International Journal of Computing and Digital Systems
ISSN (2210-142X)
Int. J. Com. Dig. Sys. 13, No.1 (Jan-2023)

http://dx.doi.org/10.12785/ijcds/130106

Design and Analysis of Low Profile E-shaped Slotted Triple-band Antenna for ISM band/WiMAX/WLAN Applications

Killol V. Pandya[1], Jeenal Barot[1], Trushit Upadhyaya[1], Upesh Patel[1], Rajat Pandey[1] and Aneri Pandya[2]

[1] *Electronics and Communication Engineering Department, Chandubhai S. Patel Institute of Technology, CHARUSAT University Changa, Gujarat, India*
[2] *Electronics and Communication Engineering Department,LJ Institute of Engineering and Technology,LJ University,Gujarat, India*

Received 29 Sep. 2021, Revised 15 Sep. 2022, Accepted 12 Jan. 2023, Published 31 Jan. 2023

Abstract: Wireless communication and embedded technology have shown rapid growth in last decade. An E-shaped slotted tri-band antenna is designed, analyzed, and proposed in this paper. The developed antenna operates for 2.4GHz, 3.5GHz and 5GHz frequencies having impedance bandwidths of 7.17%, 5.71% and 12% with an acceptable gain of 4.25dBi, 3.51dBi and 1.90dBi respectively. The efficiency for aforementioned frequencies are 74%, 75% and 80% respectively. The developed antenna utilizes FR4 as a substrate material. The presented structure is fabricated to receive the actual output parameters. There is a neighboring correlation between the software generated results and measured results. The additional vertical slots with E-shape slot offer desired return loss with optimum bandwidth for targeted resonating modes. The characteristics such as omnidirectional radiation pattern, moderate gain and adequate efficiency make the antenna an appropriate candidate for ISM band, WiMAX and WLAN applications.

Keywords: Wireless communication, Slot antenna, Microstrip antenna, WiMAX

---

1. Introduction

The embedded system and wireless communication technology need effective radiating structure with modifications to target specific applications. Before two decades, microstrip antenna was the first choice for any researcher to design and develop an antenna because of its advantages such as lower volume, light weight, cost effectiveness, compact in size and easy for fabrication [1]. Apart from these advantages, it also offers circular-dual polarization and dual band frequency operations. Despite of many advantages, microstrip antenna is struggling for achieving adequate bandwidth. Various solutions for these drawbacks were reported in literature such as use of parasitic patch and thick substrate [2]. However, application of these geometrical changes results co-planar and stack configurations. Now, stacked geometry creates hurdle against the basic advantages of microstrip antenna such as easy of fabrication and low profile. Also, co-planner structure significantly increase the lateral antenna size [3]. After applying multiple structural changes, a unique method of etching a slot on the patch surface has been reported to achieve the optimum impedance bandwidth. Concentrating on this, the researchers have analysed the behaviour U-shaped slot antennas [4]. By creating U-shaped slot, the structure gave balanced radiation pattern and steady polarization. The literature also reports that ring shaped slots could eliminate the unwanted harmonics from return loss graph [5]. Optimum gain could not be observed from the radiating structure if it radiates for various undesired frequency bands. In such situation, it is extremely important to supress the uninvited harmonics. The afore mentioned reference paper presented this harmonic suppression very diligently. Adoption of various shaped slots, slot pairs and closed loop slots provides adequate response for key antenna parameters such as wide impedance bandwidth, undesired harmonic suppression, stable and Omni directional radiation pattern and moderate gain. Such kind of slot antenna performance is presented in [6], where octa star slot was created on the top surface of radiating element. Due to this, wide bandwidth, conical radiation pattern and flat gain could be received from radiating structure. Similarly, wideband conical shaped slot antenna was designed and presented in [7]. The claimed antenna showed wide bandwidth from 600 MHz to 4 GHz. An open slot, etched from radiating surface, could offer circular polarization with desired gain and adequate bandwidth [8]. In this structure, the slot antenna was energized using a microstrip line feed and both were positioned at the end of ground plane which makes antenna asymmetrical. Furthermore, the slot antenna could also contributes in dual polarization achievement. In [9] - [10], the concept of arrays

E-mail address: dkn@gwu.edu, Dr.Sardar.Azari@ieee.org, serres@gwu.edu, badawy@gwu.edu, tarek@gwu.edu

of slot antenna is introduced to achieve dual polarization for 5G smart phone applications and mobile communications respectively. Slot antennas have proven their applicability for noteworthy applications such as wearable antennas and implantable antennas. A slot antenna using circular ring was proposed with electromagnetic band gap structure for the application of mobile body area network [11]. The size of this structure is miniaturised based on the equivalent circuit model. Likewise in [12], implantable flexible slot geometry is discussed and analysed for biomedical usage. In [13], new technique has been discussed to increase the bandwidth in slot antennas.

