Received: 27 July 2021
DOI: 10.1002/mop.33184

WILEY

RESEARCH ARTICLE

A notched UWB microstrip patch antenna for 5G lower and FSS bands

M.M. Hasan Mahfuz[1] | **Md Rafiqul Islam**[1] | **Mohamed Hadi Habaebi**[1] | **Nazmus Sakib**[1] | **A. K. M. Zakir Hossain**[2]

[1]Department of Electrical and Computer Engineering, International Islamic University Malaysia, Kuala Lumpur, Malaysia

[2]Fakulti Teknologi Kejuruterann Elektrik & Elektronik, Universiti Teknikal Melaka (UTeM), Malaka, Malaysia

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

Abstract

In ASEAN countries, the fifth generation (5G) forum proposed a 5G application lower frequency band (4.5–5.5) GHz and the fixed satellite service (FSS) C-band at (3.3–4.2) GHz. Previous research works have demonstrated that the complexity of antenna design, large size and in most of the cases, active elements that were added to antenna has made the antenna costly. Therefore, this research work focused on developing a single band notched (SBN) and double band notched (DBN) antennas by creating notched bands for 5G lower band from 4.5 to 5.5 GHz and C-band 3.3 to 4.2 GHz applications in antenna UWB spectrum. An UWB antenna has been developed using low-cost FR-4 substrate with partial grounding (PG) on a rectangular patch. A single band and dual band notched UWB antennas were realized for the 5G lower band through the use of a slot at the top of the radiating patch and by adding an arc shape open loop (ASOL) on the UWB antenna. Both antennas are fabricated using the same FR-4 substrate and tested using Vector Network Analyzer (VNA). The voltage standing wave ratio (VSWR), return loss, gain, and 2-D radiation pattern of the test results prove that all antennas have excellent performance (compared to previous research works) in notched band and UWB band frequencies. Therefore, developed single notch and dual notch UWB antennas are proposed as good candidates for 5G lower band and C-band notched application environment.

KEYWORDS

5G lower band, band-notched characteristics, microstrip patch antenna, UWB

1 | INTRODUCTION

The increasing uses of wireless technology support the need for antennas that can provide optimum performance across a wide range of frequencies. The microstrip patch antennas (MPA) have become common amongst considerably broad categories because they offer attractive advantages such as low-cost, lightweight, simple design and ease of manufacture. The Federal Communications Commission (FCC) considered the UWB frequency band between 3 and 10 GHz for commercial use in 2002. UWB operates in wide bandwidths, which have enormous importance in recent research, compared with the narrowband and broadband technology system.[1,2] For 5G networking, RFID, wireless transmission networks, the automotive industry, MIMO systems and biomedical applications, the UWB technology provides high-frequency data transmission for short distances. However, for FSS applications with a band range of (3.3–4.2) GHz[2] UWB technology has been developed recently for cellular communications 5G at (4.5–5.5) GHz.[3]

Because of the design simplicity and selectivity and the ability to adjust to meet specifications like impedance matching, microstrip antenna has significant advantages over other antenna form.[4,5] Therefore, many methods such as inset fed, CPW, defected ground (DGS), various slots and patch formats are used for further performance enhancement. It is particularly easy to achieve UWB frequency bandwidth[5] by using the defected ground plane, and band-notched characteristics can be achieved by using slots technique.[6] Recently many research projects with dual-band notched functions for different wireless applications have been proposed within UWB bandwidth.[7,8,9]

A CPW antenna with a UWB techniques is currently being considered to have a double rejection bands in Reference [6]. The antenna can operate between 3.1 and

