A Novel Three-Cut Circle Tri-Band Flexible Antenna for Wireless Application

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Abstract - *Due to their smart features of low profile, small size, ease to use, flexible, affordable, and portable wearable antenna have gained a lot of interest in recent years .when applied to various body parts of a human such antennas must conform, hence they must be implemented with flexible materials, a low profile design.*

*A Novel three-cut circle tri-band flexible antenna for wireless application is designed to be simulated in CST software to achieve a body area network for three bands of frequencies with better bandwidth operating at 3 resonant frequencies 3.892 GHz, 5.477 GHz, and 11.296 GHz. Material of substrate of the antenna is denim jeans with a dielectric constant of 1.7 and a conductive element such as copper tape. The board size is 43*43mm2. The bandwidths for the proposed design are 34.4% 12.05% 39.05% for a frequency spectrum of 3.2677 GHz to 12.12 GHz which is considered to be the optimal bandwidths for the antenna. The presented tri-band antenna can be used in wearable devices in wireless body area networks (WBANs).*

Key Words: **CST software, rectangular ground, wearable antenna, wireless application, planar micro-strip antenna.**

1. INTRODUCTION

In recent years, wireless body area networks have been widely deployed in a variety of industries, including the military, business, entertainment, and health [1, 2]. The wearable antenna, a crucial component of WBANs, is typically worn on the body, applied to clothes, a helmet, or the wrist, for instance [3-5].The high dielectric constants and imperfections that are present in human tissues often have a negative influence on wearable antenna performance. Similar to how wearable antennas affect the human body, they must adhere to established safety regulations and are typically assessed in terms of SAR values.

Recently, meta-material (MTM) structures have proven to be successful at lowering antenna radiation, SAR values to the human body. Examples include artificial magnetic conductor (AMC) structures [6, 7], EBG structures [8, 9], and meta-material surface (MS) surfaces [10]. Reference [10] provides an antenna with an MS structure, whereas sources [6, 7], [8, 9], and [10] address wearable antennas with single-band AMC structures and dual-band EBG structures, respectively. Yet, these meta-material constructions don't employ several operating frequency ranges. As wireless body area networks advance, functional requirements for wearable electronics rise. Multi-band antennas have more compact construction than combinations of single-band antennas, and these requirements can be satisfied. Several wearable dual-band antennas have been developed as of late [8, 9, 11, and 12]. In reference [11], a dual-band wearable antenna without loading meta-materials was proposed.

The references [8, 9, and 12] provide a range of dual-band wearable antennas with meta-material constructions. There have also been some suggestions for multi-band and triple-band wearable antennas [13–18], which would increase the number of bands even more. Yet, the safety for the human body has not been determined. A triple-band antenna with a Hilbert-shaped array for the radiating layer and a periodic square groove on the ground was depicted in reference [13]. For off-body communication, a tiny, low-profile button antenna with operating frequency bands of 0.867, 2.38, and 5.85 GHz was included [14]. For wearable WiMAX, military, and ISM applications, a triple-band open-ring antenna was proposed in [15]. A tri-band dual-polarized multiple-input multiple-output belt-strap antenna for the intelligent Internet of Medical Things was achieved in [16].

In [17], a wearable multi-band CPW-fed slot dipole antenna for WBAN applications was also incorporated. This antenna supports 2.4/5.2/5.8 GHz WLAN, 3.5 GHz WiMAX, and 4.4 GHz C-bands. Using a slotted radiator and a 7 by 7 array of periodic square patches, Reference [18] developed a hepta-band antenna. By employing an inductive ground plane, this antenna's SAR value is reduced. As can be seen, most recent research on wearable antennas using meta-material structures focuses on constructing single-band or dual-band antennas, with triple-band or multi-band antennas being utilised far less frequently. The use of multiband or triple-band meta-material structures hasn't improved the performance of wearable antennas either.

A Novel three-cut circle tri-band flexible antenna for wireless application is designed and simulated in CST software to achieve a body area network for three bands of frequencies with better bandwidth operating at three resonant frequencies 3.892 GHz, 5.477 GHz, and 11.296 GHz. The material used for the substrate of the antenna is denim jeans with a dielectric constant of 1.7 and a conductive element such as copper tape. The board size is 43*43mm2. The bandwidths for the proposed design are 34.4% 12.05% 39.05% for a frequency range of 3.2677 GHz to 12.12 GHz which is considered to be the optimal bandwidths for the antenna. The proposed triple-band antenna can be used in wearable devices in wireless body area networks (WBANs).

2. Wearable Antenna

Antennas that may be worn are known as wearables. Wearable antennas are frequently used in biomedical RF systems and wearable wireless communication. They are also utilised in wireless body area networks. An antenna is a crucial part of a WBAN that facilitates wireless communication, which includes off-body, on-body, and in-body communication. Wearable antennas can be used in various sectors including health monitoring, entertainment, business, security defense military applications, and various other fields. The antenna is one of the most important components of wearable technology since it improves the overall effectiveness of a wearable wireless system. Wearables have numerous applications in everyday life. In addition to wristwatches, fitness bands, and augmented reality glasses, they feature a variety of medical uses. In the healthcare industry, wearable technology is used to monitor patients' crucial health conditions. A glucose monitoring system for assessing the patient's blood sugar levels, a capsule endoscope to investigate the gastrointestinal tract, a thermometer to check the body's temperature, blood pressure, and heart rate, and a glucose monitoring system are also included.Examples of these include touchscreen smartwatches and augmented reality eyewear. A visual representation of numerous wearables utilized in the entertainment industry is shown in Fig.1.