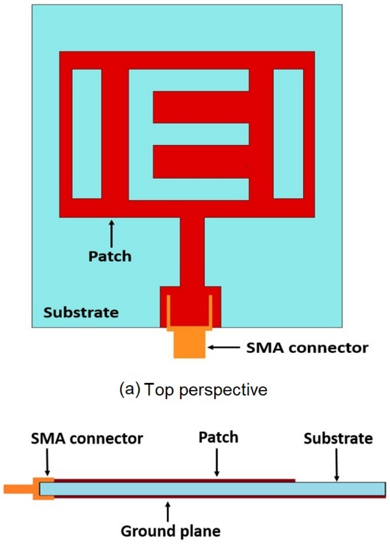
After concluding the literature survey of single and dual band slot antenna, the authors have studied and presented triple band oriented slot antennas. These research depict the various slot antenna shapes and response parameters. Table 1 illustrates the potential of claimed antenna with reference to the other similar type of triple band antenna structures. The comparison is presented based on antenna parameters such as frequency bands, bandwidth, overall size, gain optimization, and substrate material. The comparison appears more interesting and essential because of similar kind of structures

The close observation says in [14], triple band slot antenna was designed for Wi-Fi, Wireless for radio frequency access and mobile limited area network applications. However, the band width and gain is not promising. Few research papers [15],[16],[17],[18] were reported where, significant gain and bandwidth were optimized by compromising the antenna size. Such type of structures could not be embedded in a compact size communication devices. It is always an interesting task for the researcher to receive optimal parameters with size miniaturization. In [19], though the antenna is radiating for triple band with good bandwidth and gain, it contains large size and utilizes Arlon material as a substrate which is not easily available in the market. Compact size, triband slot antenna was claimed in [20] with positive gain. However, the bandwidth is too narrow to cover possible applications. The proposed structures of [21],[22],[23],[24] large size slot antennas were presented for optimal response. In these antennas, Roger RT/duroid 5880, Rogers RO4003 and other material were used having relative permittivity of 3.5. Such kind of materials are very expensive which may significantly rise the antenna production cost.

Here, an E- shaped slot antenna with two extra vertical slots is systematically demonstrated, analysed, fabricated and presented. In the section of antenna geometry, the prototype is depicted from top and side view. This section is followed by parametric study section where the antenna performance is examined by all possible parametric variations. In the successive section, the brief discussion is included on simulated and measured results. Also, the far-field radiative response from an antenna for Electric-field $\phi = 0°$ and Magnetic-field $\phi = 90°$ are discussed in this section to verify antenna behaviour. Finally, the presented research is concluded in the last phase of paper.

2. ANTENNA GEOMETRY

The Fig. 1 shows E shaped slot antenna development with vertical slots. The figure 1 (a) depicts top view of the same where patch, substrate and feeding geometry are visible. Also, how the SMA connector should be shouldered with the feed is shown.



(a) Top perspective

(b) Side perspective

Figure 1. Proposed antenna prototype

The figure 1 (b) illustrates the side view of an antenna where various layers of an antenna are displayed.The fig. 2 depicts dimensional diagram of antenna. All antenna dimensions are finalized to get optimum impedance bandwidth. The width and length dimensions of two vertical slots are fixed to obtain antenna response for multiple resonance. The literature says, dominating factors which could affect the antenna performance are dimensions of La and Wa [25],[26] .The external slot dimensions are equally important for the same. The antenna response could be further improved by using arrays of slot designs [27],[28],[29].

TABLE I. COMPARISON OF DEVELOPED ANTENNA WITH OTHER REFERENCES

Reference No.	Center frequency(GHz)	Operational bandwidth	Physical size (mm3)	Gain (dBi)	Substrate material
[14]	2.4,3.5,5	1.20,3.20,17.50	35 × 19 × 1.6	1.1,2.3,3.1	FR4
[15]	2.47,3.42,5.95	34.6,19.4,16.9	54 × 55 × 1.6	4.03,4.75,6.21	FR4
[16]	3.75,5.98,8.79	8.25,4.52,3.53	60 × 60 × 1.6	6.40,7.52,7.32	FR4
[17]	0.9,1.8,2.4	1.5,1.2,0.9	80 × 86 × 1.6	8.79,5.86,7.93	—
[18]	2.4,3.5,9	32,10,12	40 × 40 × 0.8	—	FR4
[19]	1.6,1.9,3.8	8,6,6	52 × 71 × 1.6	—	Arlon
[20]	2.3,4.7,5.85	2.1,1.7,0.7	12.5 × 12.5 × 1.6	Between 2.2 to 4	—
[21]	2.25,3.76,5.23	0.5,1.5,4.3	46 × 33.8 × 1.6	—	Roger RT/duroid 5880
[22]	1.57,2.45,5.5	0.4,10.41,10.18	60 × 60 × 1.6	0.2,3.5,2.37	FR4
[23]	2.4,3.5,5.8	3.64,4.01,3.98	35 × 32 × 1.6	Negative	Rogers RO4003
[24]	2.4,3.5,5.5	6.25,19,32	30 × 65 × 1.6	1.3,5.2,3.1	FR4
Proposed antenna	2.4,3.5,5	7.17, 5.71,12	37 × 28.33 ×1.6	4.25,3.51,1.90	FR4

