A Compact Planar Microstrip Patch Antenna in Commercial Ultra-Wideband Spectrum

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***Abstract*—A compact microstrip patch antenna of size 35mm×30mm×0.8mm is projected here. The radiator looks like Pillow which attained broad aperture and cover wide spectrum from 3 to 14.26GHz (130.5%). The antenna offers omnidirectional radiation patterns with stable gain variation and high radiation efficiency in the covered spectrum. The antenna is suitable for many ultra-wideband wireless technologies, especially for indoor communication.**

Keywords—Ultra-wideband (UWB) antenna, Radiation efficiency, antenna gain, omnidirectional pattern, indoor communication.

I. Introduction

Ultra-wideband (UWB) antennas are designed to operate over a very wide frequency range, typically spanning several Giga-hertz (GHz) of bandwidth. The UWB technology is characterized by transmitting and receiving signals with very short pulses or bursts that cover a wide frequency band. FCC has certified the frequency span from 3.1 to 10.6 GHz as the commercial ultra-wideband (UWB) spectrum in 2002 [1]. In comparison with traditional narrow band antennas the UWB antennas provide high data rates, improved spectrum efficiency, enhanced accuracy and precision, lower interference, resilience to multipath fading, privacy and security, simplified regulatory compliance, versatile applications, robustness in harsh environments and low power consumption. In [2], the authors had presented a compact UWB antenna featuring slots, which exhibits dual-band notched characteristics intended to mitigate interference from WiMAX and WLAN. The design under consideration involves a rectangular radiating patch that has been modified and includes a bevelled region near the 50-ohm feed. This antenna under consideration is well-suited for UWB applications, effectively covering a frequency range spanning from 3.1 GHz to 10.6 GHz . The UWB having a high gain and achieving a well-defined directional beam-width across a broad frequency spectrum are crucial attributes for radar applications. In [3], a planar patch array antenna had been developed, comprising twenty rectangular patch antenna elements optimized for Ultra-Wideband (UWB) characteristics, specifically designed for use in a weather radar application. In [4], the author had introduced an economically efficient and compact antenna solution for UWB applications of communication over limited distances. This antenna design minimizes interference, allowing for effective multiband operation and covers wide spectrum from 3.1GHz to 10.6GHz. A compact antenna designed for ultra-wideband (UWB) applications, featuring a dual-band notch has been designed in [5]. The proposed antenna functions within the frequencies ranging from 3.1 GHz to 12 GHz while maintaining a VSWR below 2. Notably, there are frequency notches present between 4.7 GHz to 6.8 GHz and 8.3 GHz to 9.6 GHz [5]. A planar UWB monopole antenna that exhibits omnidirectional characteristics was presented in [6]. The antenna design comprises a rectangular radiator with the incorporation of two triangular and one circular sector slots. These slots play a significant role in achieving a wideband impedance match. The experimental results showcase an impedance bandwidth spanning from 3.4 GHz to 9 GHz, wherein the magnitude of S11 is maintained at or below -10dB. In [7], a microstrip patch antenna with a rectangular shape had been developed for applications in cognitive radio systems. This antenna design incorporated a unique feature wherein its frequency tuning can be modified. By employing six switches that are interconnected with the antenna's feed line, the operational frequency range of the antenna can be dynamically adjusted. This innovative configuration enables the antenna to effectively cover encompassing frequencies from 3.14 GHz to 10.6 GHz. The particle swarm optimization technique was employed to fine-tune the parameters of the multi-band MIMO antenna under consideration [7]. In [8], a concise overview of the impact of antenna radiation properties on the modelling of on-body channels in the context of ultra-wideband (UWB) communication was studied. The concept is illustrated through a variety of experimental setups and scenarios. Antennas operating within 3GHz to 10 GHz frequency range are utilized as test antenna in two distinct illustrative examples. These case studies are employed to establish an On-body Channel model, which is subsequently verified through practical experimentation. A novel design approach for UWB antennas intended for True Wireless Stereo (TWS) earphones was introduced covering impedance band from 6.2GHz to 9.7GHz [9]. In [10], a concise design of a compact CPW fed printed monopole antenna, featuring dimensions of 36×22×0.8 mm³, had been developed and analyzed specifically for utilization in Ultra-wide band (UWB) communication applications enabling an extensive impedance bandwidth spanning 3 to 12.4 GHz. To achieve broadband properties, a dual resonance is established using two shorting components. In [11], the author presents and examines the design and analysis of a dipole antenna for UWB wireless utilizations. To improve the electrical impedance matching, the antenna was constructed using a dual circular patch dipole configuration. This configuration was accompanied by a feed point equipped with a balun featuring linear tapering, ensuring compact size. The proposed antenna operates in 4.2-6.6GHz. The particle swarm optimization technique was employed to fine-tune the parameters of the multi-band MIMO antenna under consideration. The optimization process aimed to attain a specific functional objective, which involved achieving Ultra-Wideband (UWB) performance within the range of frequencies 3.1 GHz to 10.6 GHz [12]. In [13], the researchers had put forth an innovative design for a MIMO (multiple-input multiple-output) antenna system featuring four elements and operating across an ultra-wideband (UWB) spectrum. A quasi-circular pattern with slots has been strategically positioned in front of the antenna's patch in the designed configuration. This placement aims to mitigate the effects of mutual coupling between elements. The proposed MIMO antenna functions at an operational frequency of 6.18 GHz, offering a bandwidth spanning 4.79 GHz (ranging from 4.93 GHz to 9.72 GHz). The researchers in [14] had proposed setup involving two patch antennas located 180 degrees apart from each other. The core objective of this project is to augment the antenna's gain while maintaining the original bandwidth unaffected. The examined antenna spans the Ultra-Wideband (UWB) spectrum, attaining diverse ranges across its narrow bands. Numerous instances of this concept can be found in previous literature, where the proposal of UWB antennas for harnessing the broad unlicensed bandwidth is discussed in [2-8, 15-17]. In this proposed work we have designed a UWB antenna providing broad impedance ranging from 3GHz-14.26GHz, covering commercial UWB and X-band spectrums.

