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A compact wideband antenna with detailed time domain analysis for wireless applications

Shashank Khangarot [a], B.V. Sravan [a], Namratha Aluru [a], Mohammad Saadh A.W. [b], Poonkuzhali Ramaswamy [b], Om Prakash Kumar [a], Tanweer Ali [a,*], M.M. Manohara Pai [c]

[a] Department of Electronics and Communication Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, India
[b] Division of Communication Engineering, School of Electronics Engineering, Vellore Institute of Technology, Vellore, India
[c] Department of I&CT, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, India

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ABSTRACT

In this research paper, a compact wideband monopole antenna of the dimensions $20 \times 20 \times 1.6$ mm^3(i.e. total volume = 640 mm^3) is presented. The proposed antenna configuration has simplified design in which the ground plane, as well as the radiating patch, are on the same plane. This design renders one side of the substrate consummately empty resulting in an overall design which is more facile to fabricate. It is excited by Coplanar Waveguide (CPW) feeding technique. The proposed structure has a fractional bandwidth of 40.56% (4.3–6.45 GHz) in simulation and 34.41% (4.4–6.38 GHz) in measurements for $S_{11} < -10$ dB criteria. It has linearly increasing gain over its entire operational bandwidth and has a maximum peak realized gain of 4.7 dB at 6.4 GHz in simulation and about 3.8 dBi at 6.3 GHz in measurement. The designed antenna is suitable for WLAN and WiMAX of the range corresponding to 4.70–6.19, 5.5–5.7 and 5–6 GHz. To overcome the major drawback of narrow bandwidth in printed patch antenna, the uniquely designed split patch technique is used to achieve wide bandwidth. The antenna time-domain analysis is detailed by keeping it in side-to-side and face-to-face orientations. This analysis resulted in a stable performance which is very much required from a wideband antenna. All the necessary antenna simulations are done using HFSS and are validated by fabricating a model of it.

1. Introduction

The miniaturized/compact multiband antenna has earned momentous consideration in the field of wireless communication because of its fascinating operational attributes. As the total footprint of a wireless device is declining day-by-day, it is getting extremely crucial to design an antenna that is compact and is capable of accommodating the prerequisites of wireless end terminal devices [1,2]. A monopole antenna is extensively used because of its lightweight, slender profile and uncomplicated antenna configuration with dependability, mobility and good capability [3]. They are most advisable for mobile and aerospace functions. Recently, the wideband communication systems are scrutinized to satisfy the appeal for high data transmission rate, low initial and operation cost and low power consumption. An essential component of the wideband communication systems, wideband antennas have captivated symbolic analysis activity in the latter years. The threats faced by viable wideband antenna design incorporate wide impedance matching, radiation dependability, slender profile, tight size and lesser cost [4–8].

Though the wideband wireless communication systems have established aspects and benefits. There are also a few technical problems to be clarified. The wideband antenna should envelop the assigned 7500 MHz of spectrum to completely utilise it [9]. However, there are some antennas suggested for broadband applications. All of them have broadband impedance bandwidth, and acceptable radiation performances, one of them is a monopole

* Corresponding author.
E-mail addresses: rpoonkuzhali@vit.ac.in (R. Poonkuzhali), omprakash.kumar@manipal.edu (O.P. Kumar), tanweer.ali@manipal.edu (T. Ali), mmm.pai@manipal.edu (M.M.M. Pai).

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antenna. Monopole antennas are utilized for wideband communication because of their fascinating features of determining good bandwidth, uncomplicated structure, and omnidirectional radiation pattern [10]. A broadband monopole antenna has polarization in the vertical plane, and it also has low angle radiation pattern; thus it is utilised in short-range circuits by the ground wave and in medium-range circuits by skywave.

The wideband communication system has been a topic of keen research interest for some time now. This interest has been primarily caused due to numerous advantages such as low power consumption, high data rate and compact system design [11]. A wideband communication system comprises of many components the most important of them being the wideband antenna. Literature reports numerous wideband antenna for wireless applications [12–17]. In [12], a compact metamaterial based wideband antenna for WLAN/WiMAX applications is presented. Wide bandwidth in the antenna ranging from 5.4 to 6.7 GHz is obtained by utilizing split ring resonator in the radiating patch. In [13], authors designed a wide band antenna ranging from 1.9 to 6.9 GHz covering WLAN/WiMAX bands. This wide bandwidth is accomplished in the design by etching five circular slots in the radiating patch. In [14], wide bandwidth operating from 4.4 to 5.9 GHz is obtained with the help of a inverted L-shaped radiating monopole. This wideband facilitates the antenna to be used for WLAN/WiMAX applications. In [15], a modified star-shape wideband antenna is proposed for WLAN/WiMAX applications. The wide bandwidth ranging from 2.1 to 4.2 GHz is obtained by using four circular slots embedded with equilateral triangle slots in the radiating patch. In [16], a wideband hexagonal fractal antenna operating from 1.31 to 6.81 GHz for WLAN/WiMAX band is proposed. Defected ground structure technique is utilized at the ground plane to achieve wider bandwidth. In [17], authors have designed a wideband mushroom antenna by using Frequency Selective Surface technique to obtain the bandwidth range from 4.72 to 6.04 GHz.

However, all the above-mentioned antennas suffer from some common constraints such as less gain, large active patch area size, design complexities, and less directive radiation pattern. The proposed antenna configuration is designed to eliminate the constraints of the aforementioned performances [12–17].

The three important key attributes/novelty of this research paper are as follows:

- A simple slotted uniplanar radiating patch is used in order to accomplish a wide bandwidth for the antenna.
- The antenna overcomes the major drawback of the narrow bandwidth of the patch antenna by utilising split patch technique in the radiating monopole, has a compact size, acceptable gain, and stable radiation characteristics over the entire bandwidth range of interest (i.e. 4.3 to 6.4 GHz).
- The time-domain analysis is discussed in detail. Also, these analyses reveal that the proposed configuration is more superior to the antenna proposed in the literature [12–17].

