

Rectangular microstrip antenna design with multi-slotted patch and partial grounding for performance enhancement

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ABSTRACT

This paper presents design of a rectangular microstrip patch antenna by using multi-slotted patch and partial grounding plane techniques for both the gain and bandwidth enhancement at the same time. The antenna is designed and simulated for ultra-wideband (UWB) applications using a high frequency structure simulator (HFSS) on FR4 epoxy substrate having a size of 30×20 mm with a dielectric permittivity of 4.4, a tangent loss of 0.02, and a thickness of 0.8 mm and excited by a simple 50 Ω microstrip feed line. The simulation results show that the antenna attains an improved gain of 8.06 dB with a wider impedance bandwidth of 19.7 GHz ranges from 3.15 to 22.85 GHz. The antenna also achieves an efficiency of 96.83% with a return loss of -28.35 dB, and a directivity of 9.39 dB within the entire frequency range. These results imply that the deployment of multi-slotted patch and partial grounding techniques in designing a rectangular microstrip patch antenna is effective in improving its performance.

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1. INTRODUCTION

Wideband antennas with greater gain and bandwidth are becoming more vital as wireless communication technology develops. The federal communication commission (FCC) issued guidelines in 2002 for ultra-wideband (UWB) technology, which has a frequency spectrum of 3.1 to 10.6 GHz, a highest radiated power of -41.3 dBm/MHz, and a data throughput of 110 to 200 Mbps at a distance of 10 m [1]. The merits of employing a UWB device are faster data speeds, minimum intrusion, robustness, inexpensive, and simplicity. Because the time-domain pulse duration is a fraction of a millisecond, this approach has the issue of requiring exact time synchronization on the receiver side. It has a variety of uses, including radar, medical imaging, and military communication.

The antenna is one of the most crucial characteristics of a wireless communications system; it should be small, have a high gain, and be able to operate across a wide frequency range. Among the antennas that have gained the greatest attention in recent years is the microstrip patch antenna. There are many advantages of the microstrip antenna, such as low profile, lightweight, compact, and structurally compatible, simple to produce, and integration with solid-state technologies [2]. This type of radiating element is therefore commonly used for a long time in many wireless communication networks, for instance, radar, satellite links, and mobile services [3]. Nevertheless, the microstrip antennas are suffering from a major narrow bandwidth and low gain challenge [4]. In order to overcome these drawbacks, several techniques have been performed where researchers have shown various methods such as air gap [5], metamaterial

(MTM) double-side planar periodic structures [6], partial substrate removal in multiple layer dielectric substrates [7], corrugated ladder ground plane [8], altered patch and faulty ground plane [9].

A rectangular notch was employed to control the center frequency and notched bandwidth of a tiny UWB antenna [10], which was controlled by a modified patch and electromagnetic band gap (EBG) structure. The study concluded that an improved bandwidth from 3.1 to 12.5 GHz and an utmost gain of 4.5 dBi was achieved. Metamaterials were used in [6], [11] to maximize the gain and bandwidth of an UWB patch antenna. The increased bandwidth of 3.2 to 23.9 GHz, 2.6 to 20 GHz, and gain of 6.2 dB and 5.6 dB, respectively, were found throughout the analysis. Several researchers proposed ultra-wideband monopole antennas with improved bandwidth [12]–[14]. They reported the bandwidth of 3.08 to 14.1 GHz, 3.1 to 10.6 GHz, 3.2 to 17.5 GHz, and the maximum gain of 6.12 dBi, 7.20 dB, and 6.4 dBi, respectively.

Different strategies for achieving broad bandwidth and high gain were implemented in [9], [15], [16], such as applying a modified patch and defective ground plane, several corrugated split-ring resonators, and modified ground planes. The bandwidth and highest gain of their antennas were 3.1 to 10.8 GHz, 420 MHz, and 4.5 to 11.4 GHz, 5.1 dB, 7 dB, and 4.1 dBi, respectively. Various slots were added to the printed patch compact antenna design in [17]–[19], giving in impedance bandwidths of 3.08 to 15.90 GHz, 15.27 to 15.72 GHz, and 6.4 to 13.6 GHz, and peak gains of 5.9 dBi, 6 dB, and 5.9 dBi.

The UWB system [20] was given a small cutting-edge ground adjusted circular patch antenna. This antenna's maximum gain and fractional bandwidths are 3.2 dB and 118% (3.1 to 12.13 GHz), respectively, according to the simulation results. Hammache *et al.* [21] presented a moderate stepped slot antenna for UWB operation. The simulation results demonstrated that the impedance bandwidth spans from 3.05 GHz to over 12 GHz. Hammache *et al.* [22] analyzed the notched-band properties of a lightweight UWB slit antenna with triple L-shaped grooves. The antenna provides an impedance bandwidth extending from 2.65 to 11.05 GHz at a voltage standing wave ratio (VSWR) of less than 2.