Fig -1: Different types of wearables used by humans for health tracking and leisure purpose are shown in the figure.

In addition, rescue and emergency response systems can include wearable technology in helmets, shoes, raincoats, and jackets.

Table -1: *Various wearable devices application.*

Field	Applications
Medical Care	Endoscopy, oximetry, wearable thermometers, GPS trackers, breast cancer detection devices, and glucose monitoring.
Entertainment	Smart shoes, radio jackets, LED outfits, and trackers.
Safety&Rescue	Life jackets, tracker, fitness trackers, e-shoes, raincoats, and protective gear.

The word refers to the two principal applications of wearable antennas: communication and position detection. Wearable antennas require increased bandwidth to function properly and to be widely adopted.

3. Simulation of A Novel Three Cut Circle Tri-Band Flexible Antenna

3.1 *Planar Antenna*

- To simulate antennas, tri-cut circle designs have been proposed to improve bandwidth and gain. Fig. (5) Shows a new tri-cut circle-shaped portable antenna operating at resonant frequencies of 3.892 GHz, 5.477 GHz, and 11.296 GHz. A 43 x 43mm rectangular antenna board is used. A patch is created on the substrate in the shape of a tri-cut circle, with a 21 mm x-axis length and a 22mm y-axis length.

- The main shape of the patch design is having a radius of 12mm with coordinates (0, 6) having a thickness of 0.038mm.
- The Strip line has breadth at the x-axis (-1, 1) mm and height from y-axis coordinates (6,-21) with a thickness of 0.038mm of material PEC.
- Three shapes are cut from the design with segment value 30 with 2 shapes having coordinates as 1st shape (-7,12) 2nd shape (7,12) both having a radius of 4.5mm and the 3rd shape having a radius of 4mm having coordinates (0, -1.5) with all the shapes having same thickness of 0.038mm.

All of the essential parameters are given in table.2.

Table -2: *Shows simulated parameters for the proposed antenna.*

S.NO	SIMULATED PARAMETERS	PREVIOUS WORK VALUES	PROPOSED WORK VALUES
1.	Dielectric permittivity (εr)	1.7	1.7
2.	Length (L)for stripline	22.5mm	27mm
3.	Breadth (B)for stripline	2mm	2mm
4.	Ground (Lg X Bg) [mm]	61 X 35.68	43X27.5mm
5.	Resonant Frequency	3.224 GHz	3.892GHz,5.477GHz,11.296GHz
6.	Substrate Thickness [mm]	1mm	1mm
7.	Substrate Dimensions [mm]	61X51	43X43
8.	The thickness of ground [mm]	0.0038	0.0038

3.2 *Dielectric constant*

Jeans: This textile was chosen since it is wearable, washable, inexpensive, and does not require maintaining.

Epsilon r =1.7 for Jeans.

4. Proposed Design Structure

The proposed antenna's front and back sides are shown in figures 2 and 3.

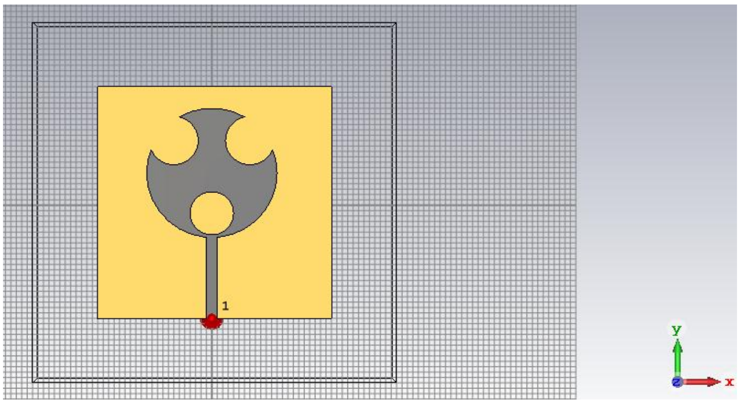


Fig-2. Image of a proposed antenna from the front.

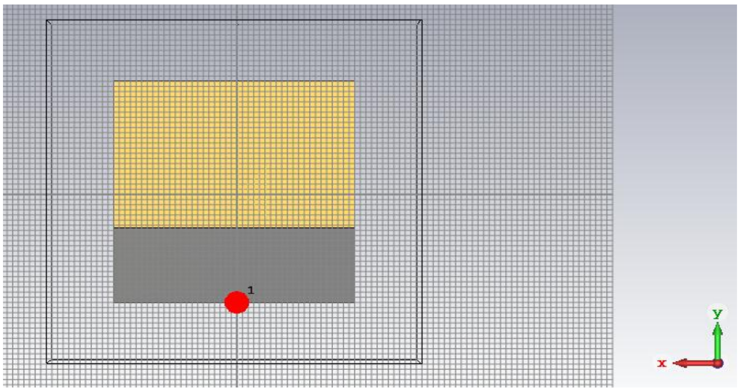


Fig-3. Image of a proposed antenna from the back.