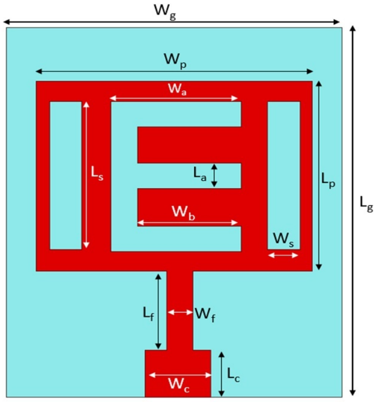
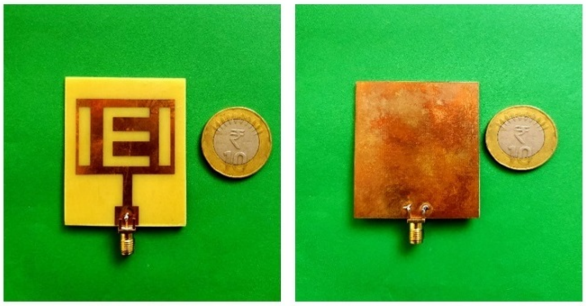


Figure 2. Prototype with detail notations

The table 2 displays the detail dimensions of antenna

Once the antenna design is fixed and software generated results are analyzed, the model was fabricated using PCB machine. The fabricated structure is shown in fig. 3 The PCB mount female SMA connector is soldered with the quadrature transmission line at the top and ground plane at the bottom. These connections are clearly visible in figure 3 (a) and (b) respectively. The high precision in fabrication process is expected to receive genuine response from fabricated model.


(a) Top View

(b) Back View

Figure 3. Fabricated antenna

3. PARAMETRIC STUDY

The proposed antenna structure is analyzed by 3D electromagnetic simulation software which is a commercial frequency solver software. To finalize the optimal designing constraints and dimensions, various parametric study has been performed and shown by graphical manner in fig. 4. The figure 4 (i) depicts the comparison of software generated return losses for different stages of antenna development. Various color lines represent different reflection coefficient (S11) parameter values against frequencies. S11 parameter of an prototype is measured by Keysight Vector Network Analyzer N9912A series. The green, black and red color lines illustrate the responses from first, second and third phase of antenna model. The magenta color line shows response from proposed structure. It is noticed that desired result for targeted frequencies could be received by proposed structure.

The figure 4 (ii) illustrates the comparison graph of scattering parameter-S_{11} values caused by the proposed slot antenna for variation in ground plane. This antenna performance was analyzed for entire copper coating at the bottom surface, 50% coating at the bottom surface and for limited surface coating. The close observation depicts that using

TABLE II. STRUCTURE MEASUREMENTS

Notations	Dimensions (mm)	Notations	Dimensions (mm)
W_P	37	W_a	17.5
L_P	28.33	L_a	3.8
W_g	40	W_b	13.9
L_g	50	W_C	8.8
W_f	3.5	L_C	7
L_f	12	W_S	4.4
H	1.6	L_s	22

half ground plane and partial ground plane, the proposed structure radiates; however, the frequency bands are not application oriented. The slot antenna with full ground plane radiates efficiently for targeted frequencies. The figure 4 (iii) illustrates the antenna performance in terms of return loss for various quarter wave transformer length. It has been proven from the diagram that optimum length which might give noteworthy antenna response is 12 mm which is shown by black color line. By optimizing the appropriated length, structure could have the better impedance matching which may lead the antenna for noteworthy output at claimed frequencies. The figure 4 (iv) gives the return loss comparison with the parametric variation in quarter wave transformer width. In this, the length and width ratio should be appropriate enough to allow maximum current to pass through the narrow passage and travel along the top surface of a slot antenna. As, current density is maximum over the surface of slot antenna, majority of radiation occurs specially at the edges of it. The blue, green, pink and brown color lines represent the output for 3.5 millimeter width, 3.4 millimeter width, 2.4 millimeter width, and 1.8 millimeter width respectively. The 3.5 mm width dimension offers optimum response. The figure 4 (v) depicts the comparison of return loss by changing the microstrip feed length (Lc). The black color dashed line shows return loss of the structure for 7 mm length dimension. The other verified dimensions are 6.5 mm and 7.5 mm which are shown by green and red color lines. After this parametric analysis, 7 mm dimension is finalized. Similarly, figure 4 (vi) represents the comparative analysis of reflection coefficient performance based on variation in microstrip feed width. As illustrated by the graph, 8.8 mm width is preferred for desired performance. This performance is shown by the pink color dashed line in the afore mentioned figure.