A novel comprehensive investigation of a small UWB antenna for direct sequence ultra wideband (DS-UWB) applications was demonstrated in [23]. A 109% impedance bandwidth was seen in the simulation result. A simple typical defective ground structure (DGS)-based single pole round-shaped patch antenna for ultra-wideband schemes was described [24]. This antenna achieves 8.1 GHz (2.5 to 10.6 GHz) impedance bandwidth and a gain of 8.4 dBi and 8.2 dBi for each resonant frequency. A redesigned UWB antenna for wireless applications was constructed employing a FR4 substrate with improved gain in [25]. According to the study, the antenna has a peak gain over more than 6.5 dB and impedance bandwidth of 138 percent fractional bandwidth, extending from 2.2 GHz to over 12 GHz. The use of DGS and horizontal patch gap (HPG) in a patch antenna design for higher bandwidth and gain were presented in [26], giving 764.4 MHz bandwidth and 2.8 dBi gain. The utilization of a hybrid of U and quad L-shaped cuts, as well as L-shaped DGS and U-shaped double spurious components, was investigated in [27], which yielded a 1.40 GHz bandwidth and 7.2 dB gain. For broadband applications, a quasi-circular UWB antenna with a bandwidth of 130.3% within 3.16 GHz and 15 GHz and a gain ranging from 4.9 to 10.9 dB was proposed [28]. The air gap approach was used to construct a rectangular microstrip patch antenna with a gain of 6.907 to 9.179 dB [29].

In study [30], an investigation of various antenna properties, as well as a new design of I-slotted patch antenna with a small shape with a broad bandwidth of 49.46% and a maximum gain of 5 dBi, was described. In study [31], a compressed patch antenna for radio frequency identification (RFID) handled applications in the ultrahigh frequency (UHF) mobile functions was designed and fabricated using apertures method, which has a wide bandwidth of 40 MHz (889 to 939 MHz) and an uttermost gain of 1.73 dBi. In research [32], it was suggested to employ a metamaterial configuration on the basis of a frequency selective surface (FSS) cell to provide an isotropic band-pass filtering response. They were able to find a 3.22 dBi gain and a 1.7 GHz bandwidth. Deflected ground rectangular patch single-pole antennas were reported for UWB purposes in [33]. This antenna gives a 3.9 dB gain and a 10 GHz bandwidth with a range of 3 to 14 GHz. For Ku-band wireless communications, an UWB antenna was introduced in [34]. The 10.48 GHz bandwidth covering 9.34 to 9.82 GHz including a gain of 6.27 dB was observed based on simulation results. In research [35], a small rectangular UWB antenna for use in the Ku/K band was designed. The antenna's bandwidth is 41.61 percent in the 16.58 to 25.29 GHz frequency range.

However, in the majority of previous studies, either bandwidth or gain enhancement of the microstrip patch antenna was accomplished. It is critical to boost the antenna's gain and bandwidth at the same time. The goal of this paper is to design a rectangular microstrip patch antenna for UWB applications employing multi-slotted patch and partial grounding plane approaches.

2. PROPOSED ANTENNA DESIGN

The microstrip-fed UWB antenna geometry without a slot is shown in Figures 1(a) and (b), which have been used in the present study as a reference antenna. The antenna is made of FR4_epoxy, which has a

dielectric constant of 4.4, a thickness of 0.8 mm, a dielectric tangent loss of 0.02, and a dimension of 30×20 mm ($L_s \times W_s$). The ground plane and the conducting patch are both composed of copper. The rectangular patch is the base of the monopole radiator, which is engraved onto the FR4_epoxy substrate with the dimensions of $L_p \times W_p$ and fed by a simple 50 Ω microstrip line with a length of L_f and a width of W_f . The microstrip feed line is utilized to reduce return loss, resulting in extremely high antenna gain. A partial ground plane of $L_g \times W_g$ dimensions is printed into the FR4_epoxy substrate to increase the antenna's impedance bandwidth. The partial ground plane's width (W_g) corresponds to the substrate's width (W_s). To improve gain-bandwidth and impedance matching of the antenna across the UWB, several slots' configurations such as right-angle triangular slots configurations are embedded in the patch lower corners, and rectangular slots structures are also introduced over the patch, with one rectangular slot shape added on the ground plane, as shown in Figure 1(c). To design, optimize, and analyze the antenna, commercial Ansoft's HFSSv15 software is employed. Table 1 shows the various parameter values for the antenna design.

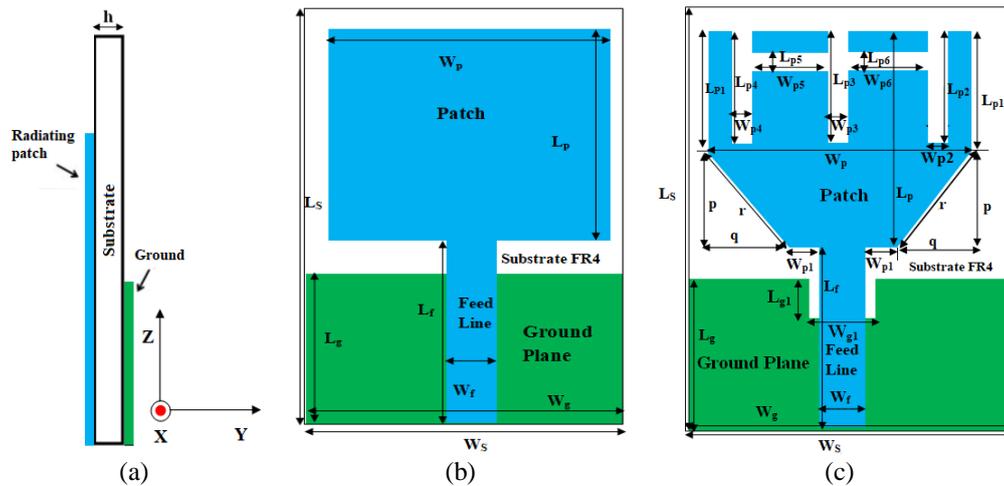


Figure 1. Design of the proposed antenna (a) side view, (b) ordinary patch antenna (without slot), and (c) with slots

