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DESIGN AND DEVELOPMENT OF UWB PATCH ANTENNA WITH VARIABLE BAND NOTCHED USING RING-SHAPED SLITS

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ABSTRACT

ASEAN countries have recently proposed the frequency band (4.5–5.5) GHz for fifth generation (5G) cellular communication, which necessitates the creation of an ultra-wideband (UWB) antenna to accommodate the band-notched function. To describe the compact shape of a UWB antenna in the context of 5G application, this article has introduced a variable notched resonant characteristic at 5G lower band. A tuning fork radiating patch with a simple defected ground plane structure was used to create the UWB antenna. In order to create the band-notched criteria, a pair of ring-shaped slits (RSS) has been applied to the ground plane. This antenna has achieved a huge bandwidth from 2.9 GHz to 11 GHz and an extremely low VSWR less than 2. It appears that the antenna covers all frequencies except for notched frequency bands at lower 5G band (4.5–5.5) GHz. The antenna has been archived a peak gain of 5 dBi for UWB, but the notched frequency band produces less than -1 dBi. The notched-band can be shifted gradually in response to changes in the different positions of RSS's along the vertical axis, resulting capability to design for variable band-notched characteristics. The preliminary design was presented in [19]. The complete design is fabricated and tested and presented in this paper. The proposed antenna is small, with a surface area of 45×34 mm^2, making it ideal for 5G lower band application.
Keywords: *Microstrip Patch Antenna, UWB, RSS, 5G Lower Band, Variable Band-Notched*

1. INTRODUCTION

Over the years, several researchers have been developing wireless communication applications for UWB. It has risen to various applications because it can transmit a larger volume of data, has lower fabrication costs, and has many other advantages. In 2002, a (3.1–10.6) GHz bandwidth has been allocated to the UWB commercially available application by the Federal Communication Commission (FCC) [1]. Since then, UWB has seen a rise in popularity and use due to the fast spread of the technology. In general, broad operating bandwidth is a requirement when working with UWB technology but designing an antenna for UWB can be challenging because the antenna must have a wide operating bandwidth, low VSWR, substantial radiation polar pattern, and compact size. Narrowband is a huge advantage when it comes to UWB applications [2]–[6, 25–27] like (3.3–3.7) GHz for Wi-MAX [7], (3.3–3.8) GHz of C-band satellite communication [8], 5G lower band (4.5–5.5) GHz [9], (5.15–5.35) GHz &

(5.572–5.825) GHz for WLAN [10], satellite downlink contact frequencies of 7.25 GHz to 7.75 GHz for the International Telecommunication Union (ITU) [11], X-band frequencies range from (7.725–8.275) GHz [12] and so many. To improve the planar UWB antenna's efficiency, various patch shapes, partial ground, inset-fed, defective ground structure (DGS), coplanar waveguide (CPW), and various types of slots on the radiating patch can be used [2, 13–19]. Most research has shown that in the majority of cases, the band-notched functions are obtained by having separate slots on the patch and ground plane, thus achieving

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UWB is simple with have a defected ground structure [20, 21]. Several studies on band-notched characteristics for different applications have recently been suggested. For dual notched-band, a UWB CPW-fed antenna with dual split-ring resonators was proposed in [20]. The UWB antenna has two rejection bands from (5.0–5.8) GHz and (7.5–8.5) GHz and operates between (3–10.6) GHz. The proposed antenna has dimensions of 50×50 mm^2.