2. Methodology

An antenna which has a smaller footprint but has the same or better bandwidth, gain and reflection coefficient is more desirable in today's world. To fulfil the criteria mentioned in the introduction, the structuring of the antenna is conducted in three steps, as presented in Fig. 1. In "Step 1" a broadband monopole antenna with radiating patch and partial ground both in the same plane is constructed. The radiating patch has a feed line is excited by a lumped CPW port. "Step 2" of antenna design involved cutting a slot into the ground plane in favour to attain a reflection coefficient (S_{11}) which is less than -10 dB, for a substantial bandwidth. It also involved making a slot in the radiating part to increase the operational bandwidth of the proposed structure. "Step 3" presents the desired configuration for the proposed structure. Steps were made in the radiating patch to increase the bandwidth. Fig. 2 shows a comparison of reflection coefficients of different steps for the design of the antenna. The reduction in the size of the radiating patch of the antenna is done by making slots in it. The final antenna has a wide operational bandwidth of 4.3–6.45 GHz. The

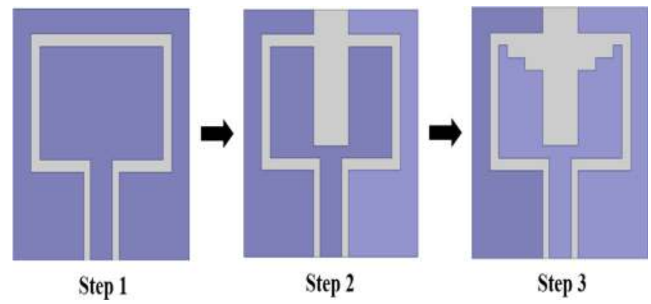

Fig. 1. Antenna design evolution.

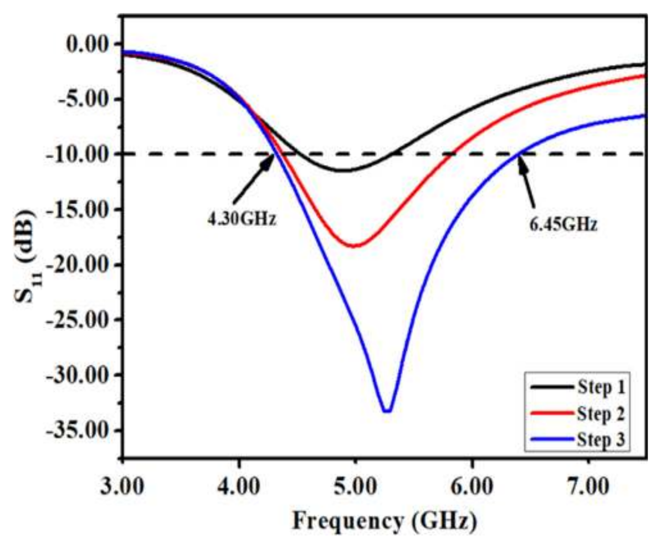

Fig. 2. Comparison of Reflection Coefficients (S_{11}) of different steps involved in antenna design.

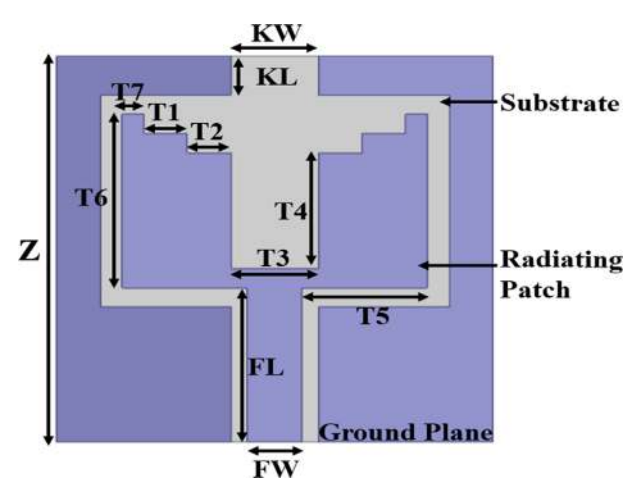

Fig. 3. Proposed antenna structure front plane.

frequency of resonance of the proposed antenna configuration can be computed as:

$$Electrical\ Length\ of\ the\ designed\ monopole = \frac{\lambda}{4} = \frac{c}{4f_r}$$

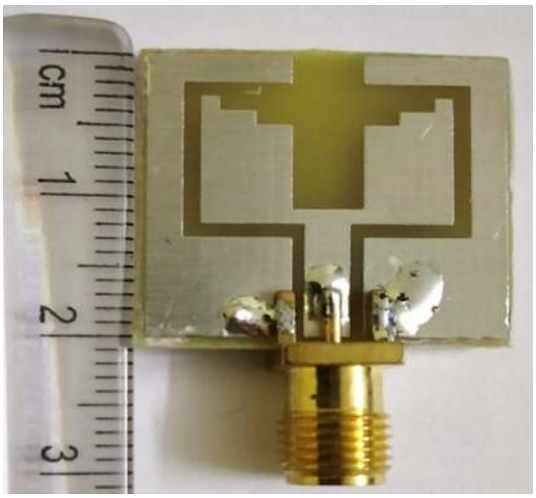

Fig. 4. Fabricated antenna.

Table 1
Proposed configuration dimensional parameters.