10.6 GHz along two stop band frequencies. The first notched band operates between 3.2 and 3.8 GHz, while the second notched band operates between 4.8 and 6.2 GHz. The first band-notch was achieved by designing two symmetrical slots on the ground plane, while the second band-notch was achieved by added a split ring slot (SRS) on the radiating patch. The proposed antenna has a 3 dB average gain with less variance over the entire bandwidth, while the band-notched frequencies have no gain. Furthermore, the antenna's surface area is as small as 30 × 30 mm.[2] A monopole antenna have been created in Reference [7], the antennas are replaced with compact spade-shaped ones that feature two notch portions (lower and upper). It has a small dimension of 34 × 30 mm^2 and operates the UWB bandwidth with two notched bands of (5.15–5.35) GHz for lower WLAN and (5.725–5.825) GHz for upper WLAN. It has been suggested with a U-shape slots on the patch and W-shape slots on the grounded section in Reference [8]. As a result, the proposed antenna has an 8.61 GHz (2.87–11.48) GHz bandwidth for UWB applications, as well as a dual band-rejection characteristic. The Wi-MAX band of (3.24–3.65) GHz and the WLAN band of (5.01–6.01) GHz were both rejected by the antenna. In the presence of notched band antenna, a 5.5 GHz WLAN antenna has been suggested in Reference [7]. With an appropriate VSWR, the entire frequency range of 3.1–11 GHz has been accommodated by the proposed design. 3.4–4 GHz and 4.9–6 GHz are two notched-bands. The antenna is 35 × 24 mm^2 in size. There has been a suggestion that CPW-fed textile antennas can be used for UWB applications in Reference [9]. This proposed antenna achieves 8.9 GHz operating frequency from 1.8 to 10.7 GHz. Wi-MAX operates at frequencies of 3.3–3.7 GHz and Bluetooth is 2.3–2.5 GHz. To achieve dual band rejection characteristics, two semi-circular split ring resonator (SSRR) slots have been built on the radiating element. Despite its large size, however, it has a dimension of 43 × 40 mm^2. An antenna dimensioning map shows that to be the majority of the antennas can be designed with broad tolerances for significant applications, with smaller dimension goals in mind. As a result, antenna architecture is a fascinating area of research.

Authors[10] offer an ultra-compact UWB patch antenna with a partial ground plane. It is initially intended for UWB applications running in the (3.1–10.6 GHz) UWB spectrum part and then it is changed to function at three unique frequencies of 2.45, 5, and 10.2 GHz. This is the final version. Instead of using traditional patch antenna elements like slots and stubs, the new antenna (18 × 18 mm^2) will make use of more advanced ones like defective ground structure (DGS). A UWB antenna with two slits is proposed in this article.[11] In addition to a circular ground plane the antenna also includes a patch radiator with two slots and a folding arm. The antenna is made up of three parts. To accomplish UWB band a patch with a folding arm is employed while a V-shaped and a split ring-shaped slit are used to avoid interference from the WLAN (5.15–5.825 GHz) and 5G (3.4–3.7 GHz) bands respectively. Antenna prototype with a surface area of 75 × 10 mm^2. With on-demand WLAN band-rejection this article[12] describes the design and implementation of a small UWB antenna. Simple rectangular patch antenna with U-slot and partial ground plane on Taconic TLY-5 substrate for the proposed antenna. The suggested antenna outperforms the current UWB antenna due to its small size radiation stability and very wide impedance bandwidth. The unique antenna has a very wide operational bandwidth of (2.9–23.5 GHz) according to simulations and measurements and band rejection for WLAN (4.9–6.1 GHz) wireless application. The dual band notched UWB (3.2–10.5 GHz) antenna[13] describes the design and construction of a compact coplanar waveguide-fed. It has on-demand notch bands from (4–5.78 GHz) and (6.83–8.22 GHz) making it a versatile antenna. One octagonal patch antenna has been designed using a low-cost FR4 substrate. Using negative permittivity unit cells a wideband UWB antenna (2.85–11.52 GHz) with quadruple band notched characteristics is shown in this paper.[14] Four complimentary split ring resonators are etched on the modified rectangular patch to obtain quad notched band characteristics at required frequency bands which are subsequently tested experimentally.

A compact monopole microstrip patch antenna with rectangular slot (RS) on the patch and ASOL on top of the radiating patch is proposed in this paper. A cost efficient FR-4 dielectric material with permittivity of 4.4, loss of 0.025, and a dielectric height of 1.6 mm is used for the proposed design. The antenna is designed and simulated for 5G and expanded frequency for UWB using both CST MWS and HFSS simulators. The simulation and test results show that the antenna operates between 2.91 and 15.3 GHz.

