capability. The VSWR, surface current, polar radiation pattern and radiation efficiency show performances with acceptable range. Hence, a simple design with compact size makes the antenna more suitable for the upcoming 5G lower band application.

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