5. Radiation Pattern

Figure 4 depicts the radiation pattern of the polar plot for resonant frequencies of 3.892GHz, 5.477GHz, and 11.296GHz for the proposed textile microstrip antenna. Figure 5 depicts the two-dimensional Cartesian radiation pattern at 3.892GHz, 5.477GHz, and 11.296GHz. Figures 6 and 7 depict the two-dimensional and three-dimensional radiation patterns at resonant frequencies 3.892GHz, 5.477GHz, and 11.296GHz are the frequencies. The radiation pattern indicates the major lobe's orientation = 177.0 degrees, 150.0 degrees, and 11.0 degrees. An angular width (3dB) of 75.6 degrees, 51.0 degrees, and 47.4 degrees, with a major lobe magnitude of 2.97 dBi at a resonant frequency of 3.892 GHz, 4 dBi at a resonant frequency of 5.477GHz, and 4.27 dBi at a resonant frequency of 11.296GHz. With a radiation efficiency of almost 0.002393dB for 3.892GHz, 0.02781dB for 5.477GHz, and 0.0007258dB for 11.296 GHz, directivity is 2.962dBi, 4.759dBi, and 4.710dBi.

The term "radiation" refers to both the emission or absorption of a wavefront at an antenna and the intensity of the wavefront. The radiation pattern of an antenna is shown by the contour used to depict its radiation in each figure. The radiation pattern might help you understand antenna operation and directivity. The power generated by the antenna affects both the near and distant fields.

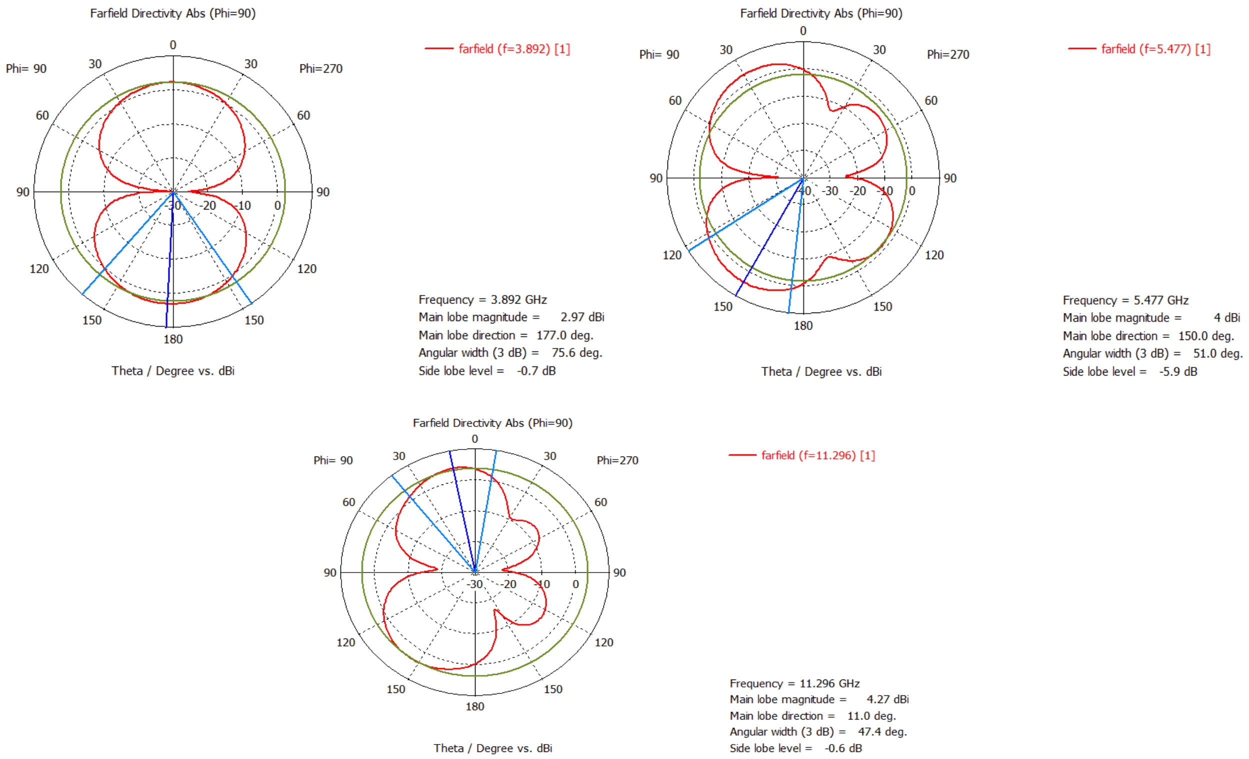


Fig-4. Polar plot radiation pattern at 3.892GHz, 5.477GHz, and 11.296GHz resonant frequencies.