2 | ANTENNA DESIGN DETAILS

2.1 | Basic UWB antenna

A rectangular patch antenna (RPA) was designed by taking in the formulas defined in Reference [4] where antenna feedline is a ($\lambda/4$) microstrip line for the resonant frequency (f_r), dielectric constant ($\varepsilon_r = 4.4$) and substrate height ($h = 1.6$ mm). The antenna operates in the center of the UWB frequency range at 6.85 GHz. A FR-4 substrate with a conductive layer trace thickness (t) of 0.035 mm is used for the design and simulation. Antenna dimension of 35 × 30 mm^2 was optimized. Equations (1–6) were used to calculate the radiating patch dimensions which were used for simulation. The optimized dimensions are width ($W_p = 11.5$ mm), patch length ($L_p = 14$ mm), feedline width ($W_f = 3$ mm), ground plane ($L_g = 35$ mm), and partial ground ($L_{g1} = 8$ mm).

$$W_{\mathrm{p}} = \frac{c}{2f_{\mathrm{r}}\sqrt{\frac{(\varepsilon_{\mathrm{r}}+1)}{2}}} \tag{1}$$

$$\varepsilon_{\mathrm{eff}} = \frac{\varepsilon_{\mathrm{r}}+1}{2} + \frac{\varepsilon_{\mathrm{r}}-1}{2}\left[1+12\frac{h}{W_{\mathrm{p}}}\right]^{-\frac{1}{2}} \tag{2}$$

$$L_{\mathrm{eff}} = \frac{c}{2f_{\mathrm{r}}\sqrt{\varepsilon_{\mathrm{eff}}}} \tag{3}$$

$$\Delta L = 0.412h\frac{(\varepsilon_{\mathrm{eff}}-0.3)\left(\frac{W_{\mathrm{p}}}{h}+0.264\right)}{(\varepsilon_{\mathrm{eff}}-0.258)\left(\frac{W_{\mathrm{p}}}{h}+0.8\right)} \tag{4}$$

$$L_{\mathrm{p}} = L_{\mathrm{eff}} - 2\Delta L \tag{5}$$

$$W_{\mathrm{f}} = \frac{7.48\times h}{e^{\left(Zo\frac{\sqrt{\varepsilon_{\mathrm{r}}+1.41}}{87}\right)}} - 1.25\times t \tag{6}$$

The light velocity (3×10^8 ms^{-1}) is c and the input impedance is Zo. Conventional RPA has a small bandwidth, but popular for its simplicity and consistent efficiency. Hence a special technique needs to be applied to enhance it is bandwidth and partial grounding technique is commonly applied for. For this purpose, the ground plane size of RPA was reduced to obtain the entire UWB bandwidth. The partial grounded RPA (PG-RPA) is designed with bandwidth of (3.4–11.83) GHz. In Figure 1A$_1$–A$_3$, the antenna physical layout and return loss characteristics are presented. From (A$_3$) it is clear the return loss which is simulated by CST and HFSS, both simulation result have excellent matching at UWB bandwidth. Moreover, the surface current (A$_4$, A$_5$) of UWB middle band at 6.95 GHz is 49.4 A/m and the resonant frequency at 4 GHz accumulated same amount of current.

2.2 | Single band notched (SBN-UWB)

A single band notched ultra-wideband (SBN-UWB) has been achieved by introducing a rectangular slot at the top side in the radiating patch. The SBN-UWB geometry is shown in Figure 2(B$_1$), the simulated (CST and HFSS) S_{11} is shown in (B$_2$) and each simulated result is same within UWB bandwidth as well as band notched. The antenna bandwidth has also increased as a result of the slot as presented in (B$_2$). It is also observed that the notched can be controlled by changing the slot dimension and the huge amount of current 339 A/m accumulated at 4.9 GHz due to this slot shown in (B$_3$). The return loss plot (B$_2$) is found to have a notched band ranging from 4.5 to 5.5 GHz with a high-return loss of about −2 dB. With the center frequency of the notch which defines by the dimension of slot and can be expressed as Reference [5], the band rejection function can be achieved by using Equations (7) and (8).

$$f_{\mathrm{notch}} = \frac{c}{4L'\sqrt{\frac{(\varepsilon_{\mathrm{r}}+1)}{2}}} \tag{7}$$