Table 1. Different parameter values of the proposed rectangular microstrip patch antenna

Parameters	Value
$W_s = W_g$	20 mm
L_s	30 mm
h	0.8 mm
W_p	18 mm
$L_p = L_g$	14 mm
L_{p1}	15 mm
L_f $W_f = W_{g1} = W_{p1}$	2 mm
L_{g1}	3 mm
L_{p1}	8 mm
$L_{p5} = L_{p6} = W_{p2} = W_{p3} = W_{p4}$	0.5 mm
$L_{p2} = L_{p3} = L_{p4}$	7 mm
$W_{p5} = W_{p6}$	6.5 mm
$p = q$	6 mm
r	8.48 mm

3. RESULTS AND DISCUSSION

The system was simulated using high frequency structure simulator (HFSS) simulator. Figure 2 demonstrates the simulation techniques or steps for the proposed rectangular patch UWB antenna. The simulation results are shown in Figures 3 to 8 in order to evaluate the intended rectangular patch microstrip UWB antenna's performance.

The impedance match between the source and the load is determined by return loss. It should be as low as possible for maximum power transfer; the lower the return loss, the better the impedance match between the source and the load, and thus less power is wasted in the load, indicating that maximum power is transferred to the load, implying that the antenna provides better performance. The change in return loss for the designed antenna as a function of frequency is shown in Figure 3.

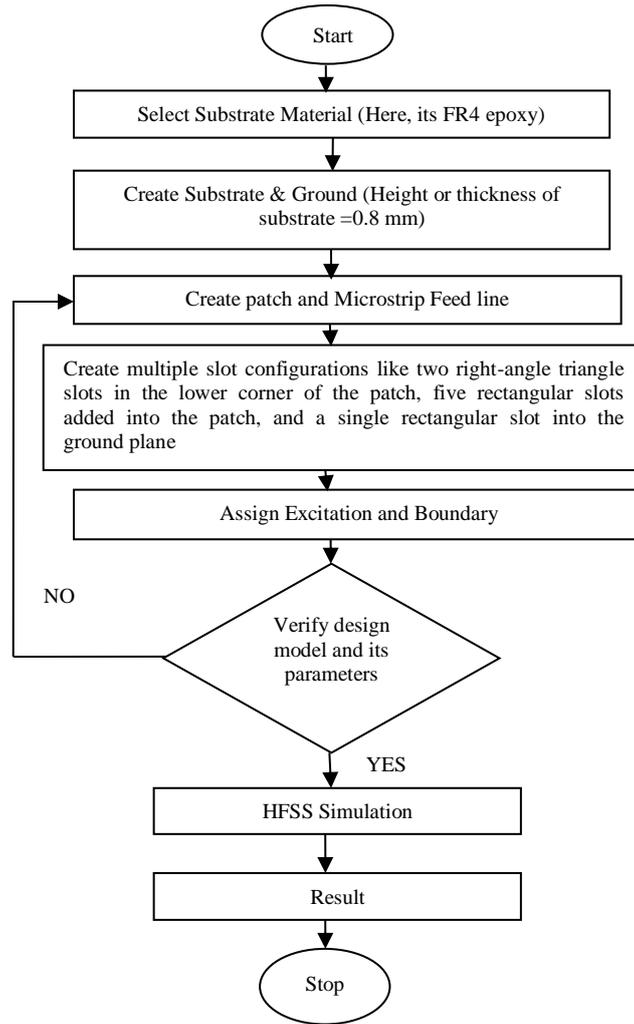


Figure 2. Flowchart of the proposed rectangular microstrip patch antenna

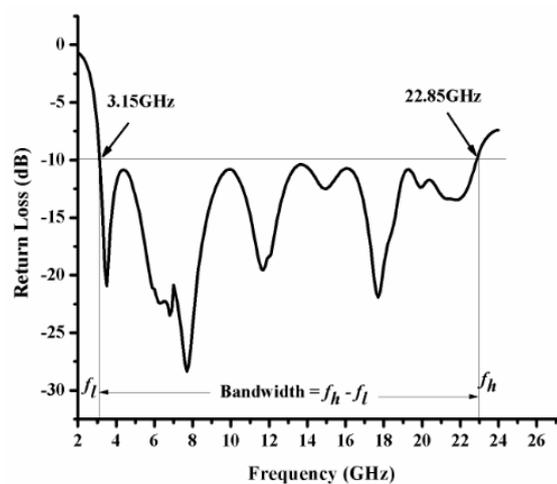


Figure 3. Return loss as a function of frequency

The graph of return loss has a characteristic of multi-band form in the ultra-wideband spectrum. The various resonant frequencies are around 3.5 GHz, 6.8 GHz, 7.7 GHz, 11.7 GHz, and 17.7 GHz, with return

losses of -20.94 dB, -23.49 dB, -28.35 dB, -19.58 dB, and -21.94 dB, respectively, as shown in the figure. The minimum return loss is found as -28.35 dB at 7.7 GHz, which is almost three times lower than that of the minimum required value of -10 dB. It indicates good impedance matching between the microstrip feed line and the radiating patch of this antenna. A return loss of -28.35 dB means about 99.85% of the input power is transmitted into the antenna.