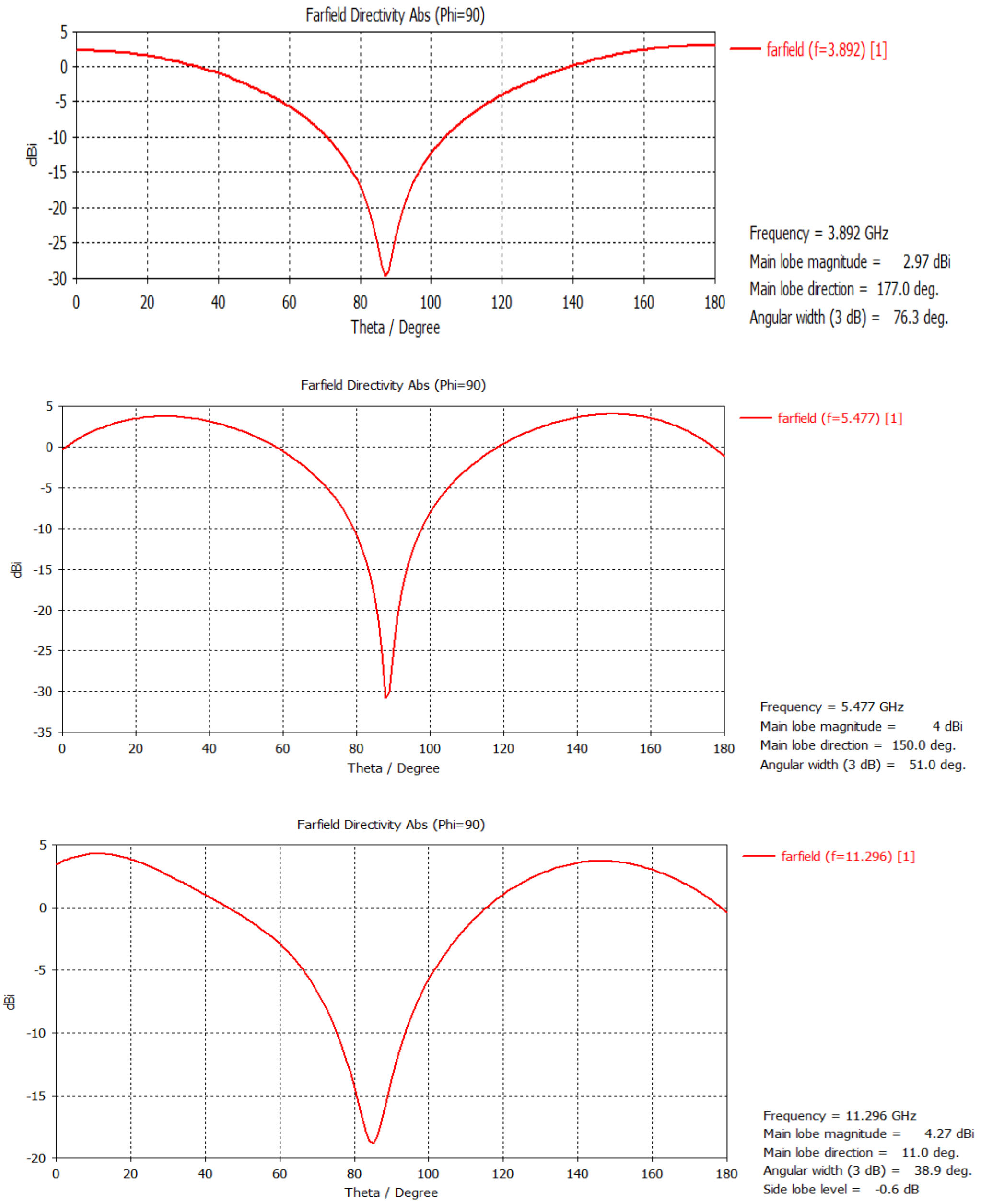
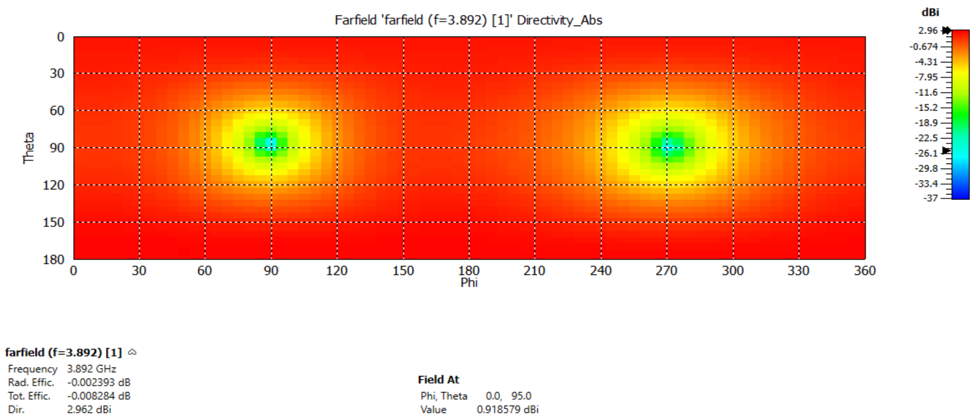


Fig-5. 2D Cartesian radiation pattern for 3.892GHz, 5.477GHz, and 11.296 GHz resonant frequencies.