Parameter	Dimensions (mm)
T2	2
T1	2
T4	4
T3	6
T6	5.75
T5	9
FL	1
T7	8
FW	2
KL	4
KW	4
Z	20

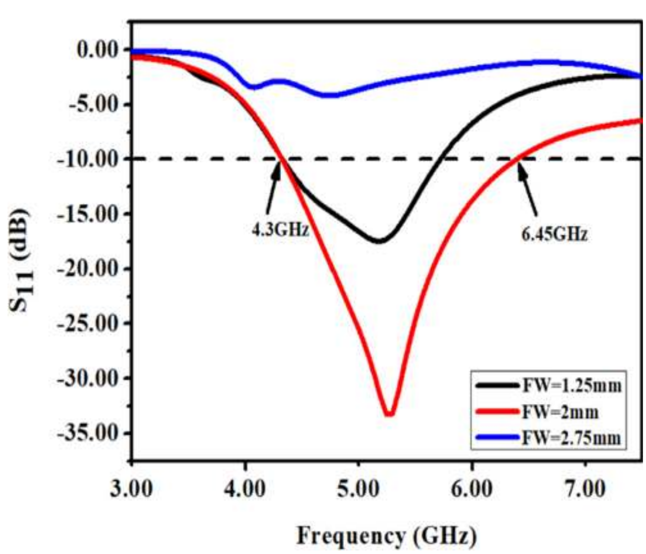

Fig. 5. Analysis of FW.

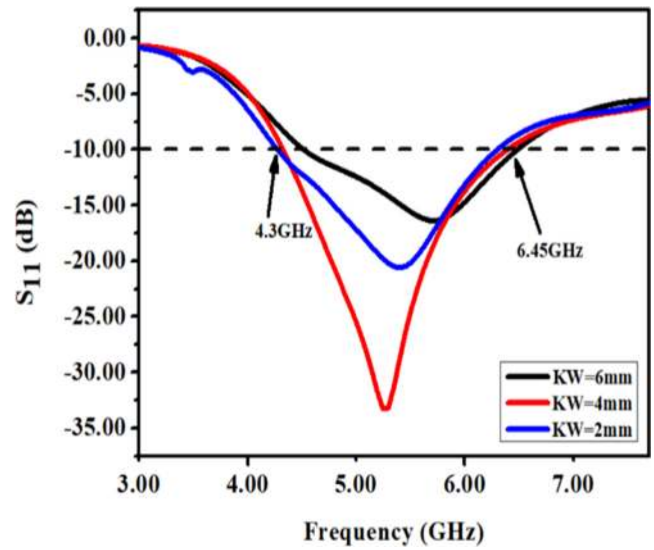

Fig. 6. Analysis of KW.

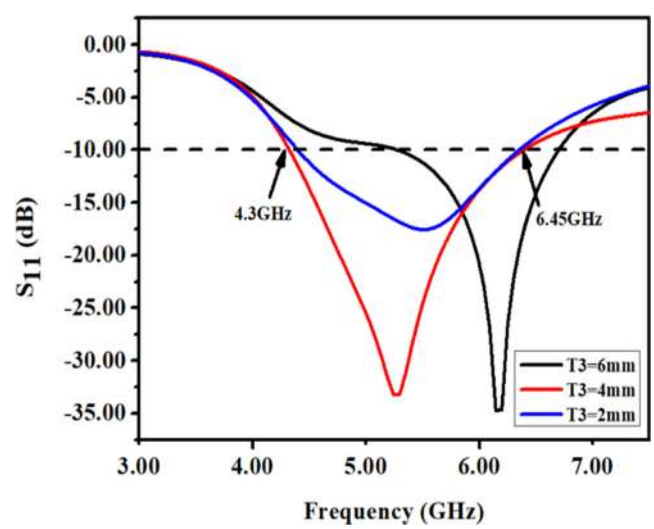

Fig. 7. Analysis of T3.

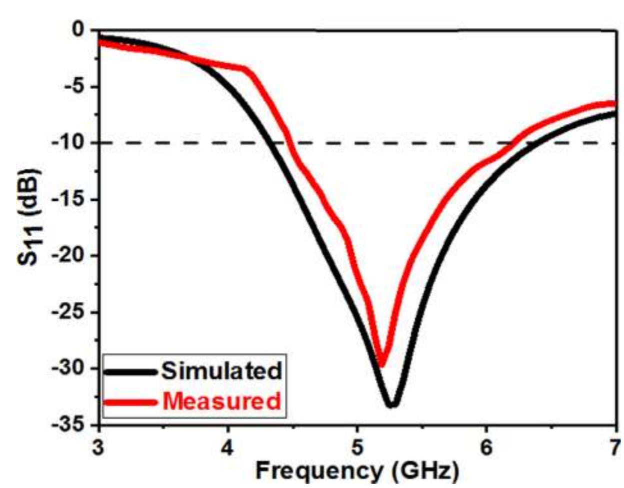

Fig. 8. Simulated and measured S_{11} of the final antenna.

Thus,

$$f_r = \frac{c}{4 \times (Electrical\ length)} \cong 5.3\ \text{GHz}$$

where c is the velocity of light while travelling in free space (3×10^{11} mm/sec). The final designed structure of the antenna is outlined in Fig. 3, the fabricated antenna of the proposed configuration is shown in Fig. 4, and the specific dimensional parameters for the presented monopole are outlined in Table 1.