The antenna bandwidth defines the range of frequencies where an antenna is properly able to work. It can be determined from the graph of return loss within the entire range of frequencies in which the return loss remains less than -10 dB. The upper and lower cut-off frequencies, $f_u=22.85$ GHz and $f_l=3.15$ GHz respectively are calculated from the -10 dB line shown in Figure 3. The calculated bandwidth of this antenna is 19.7 GHz (fractional bandwidth of 151.54%), which is better than that observed in refs [10]–[13], covering the X-band, C-band, Ku band, S-band, scanning tunneling microscopy (STM) band applications, and other wireless applications such as worldwide interoperability for microwave access (WiMAX), Wi-Fi, wireless local area network (WLAN), radio astronomy, military communication, communications and sensors, position location and tracking, satellite communication, and radar communication.

The VSWR of a given antenna indicates how much electromagnetic wave effectively transmits or receives by an antenna over a specific frequency band and also explains how much power an antenna reflects. Basically, the VSWR is a measuring quantity of impedance mismatch between the source and the load. The higher the mismatch in impedance means a high VSWR. The lower the VSWR, the better the source can match the antenna impedance, and the higher the power is supplied to the load. For low loss in reflection, the VSWR should be between 1 and 2 in practice. Figure 4 shows the simulated result of VSWR as a function of frequency. It is seen that the VSWR value of the proposed antenna is 1.079 at 7.70 GHz, and it remains less than 2 in the entire UWB. It implies that the antenna is perfectly matched to the feed line and is properly designed in the entire frequency band. A VSWR value of 1.079 indicates around 99.85% of the power is delivered to the antenna and 0.144% power is reflected from the antenna.

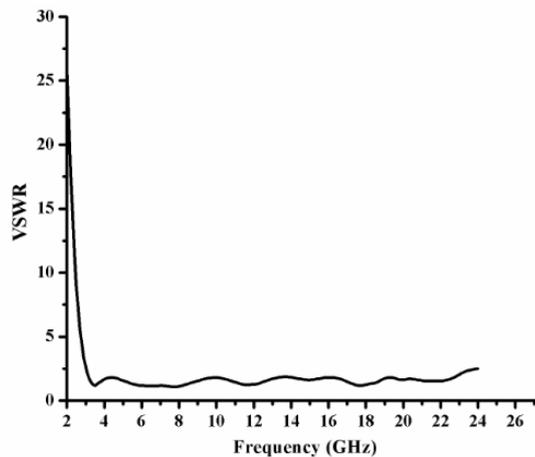


Figure 4. Simulated VSWR as a function of frequency

The directivity result of the proposed antenna for the different operating frequencies within the ultra-wideband is shown in Figure 5. The peak directivity ranges from 2.54 to 9.39 dB within the operating band (3.15 to 22.85 GHz). The designed antenna achieves a maximum directivity of 9.39 dB at 21.50 GHz. The lower directivity signifies the ability of the proposed antenna to transmit and receive information (radio frequency energy) more or less equally from and/ into all directions, while the higher directivity suggesting its ability to transmit or receive energy in a particular direction. Because of the presence of different directivities, the suggested antenna can be used in various directivity-based purposes. Lower directivity antennas are useful in mobile applications whereas the high directivity antennas find their applications in permanent installations like satellite TV.

The change in efficiency of the proposed antenna as a function of frequency is shown in Figure 6. As seen, the efficiency ranges from 76 % to 96% for most of the UWB frequencies under concern and the antenna attains a maximum efficiency of 96.82% at the operating frequency of 4.4 GHz. The high efficiency of 96.82% suggests that the designed antenna can effectively radiate the input power into free space. Due to the high efficiency, in communication wide range, long lifetime of battery and low error can be expected.

The antenna gain is a performance metric that represents the combined performance of the electrical efficiency and directivity of an antenna. The simulation result of the variation in antenna gain as a function of frequency is shown in Figure 7. It is apparent that the gain increases with increasing frequency and the maximum gain of this antenna is 8.06 dB at 21.50 GHz, which is much better than as obtained in earlier studies [6], [10], [12], [13]. The antenna gain looks rather good, and by placing this single element antenna in an array, the gain can be increased more which is suitable for longer range, better signal quality and efficient energy radiation in a particular direction.