$$L' = L_{\mathrm{c}} + L_{\mathrm{d}} \tag{8}$$

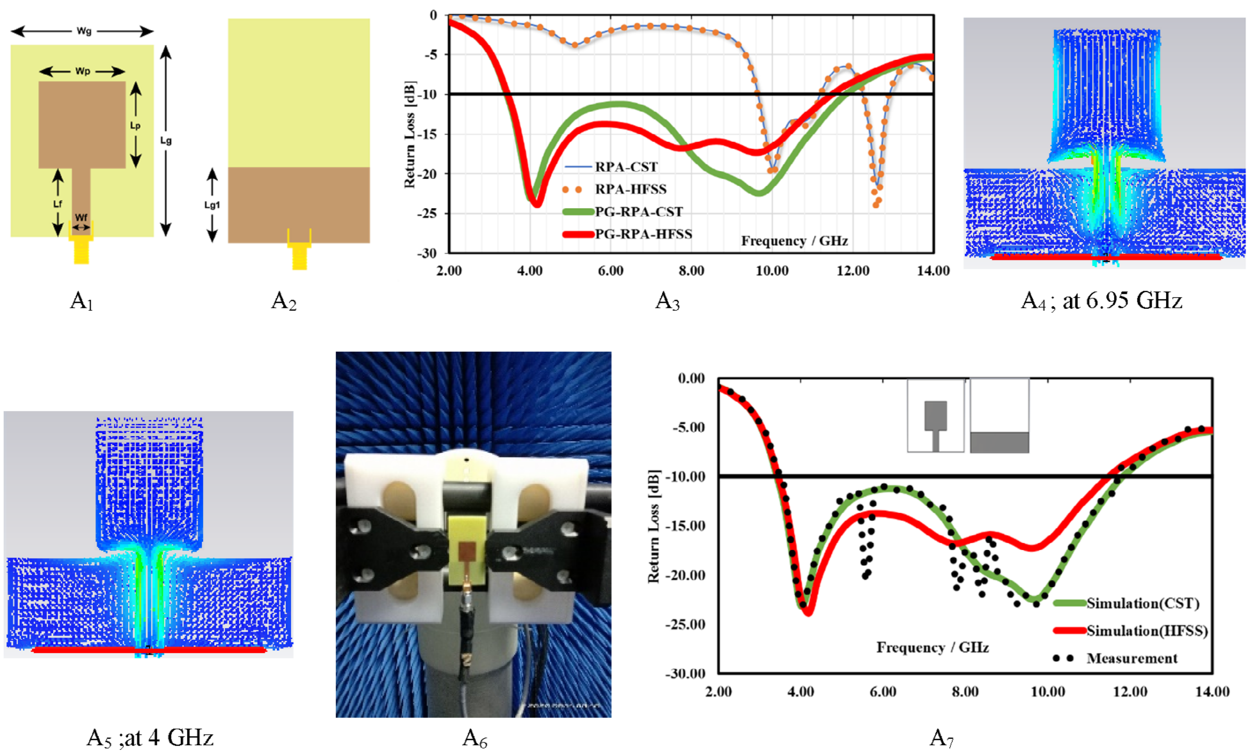

FIGURE 1 Top and bottom view (A$_1$, A$_2$)[4] of the UWB antenna, (A$_3$)[4] comparison of S_{11} between PG–RPA and PG-TFS antenna respectively, (A$_4$, A$_5$)[4] surface current distribution, (A$_6$) fabricated antenna and (A$_7$) comparison of S_{11} with simulation (CST, HFSS) and measured result