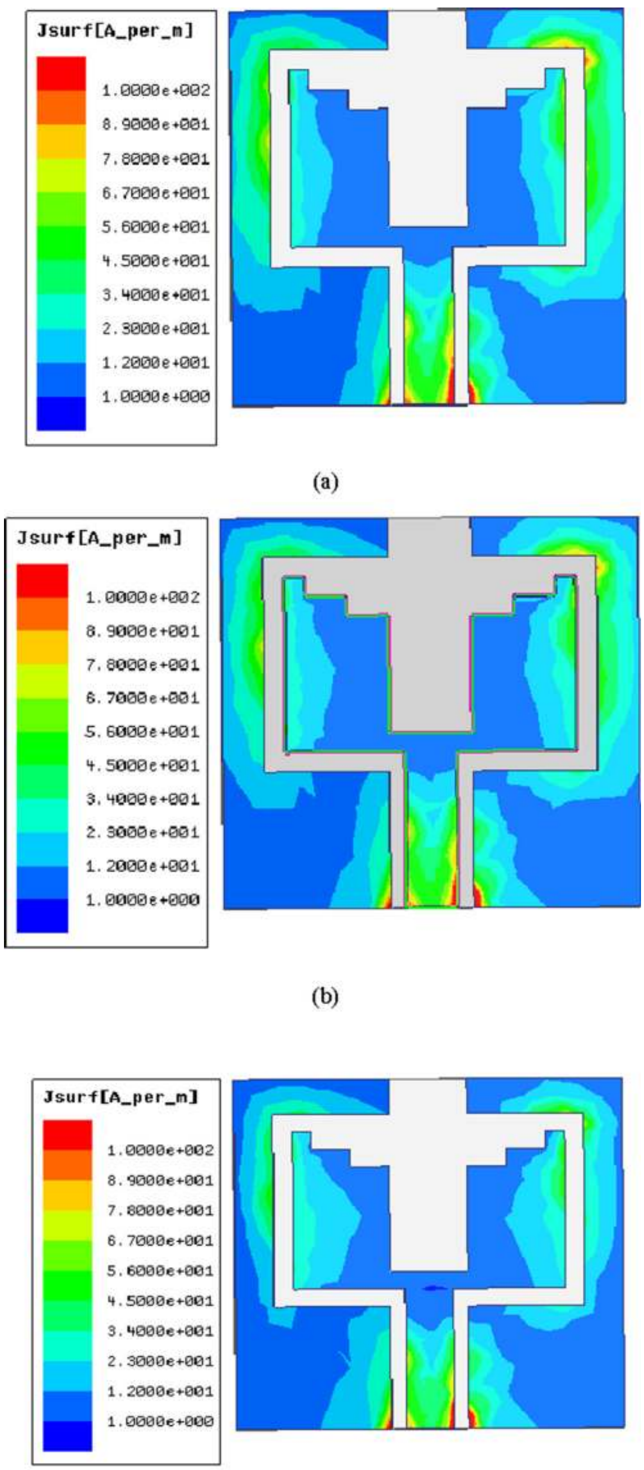

Fig. 9. Surface current variations for (a) 5, (b) 5.2 and (c) 5.8 GHz.

3. Parametric investigations

Analysis for the optimization of dimensions of the antenna for proper operational execution is carried out in this section. The analysis is executed by varying one dimension of the antenna while keeping other dimensions constant. The first dimension to be analyzed for optimization is the width of the feed line (FW). FW is first decreased by 0.75 mm and then increased by 0.75 mm. It is visible from Fig. 5 that the S_{11} performances are altered by changing FW.

Similarly, a parametric analysis is done for the width of the slot of the ground plane (KW). It is clearly visible from Fig. 6 that best performance (i.e. $S_{11} < -10$ dB) is obtained when KW = 4 mm.

The analysis for the central U-shaped slot's width (T3) is done to find its optimum dimension. It is clearly visible in Fig. 7 that the best performance (i.e. wider bandwidth) is obtained when T3 = 4 mm.

4. Results

Ansys HFSS v.14.0 has been used to simulate the proposed wideband antenna. FR4 has been used for the substrate, with the following specifications: $\varepsilon_r = 4.4$, $h = 1.6$ mm, $loss\ tangent(\delta) = 0.02$. The antenna has a fractional bandwidth of 40.56% (4.3–6.45 GHz). After fabricating the model of the proposed antenna, its S_{11} is measured to validate the results of the simulation. Fig. 8 outlines the simulated and measured S_{11} of the proposed antenna.

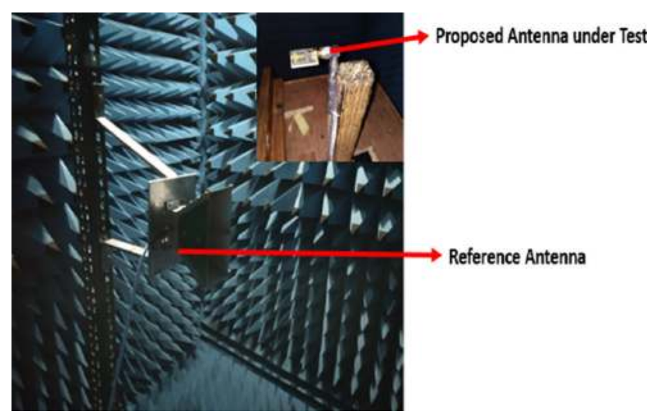

Fig. 10. Gain and radiation pattern measurement set up in anechoic chamber.

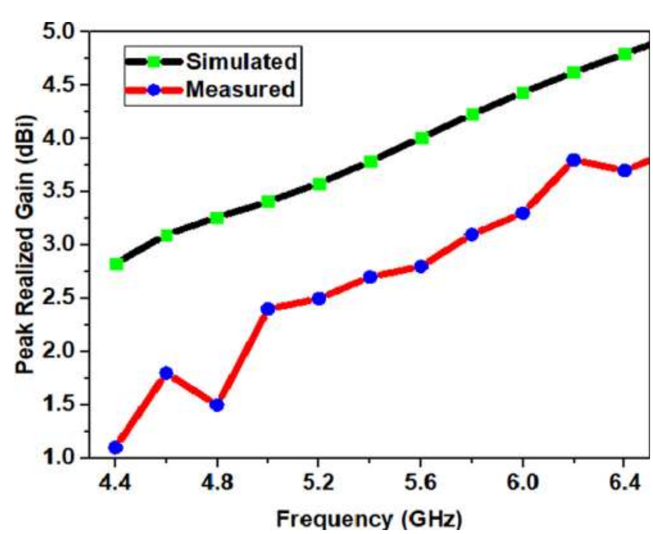

Fig. 11. Simulated and measured peak realized gain of the proposed configuration.