II. Antenna Design

The proposed antenna was evolved from conventional narrowband square patch antenna as proposed in [18]. The sharp edges and irregularities in such patch configuration exhibit spurious radiation from corners. To avoid the same, bended corners are introduced in the antenna geometry. Fig. 1 is giving the planned conformation of the Pillow shaped antenna. Co-planar wave guide (CPW) fed makes the design simple and uni-planar. Additional resonances are accomplished as circular peripheral attained at the lower end of patch, close to feed gap along with bended ground plane in other side. Bendings at the edges is achieved by cutting two arcs of radius R2 in the top side of the radiator and two arcs of radius R3 in the bottom side of the radiator. The radiator length is almost half of the substrate length. Such geometry resembles the Vivaldi like structure. Being electrically small antenna, the ground plane also contributes in radiation and this modified geometry helps to attain higher modes to get spectrum enhancement. The projected parameter values of the Pillow shaped antenna is mentioned in Table.1. The final structure is fabricated on affordable FR4 substrate which is having breadth 0.8 mm, dielectric constant 4.4 and loss tangent of 0.018 (Fig. 2). The prototype is shown in Fig. 2.

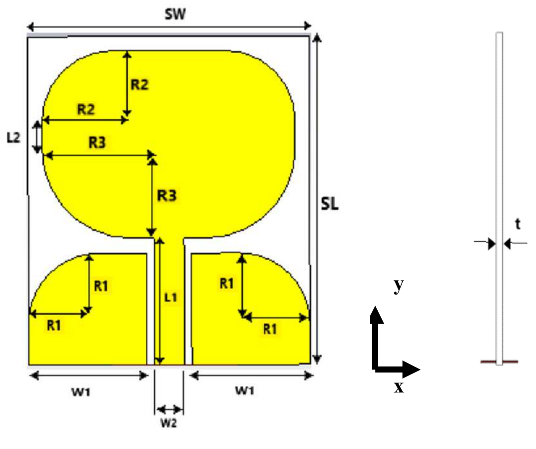

Fig. 1. Schematic of proposed antenna geometry.

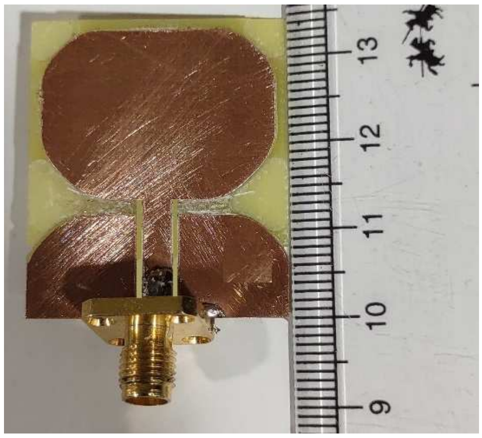

Fig. 2. Fabricated Antenna Prototype.