A couple of dual SRRs (DF-DSRR) were designed on the middle of the ground plane to achieve the first notched-band, while a pair of dual SRRs (WB-DSRR) were designed on the downside of the ground plane to achieve the second notched-band. A Vivaldi UWB antenna [21], in which the tunable and switchable band-notch features can be switched on and off, has been proposed. A stepped-impedance resonator (SIR) was used to generate the band-notched feature, and the varactor diode provided a tunable band-notched function. For UWB, the proposed antenna operates from 3.1 to 10.6 GHz. The antenna has a geometrical dimension of 50×40 mm^2, a tunable band-notched bandwidth of (3.1–6.80) GHz and a VSWR < 2 for the whole bandwidth except across the band rejection frequencies. For the full bandwidth, the antenna efficiency is greater than 80 percent, but in the band-notched frequency bandwidth, it is less than 38 percent. A multi-band UWB antenna with DGS in a circular patch shape has been proposed [22] the size in the area is 80×70 mm^2. Except for the band notched bandwidth, which comprises four rejection bands, the proposed UWB antenna has a VSWR of less than 2. The antenna has a UWB (1.5-12 GHz) bandwidth, and four bands of reject are 2.15–2.65, 3.0–3.7 GHz and 5.45 to 5.98 GHz and 8 to 8.68 GHz. The two DGS meander shapes in the top slot result in twin notched-bands of 2.15 to 2.65 GHz and 3.0 to 3.7 GHz, whereas the two DGS meander shapes in the bottom slot generate additional two notched-bands of 5.45 to 5.98 GHz and 8.0 to 8.68 GHz. –10 dB bandwidth UWB antennas 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 have been presented in [16] which have attained 50×42 mm^2 geometrical dimensions. Connected to the ground plane, the EBG structure helps to realize the band rejection capabilities and coupled with a disc-shaped radiating patch, results in a unique antenna design. The Wi-MAX (3.3–3.8 GHz), WLAN (5.15–5.825 GHz) and X-band (7.1–7.9 GHz) bands notched are achieved by using EBG method. Furthermore, in the band stop frequency regions, it has a low radiation efficiency. Alternatively, UWB antenna dimensions of 50×40 mm^2, with three rejected bands, has been proposed in [17]. This antenna offered a large –10 dB operating bandwidth of 2 to 13.7 GHz with three notched bands from (2.69–4.5) GHz, (5.49–6.37) GHz and (8.15–9.61) GHz within UWB application.

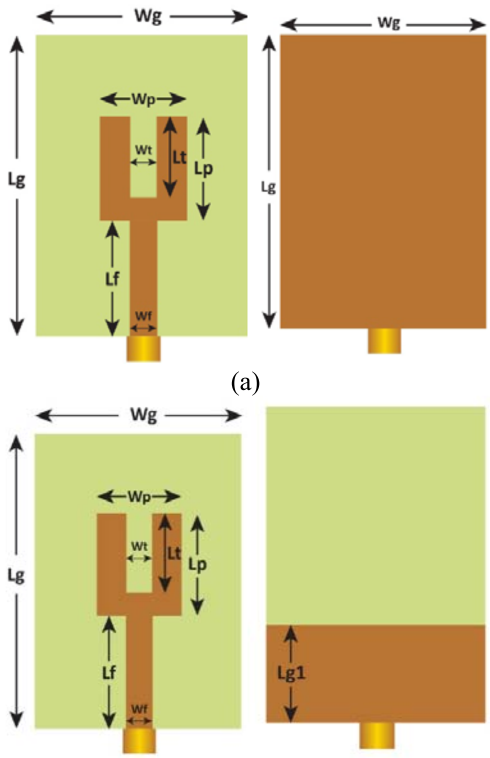
According to the literature most of the research work, either proposed antennas without tunable band-notched functions or accomplish band-notched tunability by using active elements such as a PIN diode, a varactor, or a capacitor. An active element antenna may have a complex fabrication procedure that can be avoided by using a passive construction with tunability. The following antennas should be built their dimensions are large, tuning can't go on forever, and they will need to be tuned to a certain band.

It has been awarded of the band-notched limitations while proposing UWB antennas for a particular 5G cellular frequency. The fundamental importance of the proposal of tunable band antennas is to achieve interfering bands which may differ slightly from one country to another. In this study a tuning fork shape (TFS) UWB antenna was presented for use on the 5G lower-band (4.5–5.5) GHz with the partial ground (PG) and a ring-shaped pair of slits (RSS). Due to the application of RSS in ground plane, this proposed antenna achieve notched function for 5G lower band application and dual RSS's position creates variable band notched (VBN) criteria from lower frequency to upper frequency. Moreover, TFS-UWB antenna with RSS doesn't exist on based our literature review since 2020 accept [19].

2. ANTENNA DESIGN AND CONFIGURATION

2.1 UWB Antenna Design

The UWB antenna has been built using printed circuit board (PCB) technology. Choosing PCB technology is based on the straightforward design and low manufacturing cost. Furthermore, optimizing the design to obtain desired results is simple. Fig. 1 illustrates the hierarchical method of designing a UWB antenna. Additionally, the optimized dimensions are listed in Table 1.