The configuration has a fractional bandwidth of 40.56% (4.3–6.45 GHz) in simulation and 34.41% (4.4–6.38 GHz) in measurements, for $S_{11} < -10$ dB criteria. Fabricated antenna closely mimics the simulated S_{11} of the designed antenna configuration. Slight variation in the simulated and measured S_{11} value are observed for the proposed configuration which may be due to fabrication

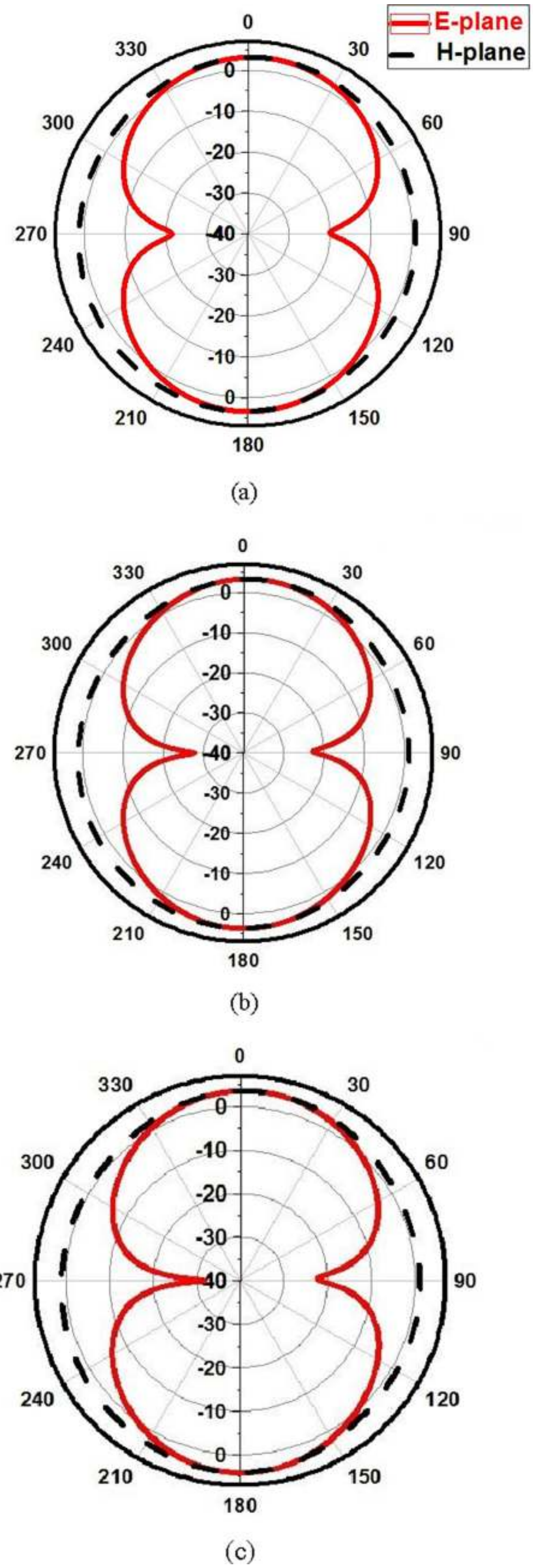

Fig. 12. Simulated radiation pattern of the proposed configuration at (a) 5, (b) 5.2 and (c) 5.8 GHz.

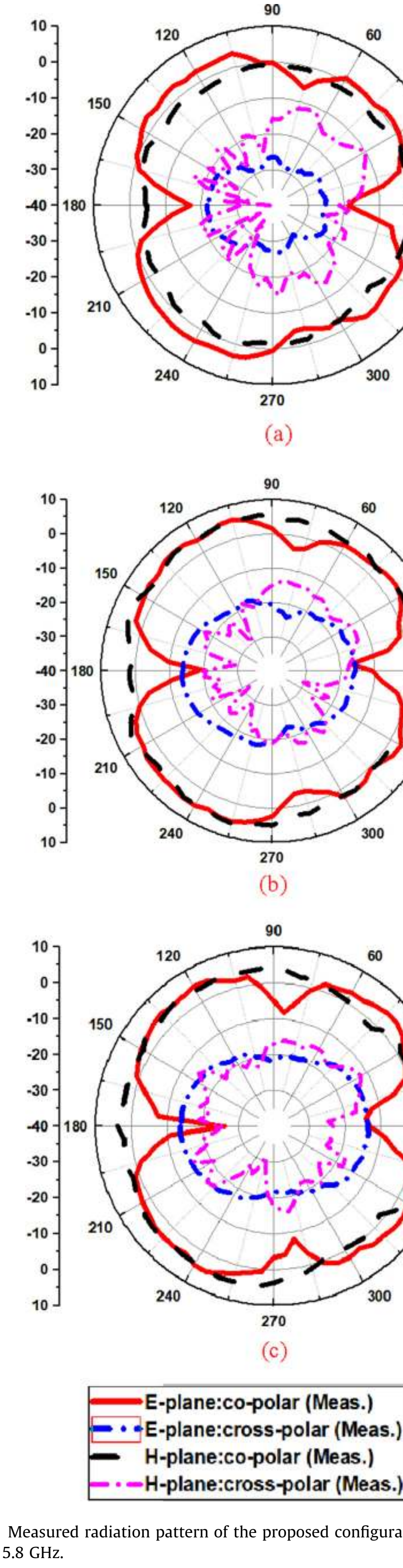

Fig. 13. Measured radiation pattern of the proposed configuration at (a) 5, (b) 5.2 and (c) 5.8 GHz.

tolerance during the photolithographic etching process, substrate material loss and soldering of SMA connectors.