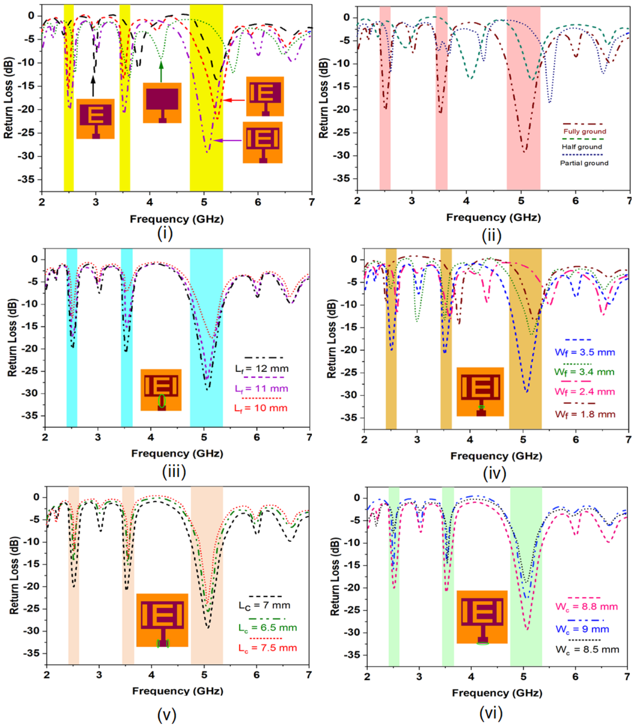


Figure 4. Iterative study of return loss from possible iterations

4. RESULTS AND DISCUSSION

After finalizing possible dimensions, the structure is again analyzed for various parameters to verify its potential. The fig. 5 represents the simulated and measured S_{11} parameter result for specific frequency range from 2 GHz to 7 GHz. Both outcomes match for given frequency range which the evidence of acceptability of the proposed antenna for targeted wireless applications.

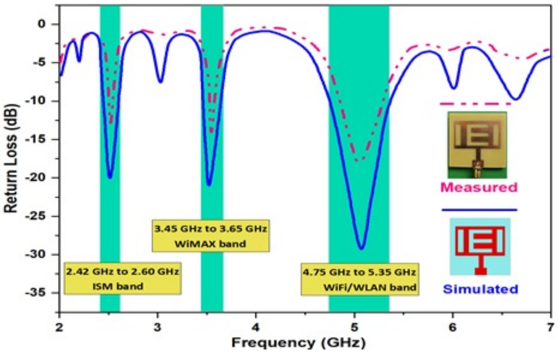


Figure 5. Graph of return loss Vs frequency (simulated against measured)

The radiation pattern is defined as a function of mathematics or a graphical method of far field radiation of a structure. It depicts departure direction of electromagnetic waves. The radiation pattern represents several parameters such as gain, directivity, radiation vector etc. The reviews depicts, if impedance matching is appropriate, even compact antenna has maximum current density which offers adequate radiation pattern [30]. The fig. 6 depicts current distribution at targeted frequencies. The red coloured part is considered having a highest current density and blue coloured part is having a lowest current density. Majority part of conducting patch is having red coloured which shows that maximum current is passing over the surface. The fig. 7 illustrates the antenna measurement test. The developed model is fixed in the anechoic chamber for E filed and H field measurement. The anechoic chamber is having a size 5m × 5m × 5m. Fig. 8 gives idea about the physical setup of an antenna measurement. For measurement, the fabricated antenna is connected at receiving side and horn antenna is connected at transmitting side. The receiving antenna is rotated at possible angles to measure the radiation pattern and return loss. These parameters are measured using vector network analyzer and desktop system.The fig. 9 shows 2D radiation pattern by fixing the antenna horizontally. Fig. 10 shows 2D radiation pattern by fixing the antenna vertically. Both are fixed for targeted frequencies. The figures show close agreement between simulated and measure results. The antenna gives directive patterns. By instrumenting appropriate reflectors, the directivity could be improved. The close observation says, antenna radiates in all directions for E-field and H-field.

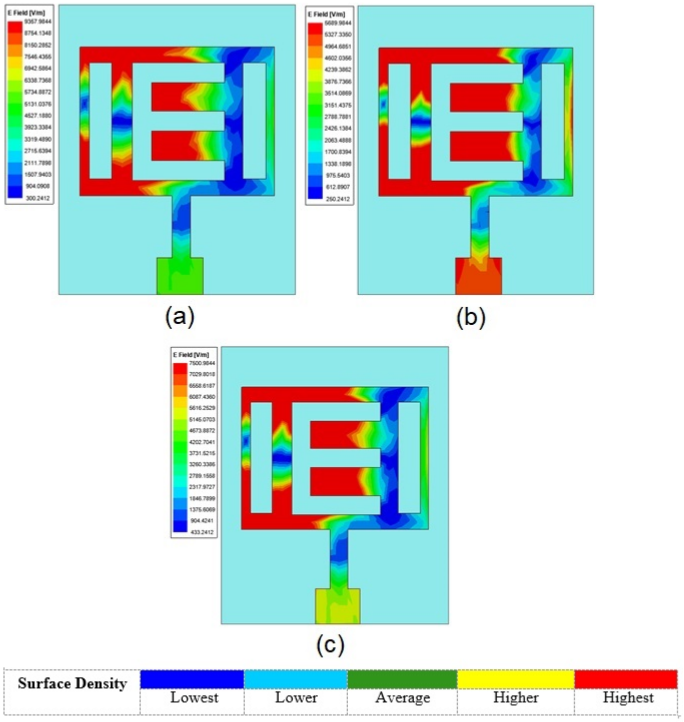


Figure 6. Current distribution at 2.4GHz freq., 3.5GHz freq. and 5GHz frequencies