(b)

Fig 1. Antenna's Layout (A) TFS (B) PG-TFS [19]

Table 1 Dimensions Of The UWB Antenna [19]

Parameter	Lg	Wg	Lf	Wf	Lp	Wp	Lt	Wt	Lg1
Value (mm)	45	34	3	7.5	15	12	10.5	3	13.5

In the first step, a TFS rectangle patch antenna [17, 20, 25] has been developed and implemented on FR-4 substrate with height, h = 1.6 mm, relative permittivity, $\varepsilon_r = 4.4$, loss tangent, δ = 0.025, and trace thickness, t = 0.035 mm. In CST MWS 2020, the antenna has been designed and simulated, and it has a narrow bandwidth. As a result of using the partial ground approach, the bandwidth has been enhanced. Therefore, a PG-TFS UWB antenna has been proposed in this work. The desired PG-TFS has an 8.05 GHz (2.95–11) GHz bandwidth of −10 dB. The simulated return loss illustrated in Fig. 2. As can be observed in Fig. 2, TFS has a quite narrow bandwidth, while the PG-TFS has wide bandwidth has been achieved by applying the partial ground plane method.

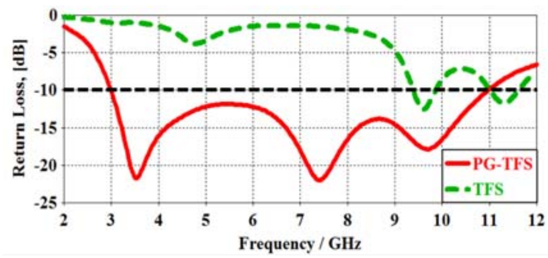
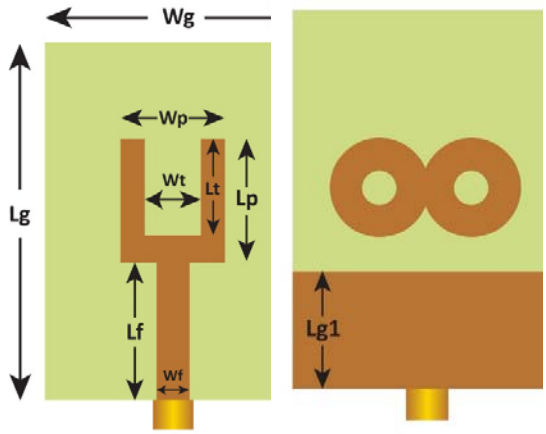


Fig 2. The combination S_{11} of TFS and PG-TFS [19]

2.2 VBN-UWB ANTENNA

A suggested variable band notched (VBN-UWB) antenna is an ultra-wideband tuning fork antenna with two symmetric RSS, with the tuning fork placed above radiating patch on the ground plane. (4.5–5.5) GHz has been identified as the frequency range for anticipated 5G usage in Asia countries. The suggested antenna's geometry is depicted in Fig. 3 and equivalent circuit shown in Fig. 4. The suggested antenna has been constructed and simulated in CST MWS. On the other hand, a single RSS doesn't provide the band notched function for 5G lower band application. Therefore, dual RSS placed on the ground plane and provide the band stop function within UWB bandwidth. In order to attain the required results reported of Table 2, few parameters in CST were optimized. An equivalent circuit of VBN-UWB antenna can be approximated as shown in Fig. 4. It is possible to build an effective equivalent circuit model of a microstrip patch antenna by employing a parallel RLC circuit. In order to represent the higher-order resonances of a rectangular microstrip patch antenna, an equivalent circuit model is devised. Patch antennas work at high frequencies, with the electrical circuit that is represented by the combined resistance R, capacitance C and inductance L.

Where, patch's resistance Rp, inductance Lp, capacitance Cp and ground's resistance Rg, inductance Lg, capacitance Cg. The RSS's inductance represents as Lg1 and Lg2. Due to the inductance (Lg1 & Lg2) creates the band notched function. The model is based on the transmission line model and may include additional modes if desired.