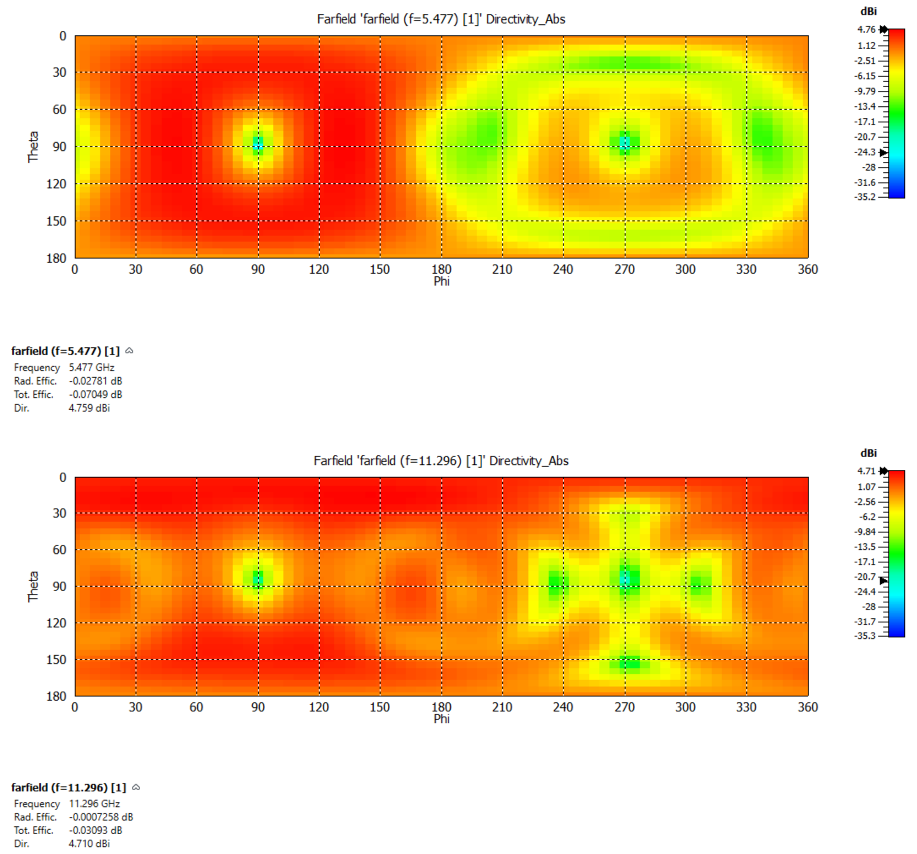
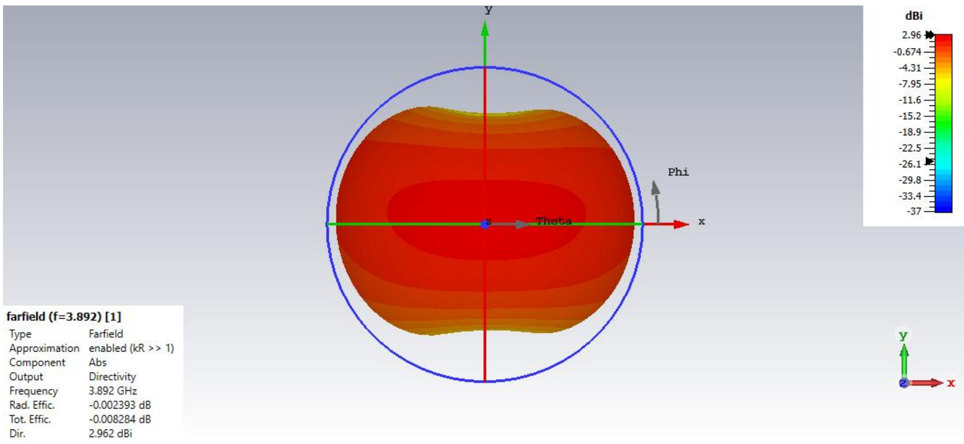
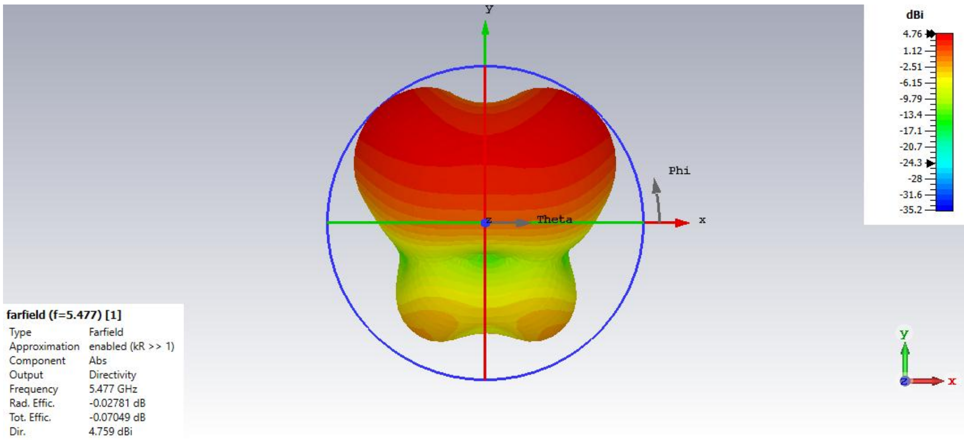