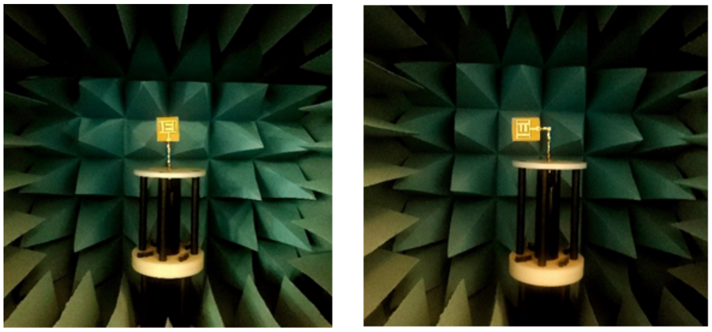

(i) E-field measurement
(ii) H-field measurement

Figure 7. Prototype under test in non-reflective chamber

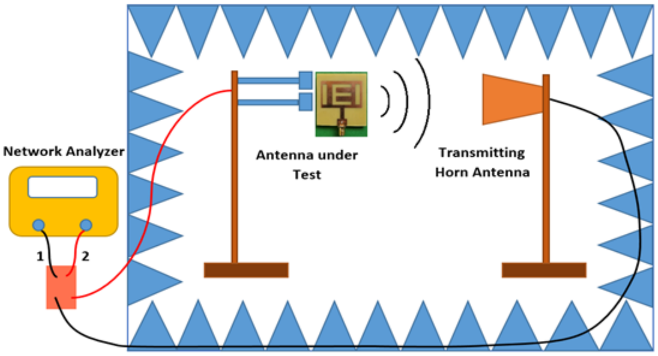


Figure 8. Antenna measurement setup

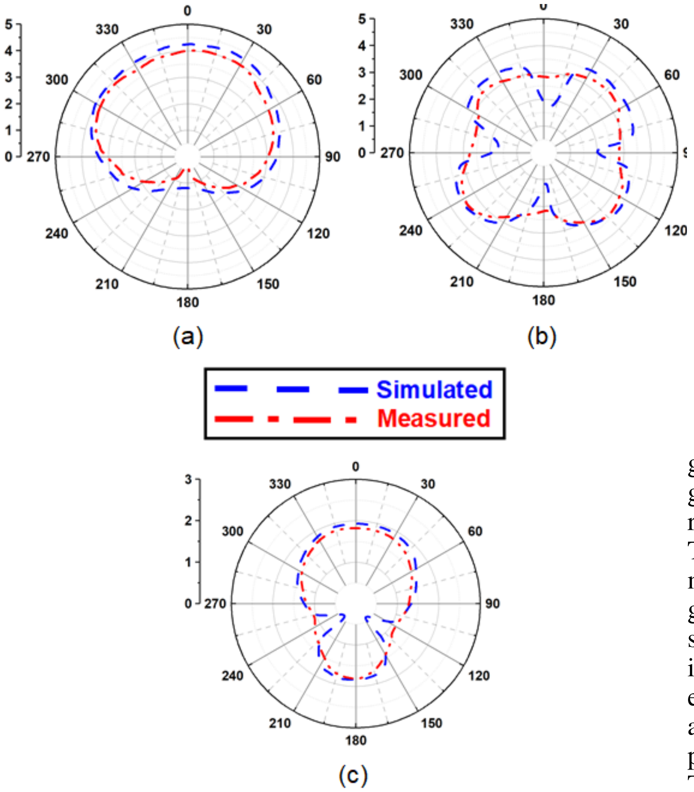


Figure 9. Far-field 2D response for 2.4GHz freq.,3.5GHz freq., and 5GHz freq.($\phi = 0°$)

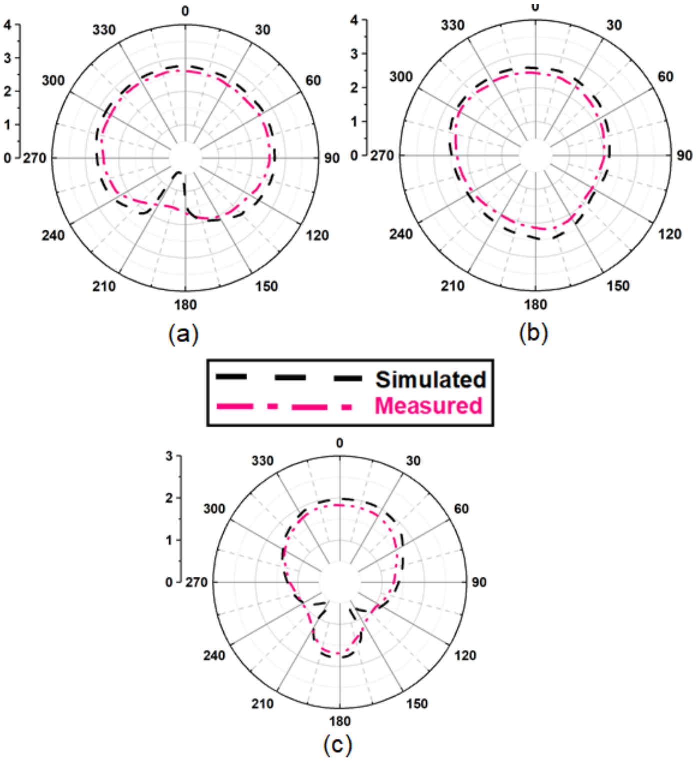


Figure 10. Far-field 2D response for 2.4GHz freq., 3.5GHz freq. and 5GHz freq.($\phi = 90°$)