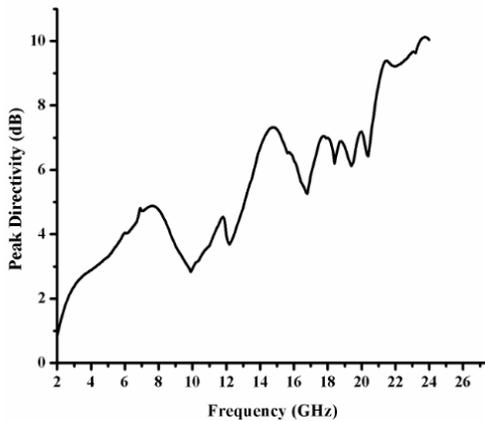


Figure 5. Different directivity peak as a function of frequency

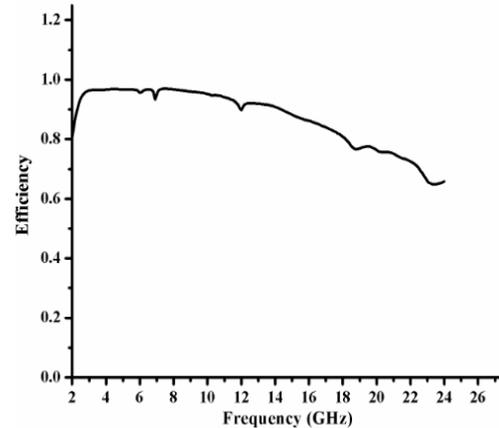


Figure 6. The efficiency of the proposed antenna as a function of frequency

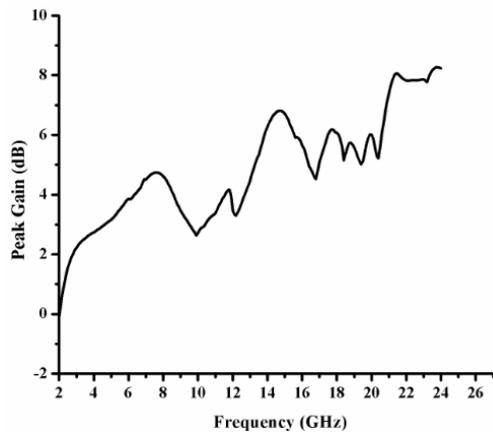


Figure 7. Simulated peak gain (in dB) of the proposed antenna

The radiation pattern of an antenna dictates how power is spread in different directions away from it. The power distribution in the E and H perpendicular planes is evaluated as a function of angle in terms of the far-field radiation pattern. The electric field vector and the direction of radiation represent by the E-plane whereas the plane comprising the magnetic field vector is the H-plane. The E-plane and H-plane far-field radiation patterns of the proposed antenna are shown in Figures 8(a), 8(b), 8(c), and 8(d). It can be seen that at the different resonance frequencies of 3.5 GHz, 6.85 GHz, and 11.7 GHz, the radiation patterns of the antenna in E-plane and H-plane are approximately the same in nature like a dipole antenna. The antenna has a good quasi-omnidirectional radiation pattern at 17.7 GHz, which is necessary for receiving information signals from all directions. Figures 8(e), 8(f), 8(g), and 8(h) shows the simulated 3D radiation pattern of the planned antenna at 3.5 GHz, 6.85 GHz, 11.7 GHz, and 17.7 GHz. It is observed that the radiation pattern appears to be substantially look-alike to that of a dipole antenna. This implies omnidirectional radiation, and a maximum power of 20.285 dB, 22.224 dB, 21.860 dB, and 23.938 dB is observed which has a great advantage in the ultra-wideband communication system.