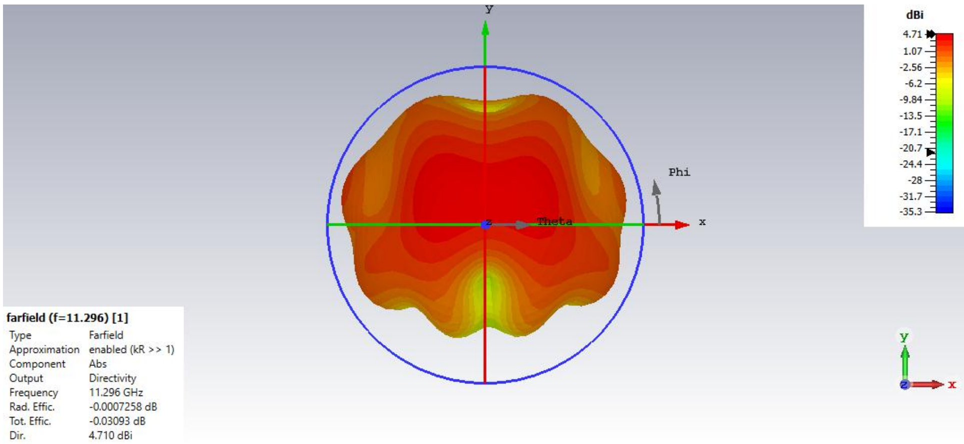
Fig-6. 2D Radiation pattern for 3.892GHz, 5.477GHz, and 11.296 GHz resonant frequencies.



(a) 3.892GHz



(b) 5.477GHz



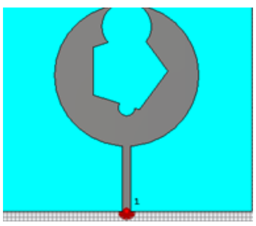
(c) 11.296GHz

Fig-7. 3D radiation pattern for 3.892GHz, 5.477GHz, and 11.296 GHz resonant frequencies.

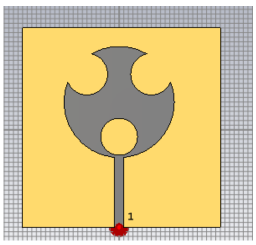
6. Results and Discussion

The first design works only on a single resonant frequency of 3.224 GHz and is suitable only for single-band applications. while the second design works on three bands of frequency for 3.892GHz, 5.477GHz, and 11.296 GHz resonant frequencies hence suitable for multiband applications.

Multiband and triple frequencies make the second design preferable over the first design.



First design.



Second design.

The second design is chosen over the first design because it has a multiband application and is having multiple frequencies of various uses such as IoT, satellite communication, and 5G.

The formula used for the calculation of bandwidth is given in Eq.1. where, F1 = 2.6 GHz and F2 = 12.2 GHz.

Bandwidth = (F2-F1/ {(F1+F2)/2}) (1)

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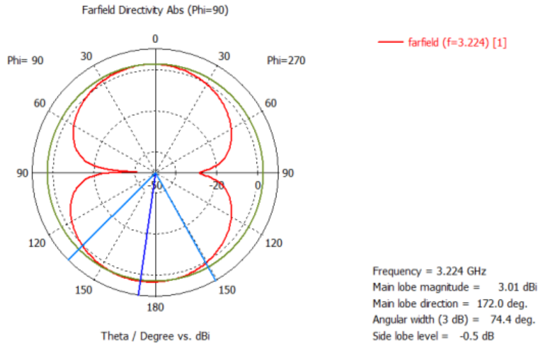
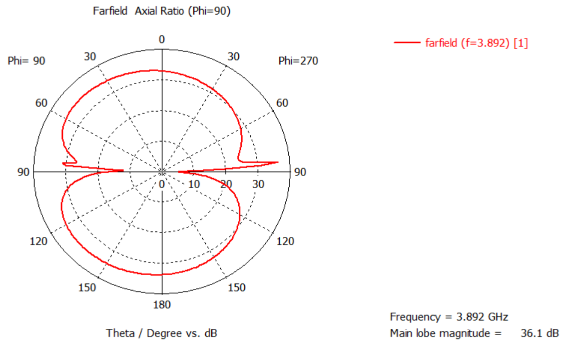
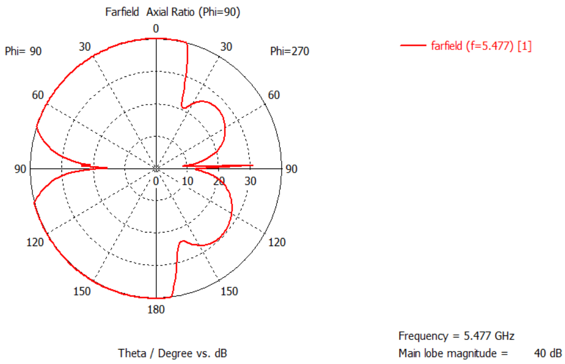


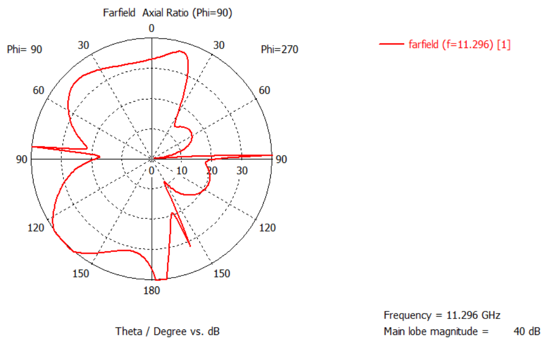
(a) Axial ratio for 3.224 GHz resonant frequency for first design.