The fig. 11 depicts the gain and radiation efficiency graph. At 2.4GHz freq., 3.5GHz freq., and 5GHz frequency, gain values are 4.25dBi, 3.51dBi and 1.90dBi having the radiation efficiency of 74%, 75% and 80% respectively. The figure shows close correlation between simulated and measured responses which verifies antenna potential. The gain could be diligently improved by introducing arrays of similar shapes. In [[31],[32]], the gain was improved significantly by introducing array of elements instead of single element design. Few researchers proposed dielectric resonator antenna where gain was improved adequately using the properties of dielectric resonator [[33],[34],[35],[36],[37]]. The obtained parameters from developed antenna are shown in table 3.

TABLE III. Developed antenna responses

Antenna particulars	First freq. band	Second freq. band	Third freq. band
Frequency (GHz)	2.4	3.5	5
Bandwidth (%)	7.17	5.71	12
Peak Gain (dBi)	4.25	3.51	1.90
Radiation Efficiency (%)	74	75	80

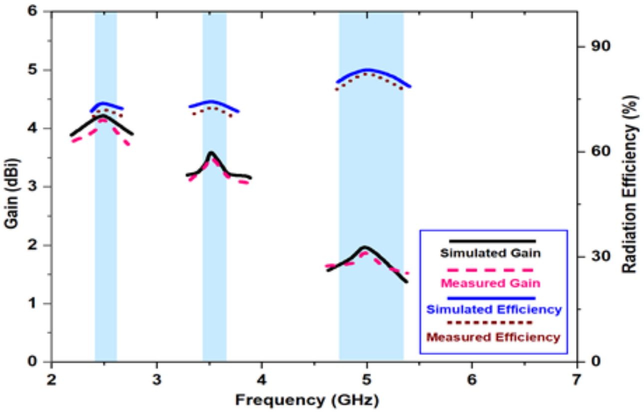


Figure 11. Antenna gain and radiation efficiency

5. CONCLUSION

A tri-band E-shaped slotted antenna is developed for ISM band, WiMAX and WLAN applications. The developed antenna resonates at 2.4GHz, 3.5GHz and 5GHz frequencies with reasonable gain of 4.25dBi, 3.51dBi and 1.90dBi. The impedance bandwidth for aforementioned resonances are 7.17%, 5.71% and 12% with an efficiency of 74%, 75% and 80% respectively. The presented design is simple to fabricate and utilizes FR4 material as a substrate. The close agreement is observed between the software generated results and actual results.The actual results have adequate output parameters for ISM band, WiMAX and WLAN applications.

ACKNOWLEDGMENT

The research was funded by Charotar University of Science and Technology (CHARUSAT) under the CHARUSAT Seed Grant for research (Project No 14). The research was performed and carried out at Electronics and Communication Engineering department, Chandubhai S. Patel Institute of Technology, CHARUSAT University, Gujarat, India.

REFERENCES

[1] I. Singh and V. Tripathi, "Micro strip patch antenna and its applications: a survey," *Int. J. Comp. Tech. Appl*, vol. 2, no. 5, pp. 1595–1599, 2011.

[2] C.-L. Mak, K. Luk, K. Lee, and Y. Chow, "Experimental study of a microstrip patch antenna with an l-shaped probe," *IEEE Transactions on antennas and propagation*, vol. 48, no. 5, pp. 777–783, 2000.

[3] S. Radavaram and M. Pour, "Wideband radiation reconfigurable microstrip patch antenna loaded with two inverted u-slots," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 3, pp. 1501–1508, 2018.

[4] S. Weigand, G. H. Huff, K. H. Pan, and J. T. Bernhard, "Analysis and design of broad-band single-layer rectangular u-slot microstrip patch antennas," *IEEE transactions on antennas and propagation*, vol. 51, no. 3, pp. 457–468, 2003.

[5] W. Li, Y. Wang, B. You, Z. Shi, and Q. H. Liu, "Compact ring slot antenna with harmonic suppression," *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 12, pp. 2459–2463, 2018.

[6] A. Kumar, "Wideband circular cavity-backed slot antenna with conical radiation patterns," *Microwave and Optical Technology Letters*, vol. 62, no. 6, pp. 2390–2397, 2020.

[7] A. Raza, W. Lin, Y. Chen, Z. Yanting, H. T. Chattha, and A. B. Sharif, "Wideband tapered slot antenna for applications in ground penetrating radar," *Microwave and Optical Technology Letters*, vol. 62, no. 7, pp. 2562–2568, 2020.

[8] M. S. Ellis, F. B. Effah, A.-R. Ahmed, J. J. Kponyo, J. Nourinia, C. Ghobadi, and B. Mohammadi, "Asymmetric circularly polarized open-slot antenna," *International Journal of RF and Microwave Computer-Aided Engineering*, vol. 30, no. 5, p. e22141, 2020.