TABLE I. Antenna Geometrical dimensions

All dimensions are in mm			
Parameter	***Value***	***Parameter***	***Value***
SL	35	W1	12.6
SW	30	W2	3.2
L1	13.50	R1	7.5
L2	3	R2	7.5
t	0.8	R3	9.5

III. Results and Discussion

The reflection coefficient (S_{11}) results by simulation and measurement is exhibited in Fig. 3. S_{11} parameter shows excellent impedance matching across the frequency range of 3GHz to 14.26 GHz (130.5%) with resonating frequencies at 3.83 GHz, 5.7 GHz, and 11.9 GHz. Good understanding between simulated and measured plots are observed. An additional -10dB impedance bandwidth up to 0.8GHz with resonating frequency at 0.5GHz is obtained.

The antenna's simulated gain exhibits a range from 2 dBi to 4.85 dBi throughout the desired frequency spectrum. At the resonant frequency of 11.4 GHz, the peak gain reaches to 4.85 dBi. Fig. 4 illustrates the radiation efficiency of the proposed UWB antenna across its entire frequency range. The efficiency is seen to be consistently high, ranging from 85% to 90%. This indicates that the majority of the input power is effectively radiated as electromagnetic waves, validating the antenna's effectiveness in delivering energy to the surrounding space.

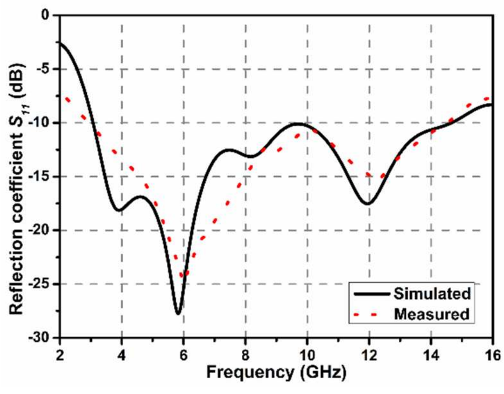

Fig. 3. Reflection coefficient vs frequency.

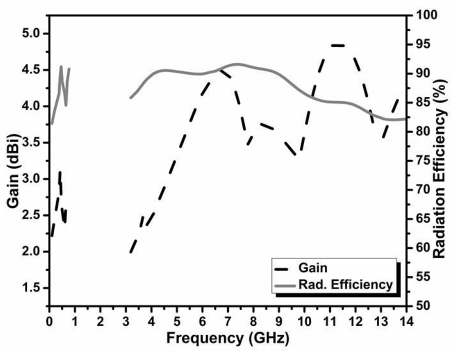

Fig. 4. Antenna Gain and Radiation Efficiency over bandwidth.

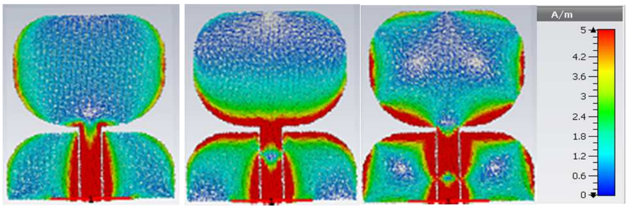

Fig. 5. Simulated surface current at 3.83GHz, 5.7GHz and 11.9GHz.

The dispersal of external currecnt on radiator, feed and ground plane at resonances of UWB is visualized in Fig. 5. Conception of further quantity of half cycles at advanced frequencies imply the attainment of UWB. The E-plane radiation pattern represents the antenna's radiation in the plane containing the electric field vector. The H-plane radiation pattern showcases the antenna's radiation behavior in the plane perpendicular to the electric field vector. Antenna radiation patterns in E and H-planes are plotted in Fig. 6 for frequencies of 0.7GHz, 3.83GHz, 4.5GHz, 5.67GHz and 8.5GHz. The antenna E-plane gives equal radiation in both forward and backward directions. The attained H-plane patterns are having equal radiation along complete 360 degree. However, the antenna pattern becomes imperfect beyond 8.5GHz as the choice of substrate is FR-4 which is high lossy in nature.