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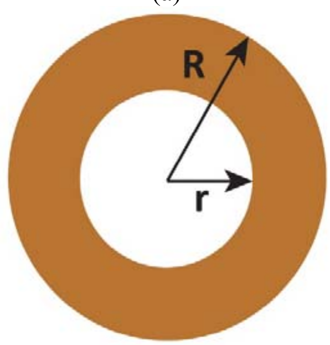

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Fig 3. Antenna geometry of the proposed VBN–UWB [19]

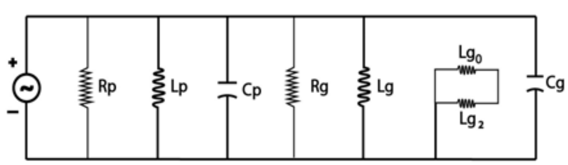

Fig 4. Rf Equivalent Circuit Of Vbn-Uwb

Table 2 Dimensions Of The VBN–UWB Antenna [19]

Variable	Wp	Lp	Ws	Ls	Lf	Wt	Lt
Value (mm)	12.5	16.8	34	45	7	5.9	13.5

Fig. 5 includes the return loss that has been illustrated the proposed VBN-UWB antenna. From the illustration, it can be deduced that the antenna has generated a notch in the frequency range of 4.5 GHz to 5.5 GHz using RSS. As seen in Fig. 3, the RSS's smaller and bigger radii are r and R respectively. RSS has a smaller radius of 2.2 mm, and a bigger radius of 6.7 mm and Fig. 6 illustrated the parametric study of (R & r) values.

For both the RSS consider of zero (0) as the center of the antenna, the suitable coordinate positions of the RSS's pairs along the X-axis are X1 = + 6, X2 = – 6, and along the Y-axis, Y = + 2. An antenna notched band has a higher impact on the measurable position of the RSS's, particularly when the position along the Y-axis changes. Actually, this shift in the RSS's position in the Y-axis was the underlying mechanism that produced the changeable band-notched features. Altering the RSS's position have been studied using parametric methods to demonstrate the shifted notched band. The parametric assessment of the S_{11} of the proposed VBN-UWB has been demonstrate in Fig. 7. The antenna notched band altered as a result of the shift in the RSS's position on the Y-axis, as can be seen in Fig. 7. As the positive Y-axis moved further from its neutral position, the notch-band changed upward in frequency. In order to obtain the notched-band from (4.5–5.5) GHz, the suitable position has been studied. Since the optimum position has been decided upon, the position with the notched band beginning at 4.5 GHz and ending at 5.5 GHz is evaluated. A notched-band antenna's performance was stated in Table 3 to have changed as a result of the adjustments. According to the table, RSS's influence on total bandwidth is small since UWB bandwidth still accounts for a significant amount of the overall bandwidth.

Table 3 Different Y values for notched bandwidth performance [19]

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

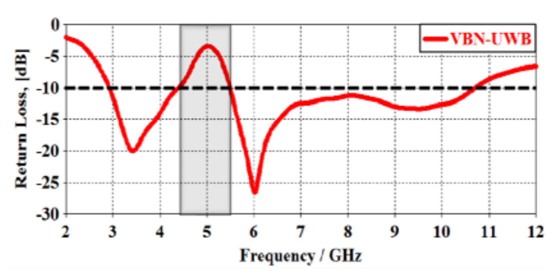

Fig 5. The S_{11} of proposed VBN-UWB [19]

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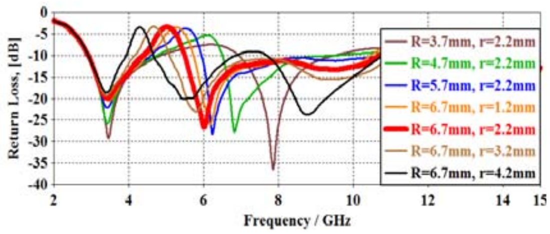


Fig 6. Different Parametric Study Of (R & R) Value Of RSS

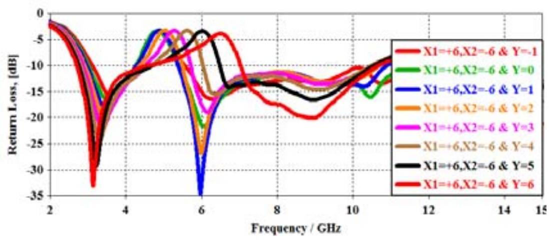
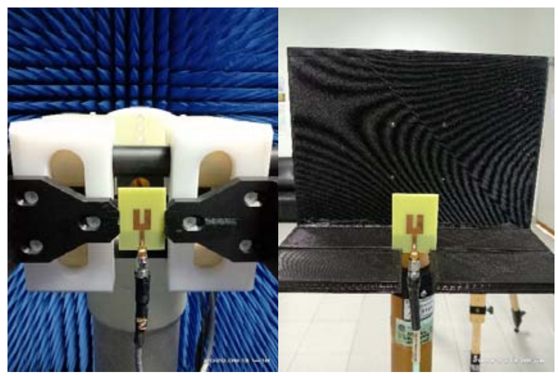