[9] N. O. Parchin, Y. I. A. Al-Yasir, A. H. Ali, I. Elfergani, J. M. Noras, J. Rodriguez, and R. A. Abd-Alhameed, "Eight-element dual-polarized mimo slot antenna system for 5g smartphone applications," *IEEE access*, vol. 7, pp. 15 612–15 622, 2019.

[10] R. Montoya Moreno *et al.*, "Millimeter-wave antennas for 5g handsets and base stations," 2020.

[11] G.-P. Gao, B. Hu, S.-F. Wang, and C. Yang, "Wearable circular ring slot antenna with ebg structure for wireless body area network," *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 3, pp. 434–437, 2018.

[12] S. Das and D. Mitra, "A compact wideband flexible implantable slot antenna design with enhanced gain," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 8, pp. 4309–4314, 2018.

[13] B. NiEXGNhzCyXCzSIUZWC and S.-W. Chang, "Studies on dual-band multi-slot antennas," *Progress In Electromagnetics Research*, vol. 83, pp. 293–306, 2008.

[14] B. Li, Z.-H. Yan, and T.-L. Zhang, "Triple-band slot antenna with u-shaped open stub fed by asymmetric coplanar strip for wlan/wimax applications," *Progress In Electromagnetics Research Letters*, vol. 37, pp. 123–131, 2013.

[15] Z.-Y. L. De Shui Cai, H. Chen, G.-L. Ning, R. B. Wang *et al.*, "Crossed oval-ring slot antenna with triple-band operation for

wlan/wimax applications," *Progress In Electromagnetics Research Letters*, vol. 27, pp. 141–150, 2011.

[16] A. Ghosh, T. Mandal, and S. Das, "Design of triple band slot-patch antenna with improved gain using triple band artificial magnetic conductor." *Radioengineering*, vol. 25, no. 3, 2016.

[17] O. Noori, J. Chebil, M. R. Islam, and S. Khan, "Design of a triple-band h slot patch antenna," in *2011 IEEE International RF & Microwave Conference*. IEEE, 2011, pp. 289–292.

[18] S. Ahdi and M. Kartal, "A new triple band circularly polarized square slot antenna design with crooked t and f-shape strips for wireless applications," *Progress In Electromagnetics Research*, vol. 121, pp. 1–18, 2011.

[19] N. K. Darimireddy, R. R. Reddy, and A. M. Prasad, "Design of triple-layer double u-slot patch antenna for wireless applications," *Journal of applied research and technology*, vol. 13, no. 5, pp. 526–534, 2015.

[20] R. Gore, "Co-axial fed rectangular tri-slot enhanced microstrip antenna."

[21] B. Bag, "Microstrip slot antenna for triple band application in wireless communication," *International Journal of Electronics and Communication Engineering*, vol. 8, no. 6, pp. 964–967, 2014.

[22] T.-H. Chang and J.-F. Kiang, "Compact multi-band h-shaped slot antenna," *IEEE Transactions on Antennas and Propagation*, vol. 61, no. 8, pp. 4345–4349, 2013.

[23] X. Wan and H. Zheng, "The design of triple band antenna applied in wlan and wimax system."

[24] J. Li, J. Guo, B. He, A. Zhang, and Q. H. Liu, "Tri-band cpw-fed stub-loaded slot antenna design for wlan/wimax applications," *Frequenz*, vol. 70, no. 11-12, pp. 521–526, 2016.

[25] J. K. Ali, "A new dual band e-shaped slot antenna design for wireless applications," *Progress In Electromagnetics Research*, vol. 1259, 2011.

[26] M. Abu, M. K. A. Rahim, and O. Ayop, "Slotted e-shape antenna design for dual frequency operation," in *2009 3rd European Conference on Antennas and Propagation*. IEEE, 2009, pp. 2416–2419.

[27] A. Wa'il, R. M. Shaaban, and Z. A. Ahmed, "A modified e-shaped microstrip patch antenna for dual band in x-and ku-bands applications," in *Journal of Physics: Conference Series*, vol. 1234, no. 1. IOP Publishing, 2019, p. 012028.

[28] A. A. Deshmukh, A. Mhatre, C. Kudoo, and S. Pawar, "E-shape microstrip antenna backed by pairs of slots cut ground plane for wideband response," *Procedia computer science*, vol. 143, pp. 101–107, 2018.

[29] Q. Chen, G. Zhang, C. He, Y. Fan, Z. Zhu, D. Zhang, J. Li, and Y. Zhao, "Wideband and high-gain circularly-polarized l-shaped slot antenna array using metamaterial," *International Journal of Microwave and Wireless Technologies*, vol. 13, no. 4, pp. 359–364, 2021.

[30] T. Upadhyaya, A. Desai, R. Patel, U. Patel, K. P. Kaur, and K. Pandya, "Compact transparent conductive oxide based dual band antenna for wireless applications," in *2017 Progress in Electromagnetics Research Symposium-Fall (PIERS-FALL)*. IEEE, 2017, pp. 41–45.