The surface current variation for some commercially used resonance frequency such as 5, 5.2 and 5.8 GHz for the desired antenna configuration is depicted in Fig. 9. To overcome the major drawback of narrow bandwidth in printed patch antenna, the uniquely designed split patch technique is used to achieve a wide bandwidth, which is evident from the dense current around the split areas.

The simulated and measured peak realized gain of the proposed antenna is measured in anechoic chamber as outlined in Fig. 10. The obtained measured gain is compared with the simulated gain and is illustrated in Fig. 11. From the plot, it is quite evident that the simulated peak realized gain is increasing linearly throughout the entire operational bandwidth of the suggested configuration. However, in case of measured peak realized gain little non linearity is observed around 4.9–5 GHz which may be due to measurement tolerance and cable effects. Also, a slight light variation (upto 1 dB) in the simulated and measured gain value are observed between, which may be due to fabrication tolerance during photolithographic etching process and soldering of SMA connectors. The antenna has a maximum peak realized gain of 4.7 dB in simulation at 6.4 GHz and about 3.8 dBi at 6.3 GHz.

The simulated and measured radiation pattern for the proposed antenna configuration at some of the commercially useful frequency (i.e. 5, 5.8 GHz (WLAN) and 5.4 GHz (WiMAX)) within its operating bandwidth is presented in Figs. 12 and 13. It is visible from the plot that the antenna is displaying an omnidirectional pattern at $\theta = 0^o$ (E-plane), and bidirectional pattern at $\varphi = 90^o$ (H-plane). Also, it is shown that the measured cross-polarization both in E and H-plane low (i.e. less than -12 dB).

As the proposed antenna is wideband in nature, so its time-domain characterization becomes important. Various time-domain parameters such as group delay, isolation analysis and phase response for the proposed configuration are carried out by placing the antenna in side-to-side and face-to-face orientations as shown in Fig. 14.

The group delay (ns) of the designed antenna for the aforementioned orientations are presented in Fig. 15. For good wideband antenna configurations the group delay should be least and constant throughout the operating bandwidth. A constant group delay (and delay is almost zero nano seconds) is observed over the entire wide operating bandwidth of the proposed antenna in both the orientations.

The phase response of the antenna for both the orientations are presented in Fig. 16, wherein we can see that the designed antenna exhibits linear phase variation over the entire bandwidth of interest (i.e. 4.3–6.4 GHz).

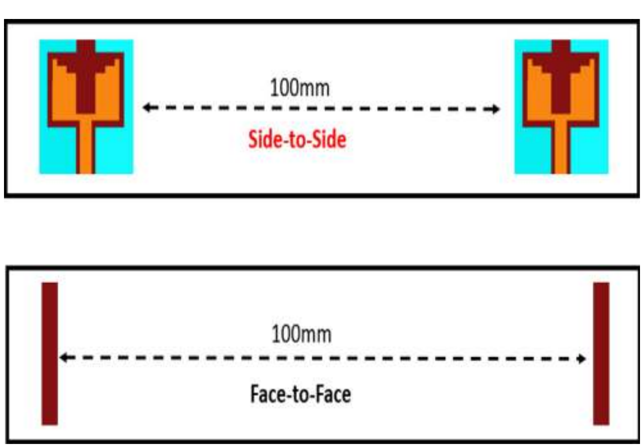

Fig. 14. Side-to-side and Face-to-Face orientations of antenna setup in HFSS to measure time doman characteristics.

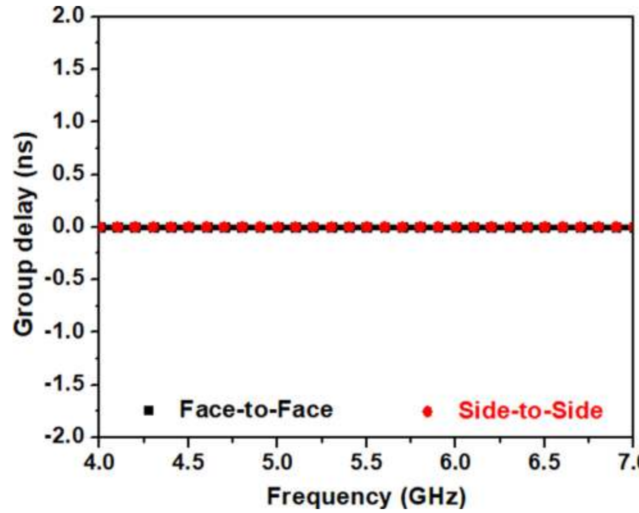

Fig. 15. Group delay for both the orientations.