Fig 7. Parametric Study Of Proposed VBN-UWB [19]

3. FABRICATION AND TEST RESULTS

Fig. 8 shows the fabricated UWB, VBN-UWB antenna testing photography. The combination of measured and simulated return loss and VSWR has been depicted in Fig. 9 & 10 respectively for UWB and VBN-UWB antenna. An excellent impedance matching can be observed between the patch and feedline due to the VSWR value for the operating bandwidth of the VBN-UWB antenna which is less than 2. The VSWR value, which measures the difference between the wanted and unwanted entire frequency bandwidth, is higher than 2.0 within the rejected frequency band. In Fig. 12, the distribution of surface current at two frequencies has been shown for the proposed VBN-UWB antenna. It can be seen from Fig. 12(a) that current flows greater in the 5 GHz notch-band midpoint where there is an RSS with more than 120 A/m. According to the current density of the patch at the notched-band frequency, it can be assumed that the band-notched characteristic has been attained with the pair of RSS's on the ground plane. The measured polar pattern of the antenna has been illustrated in Fig. 11. With monopole antennas, the radiation pattern usually matches the h-field of the antenna; hence, the radiation pattern for the proposed antenna is also an omni-directional pattern. This can be attributed to the fact that except for the notched-band frequency, the radiation patterns are more substantial. The gain increases because the rising amount of surface current at the radiating patch of the VBN-UWB antenna. It has been shown in Fig. 13 that the proposed antenna's gain is equivalent to the standard gain which is define by IEEE. The suggested UWB antenna has a maximum gain of 5 dBi, and the average gain is 3.5 dBi. In notched band the gain is -1 dBi or less, resulting in a terrible or ineffective performance. The performance claims for the VBN-UWB antenna have been benchmarked in a new study, which is provided in Table 4.

According to the data provided, the antenna has an extremely compact dimension in comparison to the other proposed antennas, and it happens to fall into the 5G cellular frequency band the UWB has a bandwidth of –10 dB and a notch-band characteristic of the lower band. The passive ground plane on the antenna was able to tune precisely to the lower 5G frequencies proposed in ASEAN, which resonant at 5 GHz.



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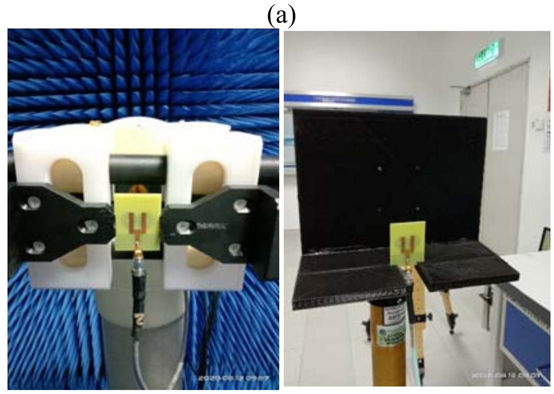
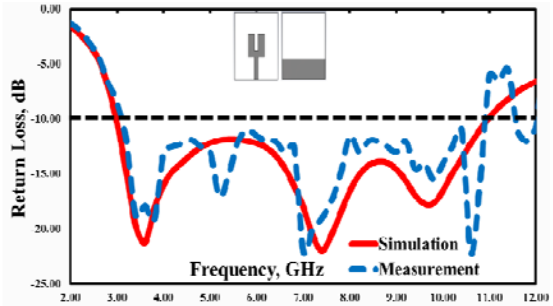


(b)

Fig 8. Testing Of Fabricated Antenna



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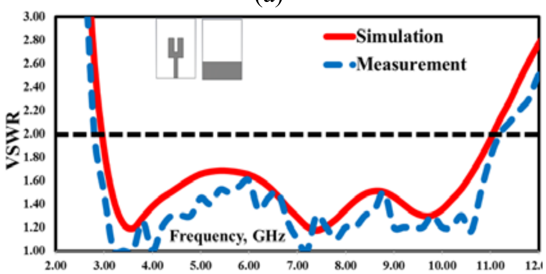
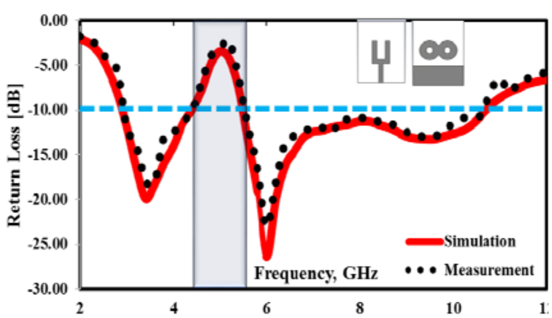