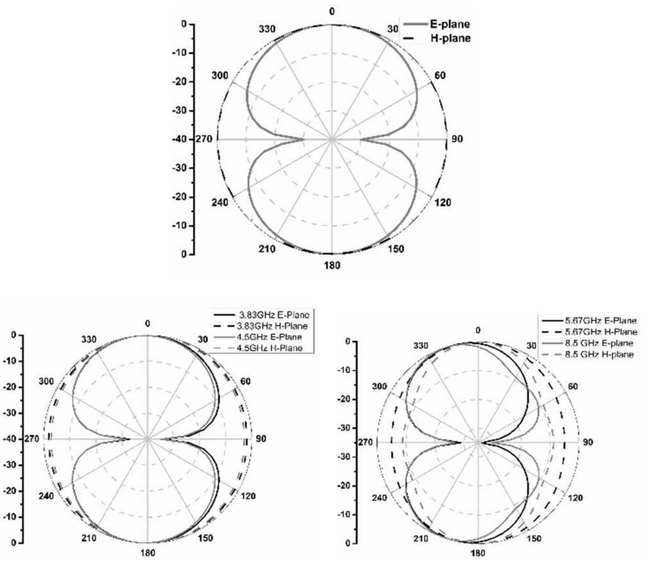

Fig. 6. Antenna radiation patterns at 0.7GHz, 3.83GHz, 4.5GHz, 5.67GHz and 8.5GHz.

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TABLE II. PROPOSED ANTENNA VS. SIMILAR WIDEBAND ANTENNAS

Ref. No./ Year	Size (mm^3)	Frequency Bands (GHz)	Peak Gain (dBi)	Rad. Eff. (%)	Remarks
2016/ 2	22×25×1.6	3.3 to 8.7	8	NA	Lower spectrum coverage
2016/ 3	162×100×1.58	3.5 to 9	NA	NA	Lower spectrum coverage, Bulky
2017/ 4	55.9×39×2.4	3.6 to 9	-15	80%	Lower spectrum coverage, Bulky
2017/ 5	32×32×1.6	3.1 to 9.6	-15.9	NA	Lower spectrum & Poor Gain
2018/ 6	40×40×1.52	3.4 to 9	-10	NA	Poor Gain
2019/ 7	40×40×1.6	3.14 to 10.6	≥10	NA	Lower spectrum coverage
2020/ 10	50×60,35×45	3 to 10	2 to 5	NA	Lower spectrum coverage, Bulky
2021/ 11	17×9×6	6.2 to 9.7	4	88%	Lower Band & gain
2022/ 13	38×46×1.6	4.2 to 6.6	3.5	80%	Lower Band & gain, Bulky
2022/ 14	40×20×0.4	2.45 to 5.8	4	80%	Lower Band & gain
2023/ 15	18×6.6×1.524	3.6 to 6.11	≥3	NA	Lower spectrum coverage.
Proposed Antenna	35×30×0.8	3 to 14.26 (130.5%)	5.6	95%	Better Spectrum coverage, good gain and rad. efficiency

IV. Conclusion

In conclusion, this research showcases the successful development of an ultra-wideband antenna that holds considerable potential in meeting the demands of modern communication systems. The insights gained from this study contribute to the broader field of antenna design and signal propagation, propelling us closer to realizing the full potential of ultra-wideband technology in an increasingly interconnected world. In Table 2, this recently introduced UWB antenna showcases a notably broader frequency coverage, spanning from 3 to 14.26 GHz, in contrast to established antennas which usually encompass a comparatively narrower range. Concerning their physical dimensions, the novel UWB antennas feature a sleeker design compared to traditional alternatives, all while maintaining comparable performance levels. More than 130% spectrum utilization covering the commercial UWB added with good gain and radiation efficiency across the spectrum identify the antenna for various UWB technologies. The additional spectrum is also usable for 0.5GHz ISM band applications.

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References

[1] Federal Communication, "Revision of Part 15 of the commission's rules regarding ultra-wideband transmission systems," First Report and Order, FCC 02, V48, April 2020.

[2] A. Saxena and R. P. S. Gangwar, "A compact UWB antenna with dual band-notched at WiMAX and WLAN for UWB applications," 2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT), Chennai, India, 2016, pp. 4381-4386, doi: 10.1109/ICEEOT.2016.7755546.

[3] A. Slimani, S. D. Bennani, A. El Alami and H. Harkat, "Conception and optimization of a bidirectional ultra wide band planar array antennas for C-Band weather radar applications," *2016 International*

Conference on Information Technology for Organizations Development (IT4OD), Fez, Morocco, 2016, pp. 1-7, doi: 10.1109/IT4OD.2016.7479269.

[4] R. S. Sherke, P. C. Kamble and L. K. Ragha, "A compact ultra wide band antenna using slots for Internet of Things applications," 2017 Fourteenth International Conference on Wireless and Optical Communications Networks (WOCN), Mumbai, India, 2017, pp. 1-4, doi: 10.1109/WOCN.2017.8065857.

[5] P. Meena and A. Garg, "A design of compact ultra-wide band antenna with dual band notched characteristics," 2017 International Conference on Information, Communication, Instrumentation and Control (ICICIC), Indore, India, 2017, pp. 1-5, doi: 10.1109/ICOMICON.2017.8279091.