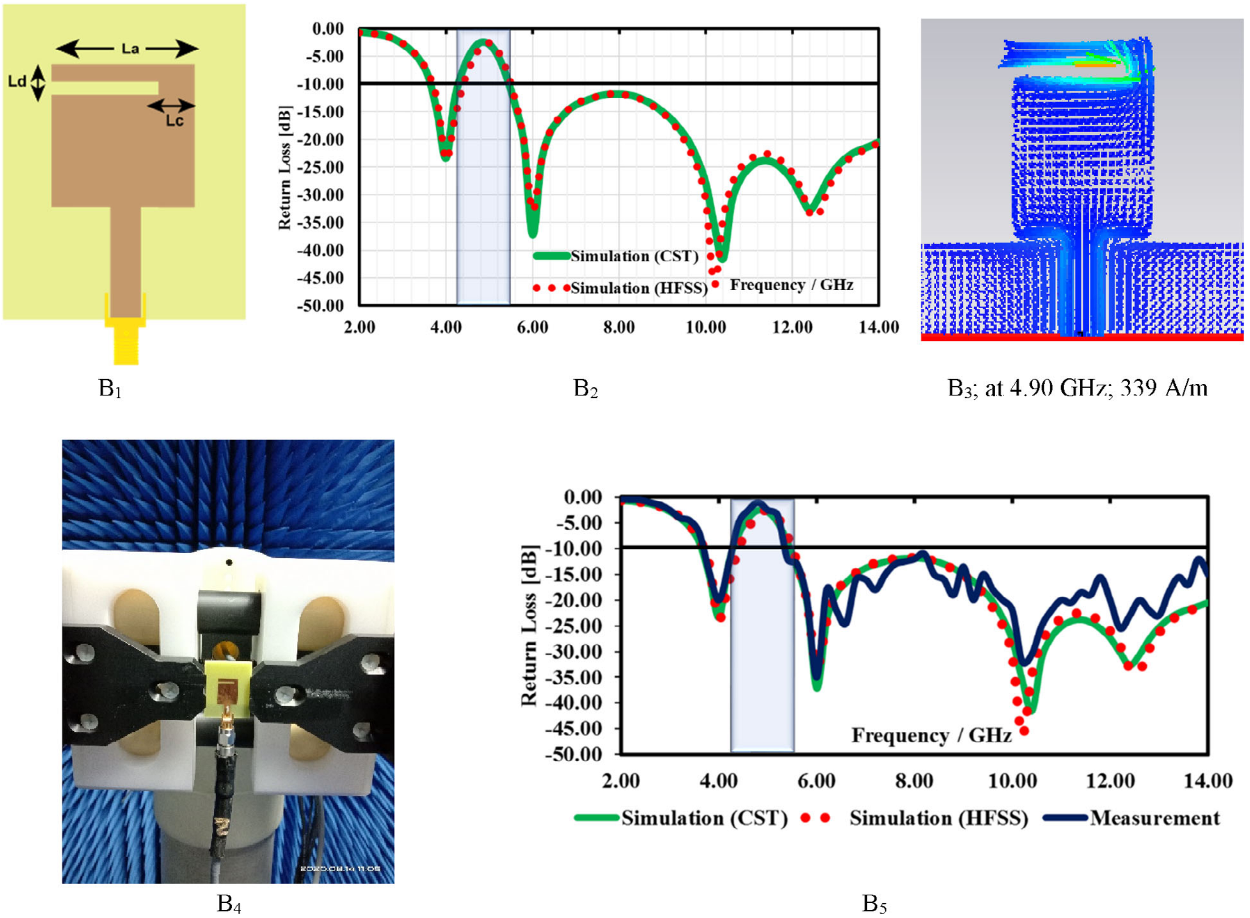

FIGURE 2 Layout of SBN-UWB (B_1)[4], simulated (CST, HFSS) return loss (B_2)[4], surface current (B_3), testing prototype antenna (B_4) and comparison between simulated and measured return loss (B_5)

Here, $L_c =$ Length of the small slot, $L_d =$ Width of the slot.

The notched bandwidth can be controlled by changing the value of L_c and L_d.

Changing the values of $L_c = 2$ mm and $L_d = 1.2$ mm has a notable impact on the output of the band-notched characteristics. The value of L_a is constant with 10 mm.

2.3 | Dual band notched (DBN-UWB)

The dual band notched was achieved by added an ASOL top on the rectangular slot. Figure 3C$_1$ depicts the DBN-UWB (open loop) antenna's geometry, (C_2) shown the close loop antenna. While (C_3) depicts the simulated (CST and HFSS) return loss. From C_3, it is proved that both simulator software has perfect matching with dual band notched and UWB bandwidth. The band notched from 3.3 to 4.2 GHz has achieved in C-band due to the open-loop and it produces strong results on the second notch from 4.5 to 5.5 GHz resulting in stable performances for both band notched. (C_3) shows that the two band have a combined return loss of over −3 dB. C_4 and C_5 show the surface current at middle notched frequency band at 3.75 GHz, 5 GHz both frequency band has accumulated around 185 A/m current due to slot and ASOL. C_6 illustrated the combine result of the open and close arc shape loop. The opened loop geometry with ($w = 0.75$ mm and $g = 2.3$ mm) has been found to have stable efficiency on dual band notched as well in UWB bandwidth. The dimensions mentioned in Table 1(T_1) further demonstrate the differences between SBN-UWB and DBN-UWB.