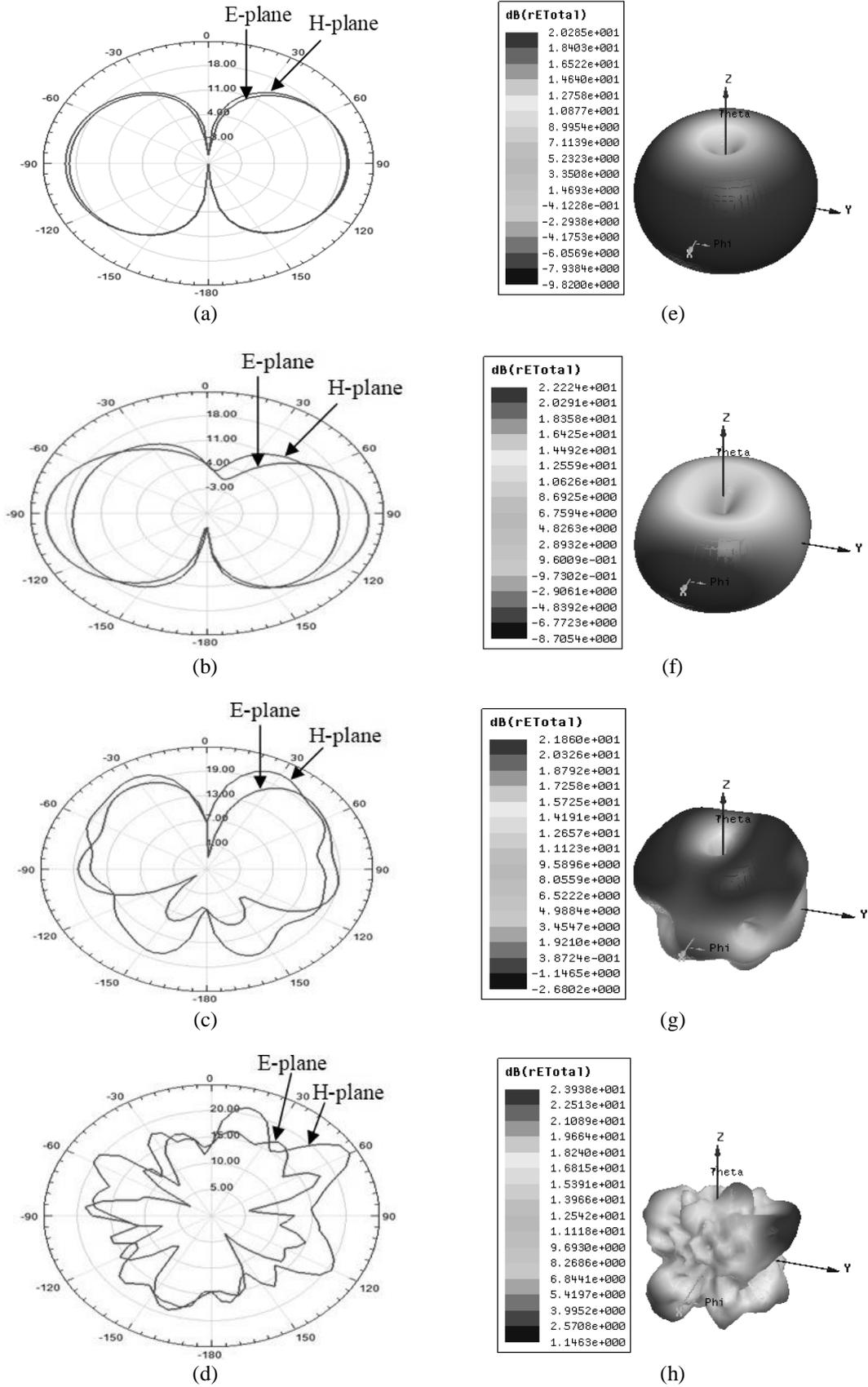


Figure 8. Antenna radiation patterns at various resonance frequencies (a) $f=3.5$ GHz, (b) $f=6.85$ GHz, (c) $f=11.7$ GHz and (d) $f=17.7$ GHz and 3D radiation patterns of the antenna at different resonant frequencies: (e) $f=3.5$ GHz, (f) $f=6.85$ GHz, (g) $f=11.7$ GHz, and (h) $f=17.7$ GHz

Table 2 compares the effectiveness of the new antenna to that of other previously developed UWB antennas. The designed antenna gives 19.7 GHz bandwidth and 8.06 dB gain. Most of the researchers have used FR4 substrate though the size of the antenna is not the same. By comparing different parameters, it can be realized that the propounded antenna is considerable improves both gain and bandwidth. The bandwidth in the current study is nearly equal to that in [6], but the gain is nearly 3 dB higher. In comparison to [11], the gain is nearly identical, but the bandwidth is 2.3 GHz higher. Not only the design mechanism but also it might be an influence of antenna size and substrate in the enhancement of gain. The studied antenna has a directivity of 9.39 dB and a return loss of -28.35 dB, resulting in a gain and bandwidth enhancement.

Table 2. Comparisons of the preceding and present designed rectangular microstrip patch antennas

Reference No's	Antenna Size, L×W×h (mm ³)	Material	Operating Bandwidth (GHz)	Bandwidth (GHz)	Bandwidth (%)	Gain (dB)	Efficiency (%)
[6]	32×27.6×1.6	FR4 substrate	3.2 to 23.9	20.7	152.76	6.2	-----
[10]	16×25×1.52	Taconic TLY-5A substrate	3.1 to 12.5	9.4	120.51	4.5	--
[11]	36×38×1.58	FR4 substrate	2.6 GHz to more than 20 GHz	17.4 (approx.)	153.98	5.6 and 8.13	----
[12]	22×14.5×1.6	FR-4 substrate	3.08 to 14.1	11.02	128.3	6.12	97
[13]	26.6×29.3×1.6	FR4 substrate	3.1 to 10.6	7.5	109.49	7.20	95
Proposed Antenna	30×20×0.8	FR4 substrate	3.15 to 22.85	19.7	151.54	8.06	96.82

4. CONCLUSION

In this paper, we have designed a rectangular microstrip patch antenna by using multi-slotted patch and partial grounding plane techniques for both the gain and bandwidth enhancement at the same time. The antenna is designed and simulated for UWB applications using HFSS simulation software on FR4_epoxy substrate having a size of 30×20 mm with a dielectric permittivity of 4.4, a tangent loss of 0.02, and a thickness of 0.8 mm and excited by a simple 50 Ω microstrip feed line. The designed antenna attained a wider impedance bandwidth of 19.7 GHz (percentage bandwidth of 151.54%) at a return loss of -10 dB line, covering a frequency band of 3.15 to 22.85 GHz. The maximum achievable gain of the designed antenna is 8.06 dB with an efficiency of 96.82% and a directivity of 9.39 dB within the entire frequency range. Based on the present simulation-based study it can be anticipated that the deployment of multi-slotted patch and partial grounding plane techniques in designing a rectangular microstrip patch antenna is effective in enhancing its performance.