(b) 3.892 GHz



(c) 5.477 GHz



(d) 11.296 GHz

Fig-8. Axial ratio for 3.892GHz, 5.477GHz, and 11.296 GHz resonant frequencies.

Axial Ratio: It is a circularly polarized antenna pattern major to minor axis ratio.

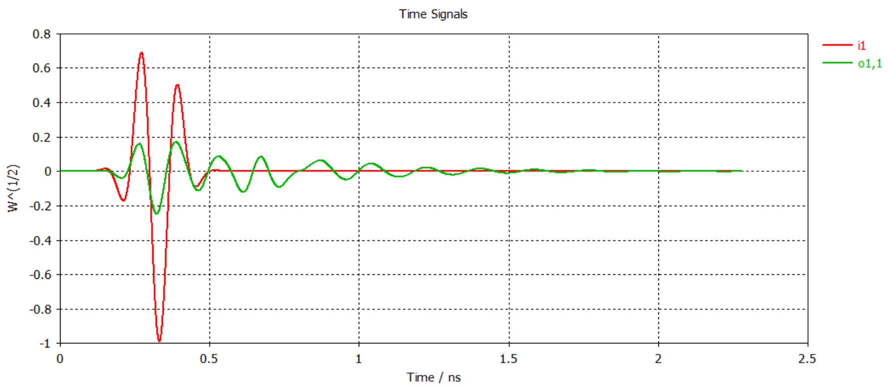


Fig-9. Port signal with respect to time.

Port Signal: It shows how strong the resonance is of the antenna it always starts at 0 and after some resonance tends towards zero.

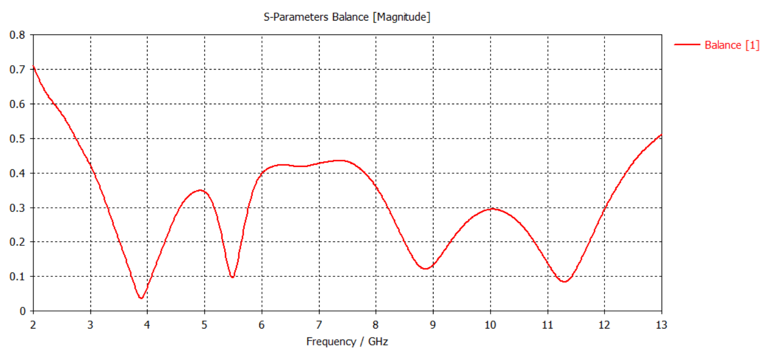


Fig-10. S Parameter balance magnitude.

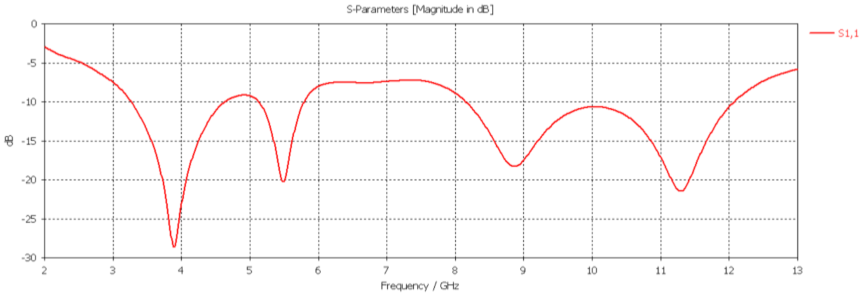
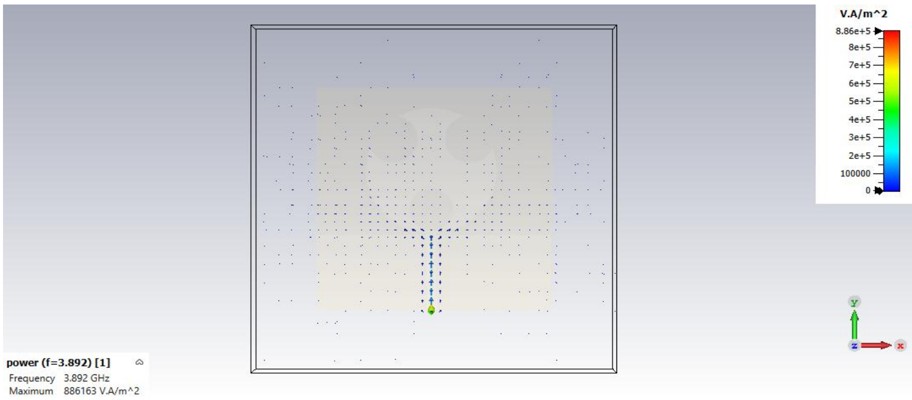
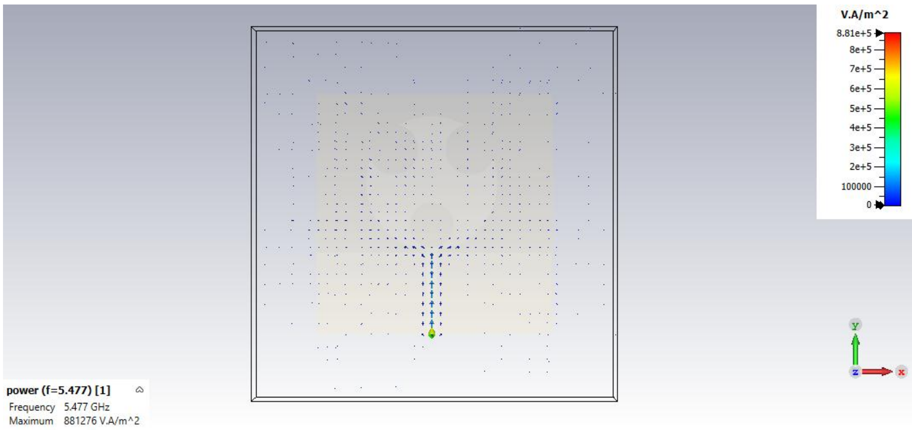