3 | EXPERIMENTAL VALIDATION

The proposed UWB, SBN-UWB, and DBN-UWB antennas are fabricated and their performances are measured to validate with simulation results. The test setup together with anechoic chamber is shown in Figures 1A$_6$, 2B$_4$, and 3C$_7$. Return loss have good agreement between simulation and measured illustrated in Figures 1A$_7$, 2B$_5$, and 3C$_8$, respectively. The simulated and measured gain is presented and compared in (C_9) for proposed antenna and found good agreement for the entire range of ultra-wide band including notches. The average gain over ultra-wide bandwidth is above 4.0 dBi for the proposed antenna. The peak gain reaches to 6.5 dBi for SBN, 6.0 dBi for DBN while the gain drops close to 0 dBi at notches for proposed designed

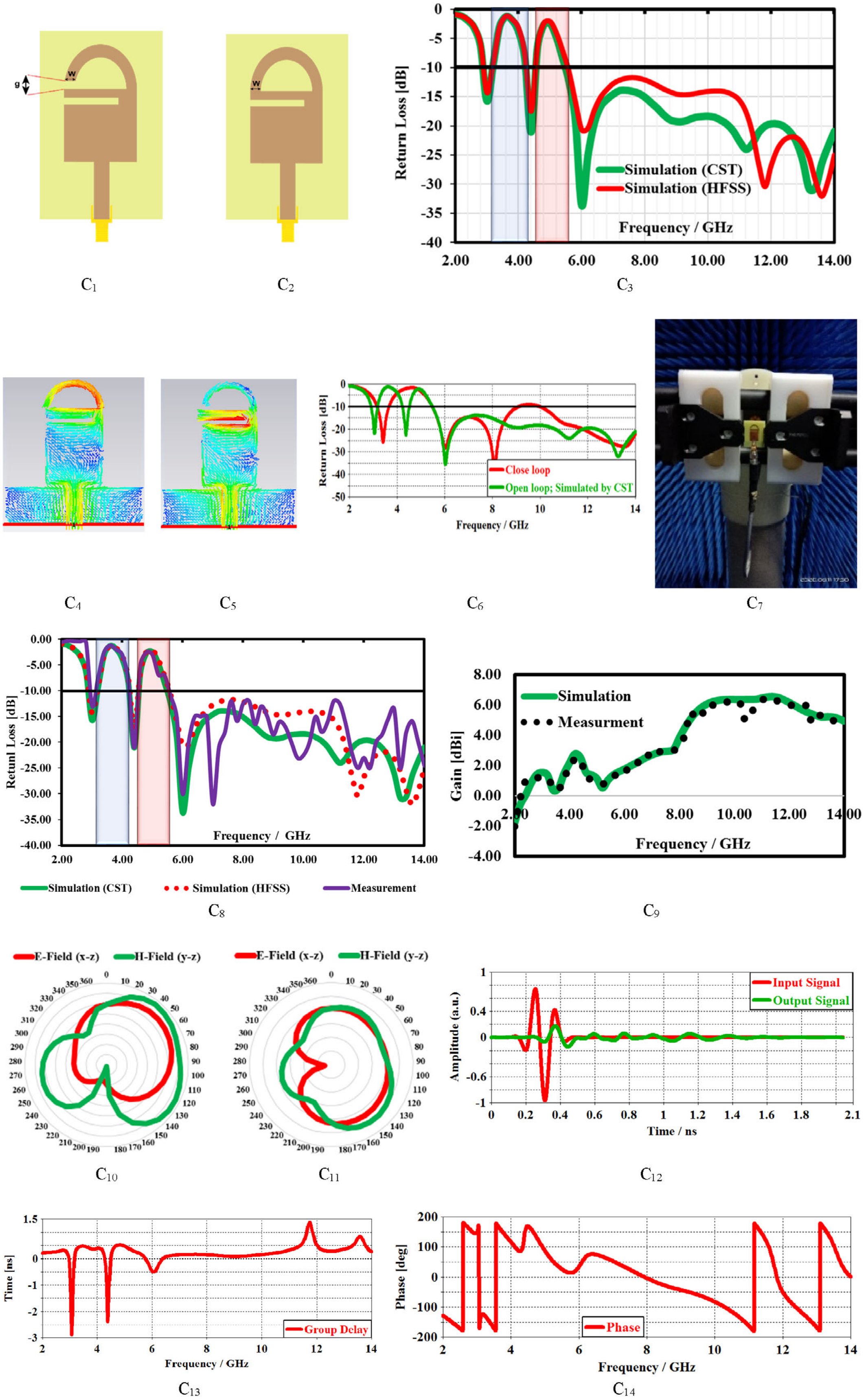

FIGURE 3 Physical dimension of the proposed DBN-UWB antenna open loop, close loop (C_1, C_2)[4], simulated return loss (C_3)[4], surface current (C_4, C_5)[4], comparison S_{11} between closed-loop and open-loop (C_6)[4], photograph of testing fabricated antenna (C_7), comparison between simulated, measured return loss (C_8), gain (C_9) and polar pattern (C_{10}, C_{11}), input and output pulses (C_{12}), group delay(C_{13}), phase (C_{14})