REFERENCES

- [1] F. C. Commission, "Revision of part 15 of the commission's rules regarding ultra-wideband transmission systems," *First Report and Order in ET*, pp. 1–118, 2002.
- [2] Y. Lo, D. Solomon, and W. Richards, "Theory and experiment on microstrip antennas," *IEEE Transactions on Antennas and Propagation*, vol. 27, no. 2, pp. 137–145, Mar. 1979, doi: 10.1109/TAP.1979.1142057.
- [3] M. T. I. Huque, M. K. Hosain, F. Samad, and F. Samad, "Design and simulation of a low-cost and high gain microstrip patch antenna arrays for the X-band applications," in *International Conference on Network Communication and Computer (ICNCC)*, 2011.
- [4] R. Ghatak, S. Chatterjee, and D. R. Poddar, "Wideband fractal shaped slot antenna for X-band application," *Electronics Letters*, vol. 48, no. 4, pp. 198–199, 2012, doi: 10.1049/el.2011.3483.
- [5] H. H. Keriee *et al.*, "High gain antenna at 915 MHz for off grid wireless networks," *Bulletin of Electrical Engineering and Informatics*, vol. 9, no. 6, pp. 2449–2454, Dec. 2020, doi: 10.11591/eei.v9i6.2192.
- [6] E. K. I. Hamad and G. Nady, "Bandwidth extension of ultra-wideband microstrip antenna using metamaterial double-side planar periodic geometry," *Radioengineering*, vol. 27, no. 1, pp. 25–32, Apr. 2019, doi: 10.13164/re.2019.0025.
- [7] S. M. Abbas, I. Saleem, B. Ahmed, and H. Khurshid, "UWB antenna with parasitic patch and asymmetric feed," *Information Sciences Letters*, vol. 2, no. 1, pp. 27–33, Jan. 2013, doi: 10.12785/isl/020104.
- [8] S. Baudha and M. V. Yadav, "A compact ultra-wide band planar antenna with corrugated ladder ground plane for multiple applications," *Microwave and Optical Technology Letters*, vol. 61, no. 5, pp. 1341–1348, May 2019, doi: 10.1002/mop.31710.
- [9] S. Baudha and M. V. Yadav, "A novel design of a planar antenna with modified patch and defective ground plane for ultra-wideband applications," *Microwave and Optical Technology Letters*, vol. 61, no. 5, pp. 1320–1327, May 2019, doi: 10.1002/mop.31716.
- [10] A. Abbas *et al.*, "A rectangular notch-band UWB antenna with controllable notched bandwidth and centre frequency," *Sensors*, vol. 20, no. 3, Jan. 2020, doi: 10.3390/s20030777.
- [11] A. F. Darweesh and G. O. Yetkin, "Enhancement of the gain and the bandwidth of a UWB microstrip patch antenna using metamaterials," *International Journal of Engineering & Technology*, vol. 7, no. 3, pp. 380–385, 2018, doi: 10.14419/ijet.v7i3.14.18822.
- [12] S. S. Al-Bawri *et al.*, "Compact ultra-wideband monopole antenna loaded with metamaterial," *Sensors*, vol. 20, no. 3, Jan. 2020, doi: 10.3390/s20030796.
- [13] J. Vijayalakshmi and G. Murugesan, "A miniaturized high-gain (MHG) ultra-wideband unidirectional monopole antenna for UWB applications," *Journal of Circuits, Systems and Computers*, vol. 28, no. 13, Dec. 2019, doi: 10.1142/S021812661950230X.