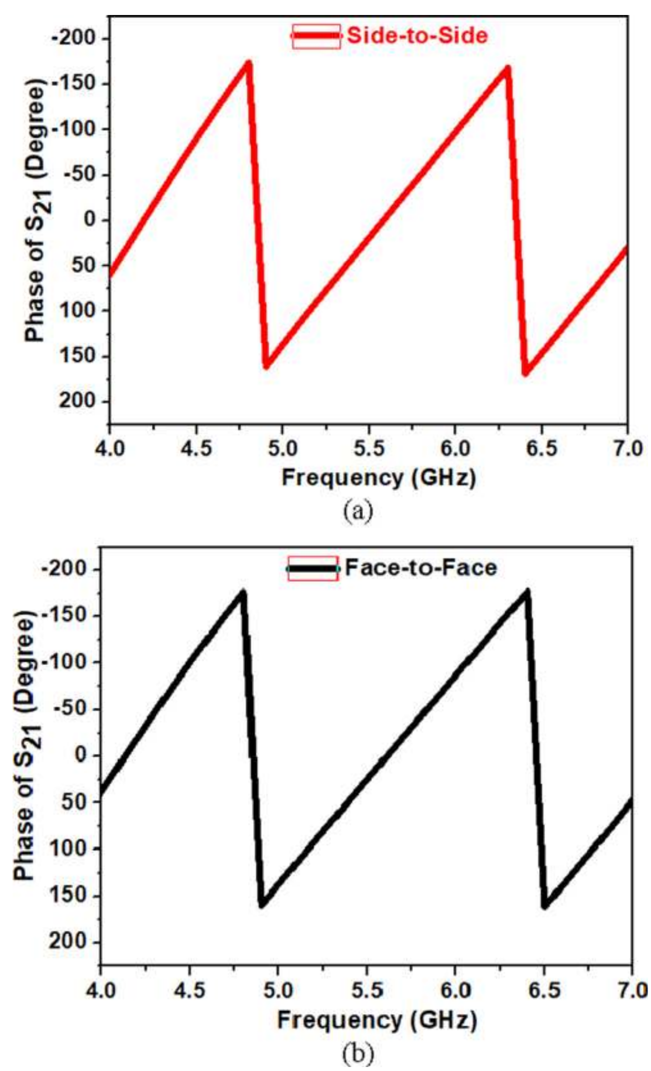

Fig. 16. Phase angle of the proposed antenna configurations for both the orientations.

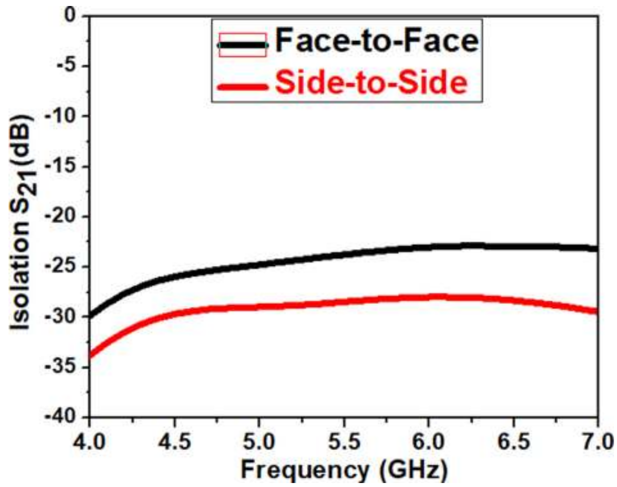

Fig. 17. Isolation analysis of the designed antenna.

Table 2
Comparative analysis of the designed antenna.

Ref.	D_S (mm^2)	F_E (GHz)	G_N (dBi)	Appl.
[12]	20 × 18	5.4–6.7	0.1	WLAN/WiM-AX
[13]	41 × 41	1.91–6.19	NA	WLAN/WiM-AX
[14]	22 × 25	4.4–5.9	2.5	WLAN/WiM-AX
[15]	39 × 39	2.1–4.2	3.01	WLAN/WiM-AX
[16]	45 × 40	1.3–6.8	4	WLAN/WiM-AX
[17]	36 × 32	4.72–6.04	3.9	WLAN/WiM-AX
Prop.	20 × 20	**4.3–6.45**	**3.8**	WLAN/WiM-AX

The isolation characteristics of the designed antenna for both the orientation are outlined in Fig. 17, wherein it can be studied that the proposed design gives isolation well below −25 dB over the entire operational bandwidth.

A comparison between the proposed antenna configuration and other wideband antennas discussed in the literature are presented in Table 2. It can be easily noticed that the designed antenna provides better performance over their counterparts. [Note:- D_S is the total area of the antennas, F_E is the frequency range of the antennas and G_N is the gain of antennas, Appl. is the applications of the proposed antennas].

5. Conclusion

A compact monopole antenna with enhanced bandwidth is proposed, fabricated and measured. The size of the antenna is 20 × 20 $mm^2$with a step slotted patch. The antenna is applicable for most of WLAN and WiMAX bands of the range corresponding to 4.70–6.19 GHz, 5–6 GHz and 5.5–5.7 GHz. The antenna excited a −10 dB bandwidth of 2.15 GHz ranging from 4.3 to 6.45 GHz. This simple designed and low-cost antenna is very useful in the field of wireless communication. Moreover, the measured S_{11} match with that of the simulated S_{11} stating that the proposed antenna configuration is a promising candidate for WLAN, WiMAX applications.