(b)

Fig 9. Comparison Between Simulated And Measured (A) S_{11} & (B) Vswr For Pg-Tfs Uwb Antenna



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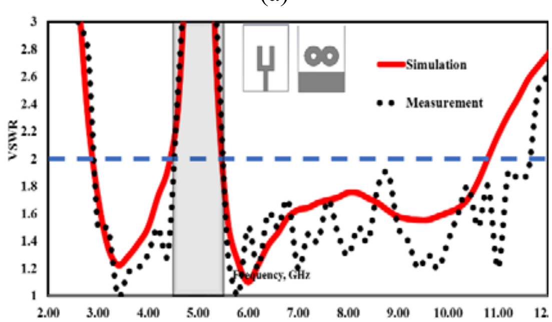

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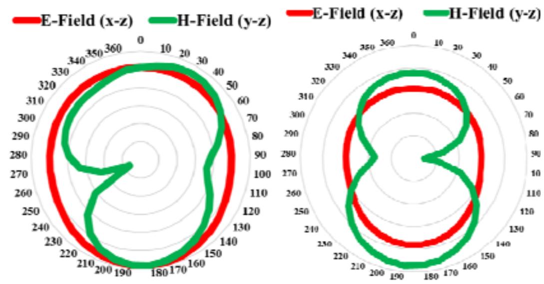
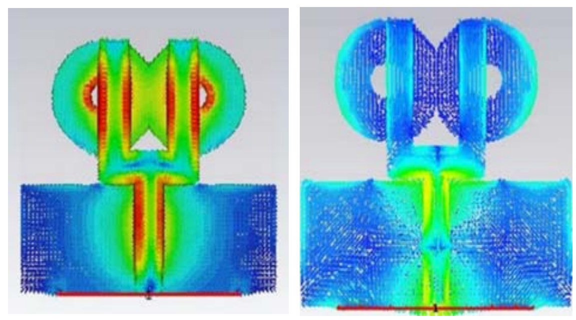
Fig 10. Comparison Of Simulated And Measured (A) S_{11} & (B) VSWR For VBN-UWB Antenna



(a) at 5 GHz (b) at 6.85 GHz

Fig 11. Measured 2-D Polar Radiation Pattern



(a) at 5 GHz (b) at 6.85 GHz

Fig 12. Surface Current Distribution [19]

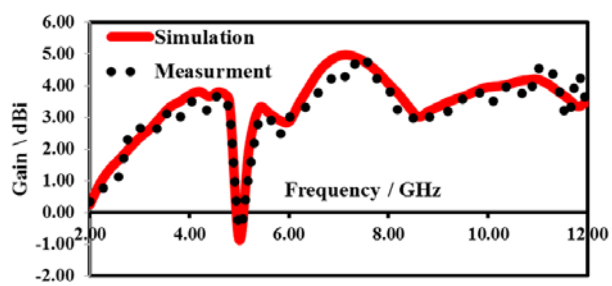


Fig 13. Simulated And Measured Gain

Table 4. Comparison Of Developed Antenna With Other Recent Work [19]

Ref.	Dimension (L×W), mm²	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
[23]	50 × 42	3.1 – 10.6	3.3 – 3.8 5.15 – 5.825 7.1 – 7.9	No
[24]	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

The design, simulations, fabrication, and validation test have successfully demonstrated the viability of a compact UWB antenna with band-notched features. The UWB antenna has a tuning fork shape and a basic PG plane on a FR-4 substrate. Another notable finding is that the notched bandwidth is shifting from (4.3–5.6) GHz to (4.7–6.5) GHz, while the RSS location on the vertical axis are changed. The proposed antenna can be easily designed with adjustable band notches therefore it is capable to model and design any interfering bands. This antenna has an excellent performance on UWB frequencies, with the potential of rejecting 5G lower band frequencies. The designed antenna is fabricated and tested in an anechoic chamber. The measured variations of return losses, VSWR, and gain with frequencies and poor radiation patterns are found good agreement with simulation results and all are within an acceptable range. With a smaller size of 45 mm × 34 mm, the proposed antenna is a suitable candidate for UWB applications with notched 5G lower bands.

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