- [14] S. Sahoo, L. P. Mishra, M. N. Mohanty, and R. K. Mishra, "Design of compact UWB monopole planar antenna with modified partial ground plane," *Microwave and Optical Technology Letters*, vol. 60, no. 3, pp. 578–583, Mar. 2018, doi: 10.1002/mop.31010.
- [15] S. K. Patel and C. Argyropoulos, "Enhanced bandwidth and gain of compact microstrip antennas loaded with multiple corrugated split ring resonators," *Journal of Electromagnetic Waves and Applications*, vol. 30, no. 7, pp. 945–961, May 2016, doi: 10.1080/09205071.2016.1167633.
- [16] K. Mandal and P. P. Sarkar, "High gain wide-band U-shaped patch antennas with modified ground planes," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 4, pp. 2279–2282, Apr. 2013, doi: 10.1109/TAP.2012.2233455.
- [17] R. Azim, M. T. Islam, and N. Misran, "Ground modified double-sided printed compact UWB antenna," *Electronics Letters*, vol. 47, no. 1, pp. 9–11, 2011, doi: 10.1049/el.2010.3160.
- [18] M. Samsuzzaman, M. T. Islam, and J. S. Mandeep, "Design of a compact new shaped microstrip patch antenna for satellite application," *Advances in Natural and Applied Sciences*, vol. 6, no. 6, pp. 898–903, 2012.
- [19] A. Srilakshmi, N. V. Koteswararao, and D. Srinivasarao, "X band printed microstrip compact antenna with slots in ground plane and patch," in *2011 IEEE Recent Advances in Intelligent Computational Systems*, Sep. 2011, pp. 851–855, doi: 10.1109/RAICS.2011.6069430.
- [20] M. V. Yadav and S. Baudha, "A compact mace shaped ground plane modified circular patch antenna for ultra-wideband applications," *Telecommunications and Radio Engineering*, vol. 79, no. 5, pp. 383–397, 2020, doi: 10.1615/TelecomRadEng.v79.i5.20.
- [21] B. Hammache, A. Messai, I. Messaoudene, and T. A. Denidni, "Compact stepped slot antenna for ultra-wideband applications," *International Journal of Microwave and Wireless Technologies*, pp. 1–7, May 2021, doi: 10.1017/S1759078721000726.
- [22] B. Hammache, A. Messai, I. Messaoudene, and T. A. Denidni, "Compact ultra-wideband slot antenna with three notched-band characteristics," *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 30, no. 5, May 2020, doi: 10.1002/mmce.22146.
- [23] T. Sarkar, A. Ghosh, S. Chakraborty, L. L. K. Singh, and S. Chattopadhyay, "A new insightful exploration into a low profile ultra-wide-band (UWB) microstrip antenna for DS-UWB applications," *Journal of Electromagnetic Waves and Applications*, vol. 35, no. 15, pp. 2001–2019, Oct. 2021, doi: 10.1080/09205071.2021.1927855.
- [24] D. Gopi, A. R. Vadaboyina, and J. R. K. K. Dabbakuti, "DGS based monopole circular-shaped patch antenna for UWB applications," *SN Applied Sciences*, vol. 3, no. 2, pp. 198–210, Feb. 2021, doi: 10.1007/s42452-020-04123-w.
- [25] K. G. Tan *et al.*, "FR-4 substrate based modified ultrawideband antenna with gain enhancement for wireless applications," *Journal of Engineering Science and Technology Review*, vol. 12, no. 4, pp. 108–112, Aug. 2019, doi: 10.25103/jestr.124.13.
- [26] D. Rusdiyanto, C. Apriono, D. W. Astuti, and M. Muslim, "Bandwidth and gain enhancement of microstrip antenna using defected ground structure and horizontal patch gap," *SINERGI*, vol. 25, no. 2, pp. 153–158, Feb. 2021, doi: 10.22441/sinergi.2021.2.006.
- [27] G. V. Raviteja, B. T. V Madhan, M. Kshetra Sree, N. Avinash, and P. R. S. Naga Surya, "Gain and bandwidth considerations for microstrip patch antenna employing U and quad L shaped slots with dgs and parasitic elements for WiMax/WiFi applications," *European Journal of Engineering Research and Science*, vol. 5, no. 3, pp. 327–330, Mar. 2020, doi: 10.24018/ejers.2020.5.3.1834.
- [28] A. Swetha and K. Rama Naidu, "Gain enhancement of an uwb antenna based on a fss reflector for broadband applications," *Progress In Electromagnetics Research C*, vol. 99, pp. 193–208, 2020, doi: 10.2528/PIERC19120905.
- [29] K. W. S. A. Kharusi, N. Ramli, S. Khan, M. T. Ali, and M. H. A. Halim, "NoGain enhancement of rectangular microstrip patch antenna using air gap at 2.4 GHz," *International Journal of Nanoelectronics and Materials*, vol. 13, pp. 211–224, 2020.
- [30] K. K. Parashar, "Design and analysis of i-slotted rectangular microstrip patch antenna for wireless application," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 4, no. 1, pp. 31–36, Feb. 2014, doi: 10.11591/ijece.v4i1.4594.
- [31] Y. El Hachimi, Y. Gmih, E. M. Makroum, and A. Farchi, "A miniaturized patch antenna designed and manufactured using slot's technique for RFID UHF mobile applications," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 6, pp. 5134–5143, Dec. 2018, doi: 10.11591/ijece.v8i6.pp5134-5143.
- [32] M. Daghari and H. Sakli, "Radiation performance enhancement of an ultra wide band antenna using metamaterial band-pass filter," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 10, no. 6, pp. 5861–5870, Dec. 2020, doi: 10.11591/ijece.v10i6.pp5861-5870.
- [33] S. Elajoumi, A. Tajmouati, A. Errkik, A. Sanchez, and M. Latrach, "Microstrip rectangular monopole antennas with defected ground for UWB applications," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 7, no. 4, pp. 2027–2035, Aug. 2017, doi: 10.11591/ijece.v7i4.pp2027-2035.
- [34] A. El Fatimi, S. Bri, and A. Saadi, "An ultra wideband antenna for Ku band applications," *International Journal of Electrical and Computer Engineering*, vol. 9, no. 1, pp. 452–459, 2019, doi: 10.11591/ijece.v9i1.pp452-459.
- [35] M. El Jourmi, H. Ouahmane, and F. Kharroubi, "Design and simulation of UWB microstrip patch antenna for Ku/K bands applications," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 9, no. 6, pp. 4845–4849, Dec. 2019, doi: 10.11591/ijece.v9i6.pp4845-4849.

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