[6] M. N. Hasan and M. Seo, "A Planar 3.4 -9 GHz UWB Monopole Antenna," 2018 International Symposium on Antennas and Propagation (ISAP), Busan, Korea (South), 2018, pp. 1-2.

[7] R. M. C. Cleetus and G. J. Bala, "Design and Analysis of a Frequency Reconfigurable Antenna for Ultra wide band and Cognitive Radio Applications," *2019 2nd International Conference on Signal Processing and Communication (ICSPC)*, Coimbatore, India, 2019, pp. 1-4, doi: 10.1109/ICSPC46172.2019.8976633.

[8] D. Ganguly, D. Sarkar, Y. M. M. Antar, E. George and C. Saha, "Experimental UWB ON-Body Channel Modelling: Effect on Antenna Transmission Characteristics," 2020 IEEE International Symposium on Antennas and Propagation and North American Radio Science Meeting, Montreal, QC, Canada, 2020, pp. 1839-1840, doi: 10.1109/IEEECONF35879.2020.9330285.

[9] T. H. Woo, Y. J. Yoon and H. Kim, "Ultra Wide Band Antenna for True Wireless Stereo Earphones," 2021 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI), Singapore, Singapore, 2021, pp. 733-734, doi: 10.1109/APS/URSI47566.2021.9704483.

[10] S. Kundu and S. Kundu, "A Compact U-Shaped Antenna with Bandwidth Enhancement for Ultra- Wideband Communication," 2021 2nd International Conference on Range Technology (ICORT), Chandipur, Balasore, India, 2021, pp. 1-4, doi: 10.1109/ICORT52730.2021.9581344.

[11] K. B. Suleiman, A. A. Albishti and S. A. Hamzah, "Design and Analysis of Dipole Ultra Wide Band Antenna for Wireless Applications," *2022 IEEE 2nd International Maghreb Meeting of the Conference on Sciences and Techniques of Automatic Control and Computer Engineering (MI-STA)*, Sabratha, Libya, 2022, pp. 427-430, doi: 10.1109/MI-STA54861.2022.9837683.

[12] S. Salma, H. Khan, B. T. P. Madhav, V. V. Sai Varun, A. K. Priyatham and D. R. Sandeep, "Particle Swarm Optimization of a Multi-band MIMO Antenna for Ultra-Wide Band characteristics," *2022 First International Conference on Electrical, Electronics, Information and Communication Technologies (ICEEICT)*, Trichy, India, 2022, pp. 01-04, doi: 10.1109/ICEEICT53079.2022.9768597.

[13] H. M. Naser, O. A. Al-Ani and M. F. Mosleh, "Design Wideband MIMO Antenna for UWB Applications," 2023 IEEE Jordan International Joint Conference on Electrical Engineering and Information Technology (JEEIT), Amman, Jordan, 2023, pp. 264-269, doi: 10.1109/JEEIT58638.2023.10185720.

[14] A. Hindi, E. Trrad and M. Dwairi, "A Compact 2 × 1 MIMO Microstrip Patch Antenna with Enhanced Gain for UWB Applications," *2023 IEEE Jordan International Joint Conference on Electrical Engineering and Information Technology (JEEIT)*, Amman, Jordan, 2023, pp. 255-258, doi: 10.1109/JEEIT58638.2023.10185806.

[15] S. Kundu, "An ultra-wideband dual frequency notched circular monopole antenna for ground penetrating radar application." In *2019 URSI Asia-Pacific Radio Science Conference (AP-RASC)*, pp. 1-4. IEEE, 2019. doi: 10.23919/URSIAP-RASC.2019.8738452

[16] S. Kundu, "Gain Augmentation of a Triple Notched Ultra-wideband Antenna using Compact Uniplanar Frequency Selective Surface for Ground Penetrating Radar." *IETE Journal of Research,* vol. 69, no. 2, pp. 813-824, 2023. doi:10.1080/03772063.2020.1838348

[17] D. Pandey, V. Sharma, and S. Kundu. "CPW fed Heart shaped Antenna for Ultra-Wide Band Applications." In *2023 3rd International Conference on Range Technology (ICORT)*, pp. 1-4. IEEE, 2023. doi: 10.1109/ICORT56052.2023.10249142

[18] S. Y. Pachigolla, V. Dab, A. Chatterjee, and S. Kundu, "A compact rectangular microstrip patch antenna for 2.4 GHZ ISM band applications." In *2018 IEEE Indian conference on antennas and propogation (InCAP)*, IEEE, 2018, pp. 1-3.