[31] V. P. Kodgirwar, S. Deosarkar, and K. Joshi, "Design of adaptive array with e-shape slot radiator for smart antenna system," *Progress In Electromagnetics Research M*, vol. 90, pp. 137–146, 2020.

[32] A. Vahora and K. Pandya, "Implementation of cylindrical dielectric resonator antenna array for wi-fi/wireless lan/satellite applications," *Progress In Electromagnetics Research M*, vol. 90, pp. 157–166, 2020.

[33] K. Pandya, T. Upadhyaya, U. Patel, R. Pandey, and A. Pandya, "Dielectric resonator antenna array development for gsm 1800/wlan/radar/direct broadcast satellite applications," *Radar/Direct Broadcast Satellite Applications (July 12, 2021)*, 2021.

[34] P. R. Pimpalgaonkar, T. K. Upadhyaya, K. Pandya, M. R. Chaurasia, and B. T. Raval, "A review on dielectric resonator antenna," in *1ST International Conference on Automation in industries (ICAI)*, 2016, pp. 106–109.

[35] P. R. Pimpalgaonkar, M. R. Chaurasia, B. T. Raval, T. K. Upadhyaya, and K. Pandya, "Design of rectangular and hemispherical dielectric resonator antenna," in *2016 International Conference on Communication and Signal Processing (ICCSP)*. IEEE, 2016, pp. 1430–1433.

[36] A. K. Roy and S. Basu, "Broadband, high gain, narrow width rectangular dielectric resonator antenna with air gap," *Journal of Electronic Science and Technology*, vol. 17, no. 1, pp. 90–96, 2019.

[37] N. M. Nor, M. H. Jamaluddin, M. R. Kamarudin, and M. Khalily, "Rectangular dielectric resonator antenna array for 28 ghz applications," *Progress In Electromagnetics Research C*, vol. 63, pp. 53–61, 2016.

Dr. Killol V. Pandya Dr. Killol V. Pandya is working as an Associate Professor at Electronics Communication Engineering Department, Chandubhai S Patel Institute of Technology, Charotar University of Science Technology (CHARUSAT), Changa. He did his Bachelor of Engineering from Gujarat University in 2006, Masters of Engineering from Charotar University of Science and Technology in 2010 and Ph.D. from Charotar University of Science and Technology on Liquid Based Electronic Circuits in 2017. His area of interest is development of DRAs, patch antennas and metamaterial based antennas. He has carried out research and consultancy projects from Gujarat Council on Science and Technology (GUJCOST) and private organizations. He has published presented several research articles in his area of research in India and abroad he has delivered invited talk at various organizations across Gujarat.

Jeenal Barot Jeenal Barot has received her B. Tech. degree from Kalol Institute of Technology and Research Centre in 2017. Jeenal Barot is has received her M. Tech. degree from Charotar University of Science and Technology in July 2021.

Dr. Trushit Upadhyaya Dr. Trushit Upadhyaya is working as a Professor and Head of Department at Electronics Communication Engineering, Charotar University of Science Technology (CHARUSAT), Changa. He did his Bachelors of Engineering from Gujarat University in 2004 and Masters of Engineering from Institute of Telecommunication Research, University of South Australia, Adelaide in 2007 and Ph.D. from Charotar University of Science and Technology (CHARUSAT) specializing in Satellite Communication Antennas in 2014. He was Visiting Scientist at Physical Research Laboratory (PRL), Ahmedabad during January–June 2020. Dr. Trushit Upadhyaya was awarded Young Scientist Travel Grant by Department of Science and Technology in 2017. He has carried out research consultancy projects for Indian Space Research Organization (ISRO), Australian defence agency (DSTO), Gujarat Council on Science and Technology (GUJCOST), System Level Solutions, and other Private Consultants. He has published presented 70+ research papers in his area of research.

Dr. Upesh Patel Dr. Upesh Patel is working as Assistant Professor in V.T. Patel Department of Electronics Communication Engineering of C S Patel Institute of Technology, Faculty of Technology Engineering. He has more than 10 years of experience in academics. He is involved in teaching at UG, PG level. His areas of interest for research include commercial antenna design, RF microwave engineering, Digital Signal Processing. He has published several research papers in international journals and conferences. He is member of IEEE Antenna and Wave Propagation Society and Indian Society of Technical Education.

Rajat Pandey Rajat Girjashankar Pandey is pursuing his doctoral research in dielectric resonator antennas from Charotar University of Science and Technology (CHARUSAT), Changa. He completed his M.Tech in communication systems from the University of Kerala in 2014 and his Bachelors of Engineering from Gujarat Technological University in 2012. He is presently working as Assistant Professor in Electronics Communication Engineering Department, Faculty of Technology Engineering, Charotar University of Science Technology, Changa. His research interests are the design and optimization of antennas and microwave devices.

Aneri Pandya Aneri K. Pandya is working as an Assistant Professor at Electronics Communication Engineering Department, Alpha college of Engineering and Technology, Ahmedabad, Gujarat, India. She did his Bachelor of Engineering from M. S. University in 2008, Masters of Engineering from M. S. University in 2012 and She