TABLE 1 Optimize dimensions of the proposed SBN-UWB and DBN-UWB antenna (T_1)[4] and comparison between our work with recent research works (T_2)

(T1)							
SBN-UWB							
Variable	W_p	L_p	W_f	L_f	W_g	L_g	L_{g1}
Size (mm)	10	11	3	7.5	23	29	8
DBN-UWB							
Variable	W_p	L_p	W_f	L_f	W_g	L_g	L_{g1}
Size (mm)	10	11	3	7.5	23	29	8

(T₂)

Works	Dimension (mm^2)	Bandwidth (GHz)	Dual band notched	Max. gain (UWB) (dBi)	Applications
6	35 × 24 = 840	3.1–11	Yes	4.2	Wi-MAX, WLAN
7	35 × 30 = 1050	2.87–11.48	Yes	3.7	Wi-MAX, WLAN
8	43 × 40 = 1720	1.8–10.7	Yes	–	Bluetooth, Wi-MAX
11	75 × 10 = 750	2.75–14.66	Yes	5	5G, WLAN
13	20 × 23 = 460	3.2–10.5	Yes	3	Controllable notch-band
15	30 × 30 = 900	3.1–10.6	Yes	2.8	Wi-MAX, WLAN
16	16 × 25 = 400	3.1–12.5	No	3	WLAN
17	27 × 32 = 864	2.8–10	Yes	4	Wi-MAX, WLAN
18	35 × 18 = 630	2.3–12	Yes	6	Wi-MAX, WLAN
19	30 × 30 = 900	3.1–10.6	Yes	5.6	Wi-MAX, WLAN
20	25 × 25 = 625	3.1–10.6	Yes	–	Wi-MAX, WLAN
This work	29 × 23 = 667	2.91–15.3	Yes	6.2	5G, FSS

antennas. The measured E-field and H-field patterns are shown in (C_{10}, C_{11}) which resemble to monopole antenna's pattern. It observed from the 2-D polar patterns are not stable in middle of band notched frequency such as 3.75 and 5 GHz. (C_{12}) depicts the proposed DBN-UWB antenna's transient response to a Gaussian pulse. For both the input and output voltages, the waveform responses exhibit very good matching of antenna impedance with transmission line at resonant frequency. The group delay varies from −3 to 1.5 ns for the entire range of UWB. The group delay is less than 1 ns for frequency ranges (5–11) GHz which conform the performance is very good shown in (C_{13}). The phase varies from +180° to −180° for frequency range (3–11.40) GHz. At higher and lower frequency bands, the phase version is unstable as shown in (C_{14}). Some recent research presented in Table 1(T_2). From this table, it has been comparable with this research work, within size, UWB bandwidth, max. gain and applications.[6–8,11,15–19]

4 | CONCLUSION

This article has planned, analyzed, and valued a compact UWB antenna with dual-banded characteristics. FR-4 is the basic RF substrate used in the UWB antenna design. The dual-band rejection is achieved by an arc shape open loop with a rectangular slot top on the radiating patch. Since the slot parameters have the same advantages as the antenna, it is easy to use them as a mechanism for tuning and in an improved rejection bandwidth. With the ASOL and slot was supported with bandwidth ranged from 3.3 to 4.2 GHz and 4.5 to 5.5 GHz, respectively. Furthermore, it performs well over the entire spectrum of UWB frequencies. The experimental results have been supported with simulated result. In addition, the compact size, simple design, and band rejection make the antenna ideal for future 5G applications.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

M.M. Hasan Mahfuz https://orcid.org/0000-0003-2602-7255

REFERENCES

[1] F. C. Commission. 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, 2002, December 24, 2019.

[2] A roadmap for C-band (3.3–3.8 GHz) in ASEAN on 15 Aug 2019. Spectrum, Dec. 26 2019. https://www.gsma.com/spectrum/resources/releasing-cband-asean/ (accessed December 26, 2019).

[3] "Final report by 5G taskforce in Malaysia, submitted to MCMC, Cyberjaya, Malaysia on 15 Oct, 2019," Dec. 26, 2019. https://www.nfcp.my/5G-Task-Force/5GMedia (accessed December 26, 2019).