References

[1] Hosseini H, Hassani HR, Amini MH. Miniaturised multiple notched omnidirectional UWB monopole antenna. Electron Lett 2018;54(8):472–4.
[2] Ali T, Fatima N, Biradar RC. A miniaturized multiband reconfigurable fractal slot antenna for GPS/GNSS/Bluetooth/WiMAX/X-band applications. AEU-Int J Electron Commun 2018;94:234–43.
[3] Fotedar R, Garia P, Saini R, Vidyarthi A, Gowri R. Performance analysis of microstrip antennas using different shapes of patch at 2.4 GHz. In: 2015 second international conference on advances in computing and communication engineering, Dehradun. p. 374–7.
[4] Fathima, N., Nayana, K. S., Ali, T., & Biradar, R. C. (2017, May). A miniaturized slotted ground fractal Koch multiband antenna for wireless applications. In 2017 2nd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT) (pp. 251-255). IEEE.
[5] Ali T, Saadh MA, Pathan S, Biradar RC. A miniaturized circularly polarized coaxial fed superstrate slot antenna for L-band application. Inter Technol Lett 2018;1(6):e21.
[6] Ali T, Aw MS, Biradar RC, Andújar A, Anguera J. A miniaturized slotted ground structure UWB antenna for multiband applications. Microw Opt Technol Lett 2018;60(8):2060–8.
[7] Ali T, Subhash BK, Pathan S, Biradar RC. A compact decagonal-shaped UWB monopole planar antenna with truncated ground plane. Microwa Opt Techn Let 2018;60(12):2937–44.
[8] Tang Z, Wu X, Zhan J, Hu S, Xi Z, Liu Y. Compact UWB-MIMO antenna with high isolation and triple band-notched characteristics. IEEE Access 2019;7:19856–65.
[9] Balani W, Sarvagya M, Ali TMMMP, Anguera J, Andujar A, Das S. Design techniques of super-wideband antenna-existing and future prospective. IEEE Access 2019;7:141241–57.
[10] Bhattacharjee A, Dwari S, Mandal MK. Polarization-reconfigurable compact monopole antenna with wide effective bandwidth. IEEE Antennas Wirel Propag Lett 2019;18(5):1041–5.
[11] Liu H, Yin C, Gao W, Sun Y. Optimization and design of wideband antenna based on Q factor. Int J Anten Propag 2015;2015.
[12] Ali T, Aw MS, Biradar RC. A compact bandwidth enhanced antenna loaded with SRR for WLAN/WiMAX/satellite applications. Adv Electromagn 2018;7(4):78–84.
[13] Gangwar SP, Gangwar K, Kumar A. A compact microstrip patch antenna with five circular slots for wideband applications. In: 2018 3rd International Conference on Microwave and Photonics (ICMAP), February. IEEE; 2018. p. 1–2.
[14] Perli P, Rushi V, Shankar S, Kumar OP, Saadh AM, Ali T. A compact planar wideband monopole antenna with dipole like radiation characteristics for wireless applications. IOP Conference Series: Materials Science and Engineering, October, Vol. 561, No. 1. IOP Publishing; 2019. p. 012102.
[15] Gangwar SP, Gangwar K, Kumar A. A compact modified star shape microstrip patch antenna for wideband application. In: 2018 3rd International Conference on Microwave and Photonics (ICMAP), February. IEEE; 2018. p. 1–2.
[16] Desai A, Upadhyaya TK, Patel RH, Bhatt S, Mankodi P. Wideband high gain fractal antenna for wireless applications. Prog Chem Org Nat Prodln Electromagn Res 2018;74:125–30.
[17] Jia Y, Liu Y, Wang H, Li K, Gong S. Low-RCS, high-gain, and wideband mushroom antenna. IEEE Anten Wirel Propag Lett 2015;14:277–80.

Shashank Shekhar Singh Khangarot working with L&T as an Graduate Engineer Trainee. He has completed his engineering in Electronics & Communication from Manipal Institute of Technology, Manipal. He is an enthusiast about Antennas and Wireless Communications.

Sravan B V is working as a Graduate Engineer Trainee at Schneider Electric Private Limited, Bangalore. He has completed his engineering in Electronics & Communication at Manipal Institute of Technology, Manipal. He is an enthusiast about Antennas, Wireless Communications.

Namaratha Aluru is working as a Graduate Engineer Trainee at Schneider Electric Private Limited, Bangalore. She has completed her engineering in Electronics & Communication at Manipal Institute of Technology, Manipal. She is an enthusiast about Antennas, Wireless Communications.

Mohammad Saadh AW is currently pursuing M.Tech in Communication Engineering in Vellore Institute of Technology, Vellore, India. He has completed B.E in Electronics and Communication Engineering in 2017 from REVA University, Bangalore, India. He is currently working on microstrip patch antenna under Prof. R. Poonkuzhali, and Prof. Tanweer Ali. He has 15 research publications in reputed international journal/conferences. His research area includes wideband, multiband, MIMO and metamaterial based antennas. He is a reviewer of IET Microwaves, Antennas & Propagation and IET Electronics Letters.

Poonkuzhali R is an Associate Professor in school of ECE, VIT University Vellore. She is an active researcher in the field of antenna design and has more than 30 papers in reputed journals and conferences. 2008, and the IEEE Electromagnetic Compatibility Society Best Symposium Paper Award in 2011.

Mr. Om Prakash Kumar is an Assistant Professor in the Department of ECE, Manipal Institute of Technology, Manipal Academy of Higher Education, India. He received his Bachelor of Technology degree from Karunya University, India in Electronics and Communication Engineering. He received her Master of Technology degree from Karunya University, India in VLSI. His research areas of interest include the design of VLSI systems and Antenna Design.

Tanweer Ali is working as Assistant Professor in the Department of Electronics & Communication Engineering at Manipal Instituteof Technology, Manipal Academy of Higher Education, Manipal. He is an active researcher in the field of microstrip antennas, wireless communication and microwave Imaging. He has published more than 80 papers in reputed peer reviewed international journal and conferences. He is a senior member IEEE (SMIEEE), and Associate Member of IETE India. He is on the board of reviewers of journals like the IEEE Transactions on Antennas and Propagation, IEEE Antennas and Wireless Propagation Letters, IET Microwaves, Antennas & Propagation, IET Electronics letter, Wireless Personal Communication (WPC), Springer, AEU-International Journal of Electronics and Communications, Microwave and optical Technology letters (MOTL), Wiley, International Journal ofAntennas and Propagation, Hindawi., Advanced Electromagnetics, Progress in Electromagnetic Research (PIER), KSII Transaction ofEngineering Science, Korea, International Journal of Microwave andWireless Technologies, Frequenz, Radio engineering etc

Manohara M. M. **Pai** holds Ph.D. in Computer Science and Engineering and has been the Professor in the Department of Information and Communication Technology at Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, India for the last 27 years. He holds 6 patents to his credit and has published 80 papers in National and International Journals/ Conference proceedings. He has published two books, guided 5 PhDs and 65 Master thesis. His areas of interest includes Data Analytics, Cloud computing, IoT, Computer Networks, Mobile Computing, Scalable Video Coding, Robot Motion Planning. He is Senior Member of IEEE, Life member of ISTE and Life member of Systems Society of India. He is also the Chair of IEEE Mangalore SubSection (2019).