[4] Mahfuz MMH, Islam MR, Malek NA, Islam MS, Asadullah GM. Design of dual band notched ultra wideband microstrip patch antenna for 5G lower bands application. *AIP Conf Proc*. 2020; 2306(1):020009. doi:10.1063/5.0032481

[5] Alam AHMZ, Islam R, Khan S. Design of a tuning fork type UWB patch antenna. *International Journal of Computer Science and Engineering Volume 1, Number 4*. 2007;1(8):240-243.

[6] Zheng Z-A, Chu Q-X. Compact CPW-fed UWB antenna with dual band-notched characteristics. *Prog Electromagn Res Lett*. 2009;11:83-91. http://www.jpier.org/pierl/pier.php?paper=09071809

[7] Gao G, Hu B, Yang C, Wang S, Zhang R. Design of a dual band-notched UWB antenna and improvement of the 5.5 GHz WLAN notched characteristic. *J Electromagn Waves Appl*. 2019;33(14):1834-1845. doi:10.1080/09205071.2019.1638836

[8] Ahmed MS, Islam MR, Khan S. Design of dual band notched ultra wideband antenna using (UW) shaped slots. *ARPN J Eng Appl Sci*. 2015;10(23):17375-17379.

[9] Gogikar S, Chilukuri S. A compact wearable textile antenna with dual band-notched characteristics for UWB applications. Paper presented at: 2019 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC), Sep. 2019, pp. 426–430.

[10] Ghaffar A, Awan WA, Zaidi A, Hussain N, Rizvi SM, Li XJ. Compact ultra wide-band and tri-band antenna for portable device. *Radioengineering*. 2020;29(4):601-608. https://www.radioeng.cz/fulltexts/2020/20_04_0601_0608.pdf

[11] Bong H-U, Jeong M, Hussain N, Rhee S-Y, Gil S-K, Kim N. Design of an UWB antenna with two slits for 5G/WLAN-notched bands. *Microw Opt Technol Lett*. 2019;61(5):1295-1300.

[12] Hussain N, Jeong M, Park J, Rhee S, Kim P, Kim N. A compact size 2.9-23.5 GHz microstrip patch antenna with WLAN band-rejection. *Microw Opt Technol Lett*. 2019;61(5):1307-1313.

[13] Awan WA, Zaidi A, Hussain N, Iqbal A, Baghdad A. Stub loaded, low profile UWB antenna with independently controllable notch-bands. *Microw Opt Technol Lett*. 2019;61(11):2447-2454.

[14] Jeong MJ, Hussain N, Bong HU, et al. Ultrawideband microstrip patch antenna with quadruple band notch characteristic using negative permittivity unit cells. *Microw Opt Technol Lett*. 2020;62(2):816-824.

[15] Yang Y-B, Zhang F-S, Zhang F, Zhang L, Jiao Y-C. Design of novel wideband monopole antenna with a tunable notched-band for 2.4 GHz WLAN and UWB applications. *Prog Electromagn Res*. 2010;13:93-102.

[16] Abbas A, Hussain N, Jeong M-J, et al. A rectangular notch-band UWB antenna with controllable notched bandwidth and centre frequency. *Sensors*. 2020;20(3):1-11. https://www.mdpi.com/1424-8220/20/3/777

[17] Li X-P, Xu G, Ma M-R, Duan C-J. UWB dual-band-notched lanky-leaf-shaped antenna with loaded half-square-like slots for communication system. *Electronics*. 2021;10(16):1-9. https://www.mdpi.com/2079-9292/10/16/1991

[18] Bahmanzadeh F, Mohajeri F. Simulation and fabrication of a high-isolation very compact MIMO antenna for ultra-wide band applications with dual band-notched characteristics. *AEU - Int J Electron Commun*. 2021;128:153505. https://www.sciencedirect.com/science/article/pii/S1434841120319841

[19] Negi D, Khanna R, Kaur J. Design of a guitar shaped UWB antenna with wide band notched characteristics for wireless applications. *Wirel Pers Commun*. 2021;119(4):2929-2950.

[20] Khan M, Masud M, Gaba G. Novel compact UWB band notch antenna design for body-centric communications. *Comput Syst Sci Eng*. 2021;40:673-689.

How to cite this article: Mahfuz MMH, Islam MR, Habaebi MH, Sakib N, Hossain AKMZ. A notched UWB microstrip patch antenna for 5G lower and FSS bands. *Microw Opt Technol Lett*. 2022;1-7. doi:10.1002/mop.33184