Fig-11. S11 Parameter.

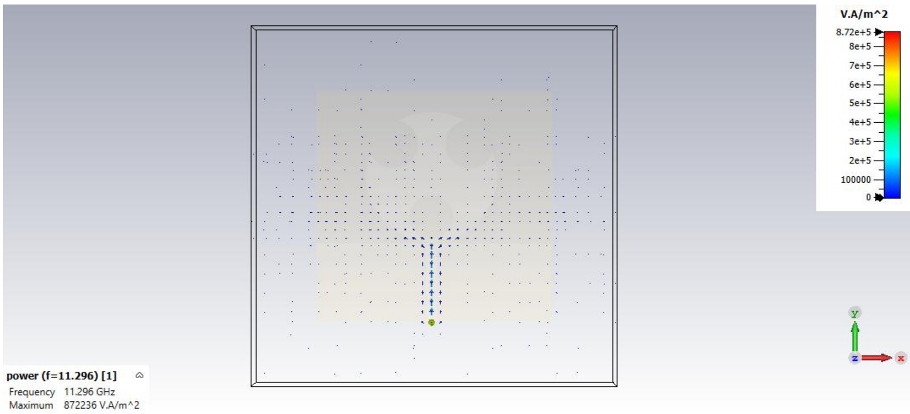
S-Parameter: It is the reflection coefficient between the port impedance in addition to the input impedance of the circuit.



(a) 3.892 GHz.



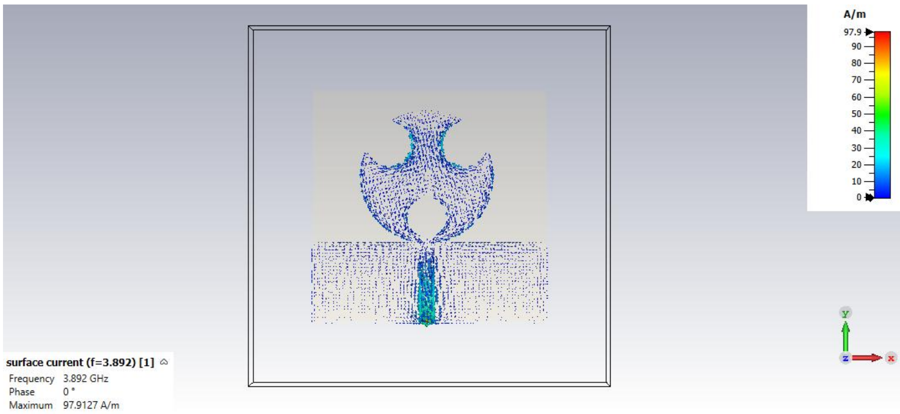
(b) 5.477 GHz.



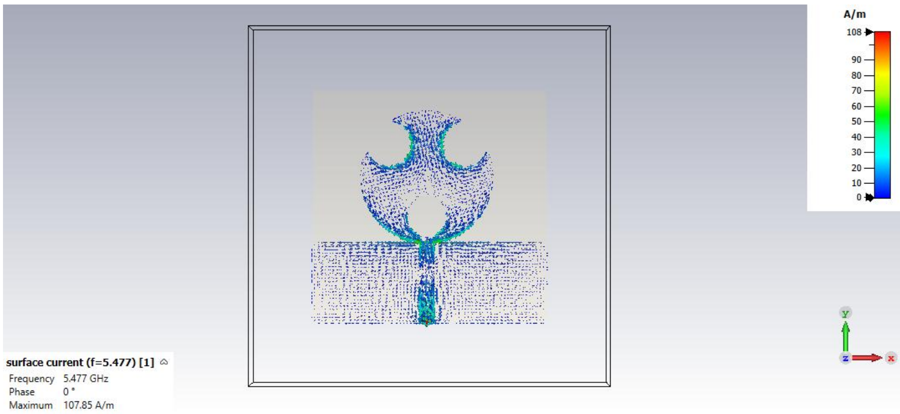
(c) 11.296 GHz

Fig-12. Power flow for 3.892 GHz, 5.477 GHz, 11.296 GHz.

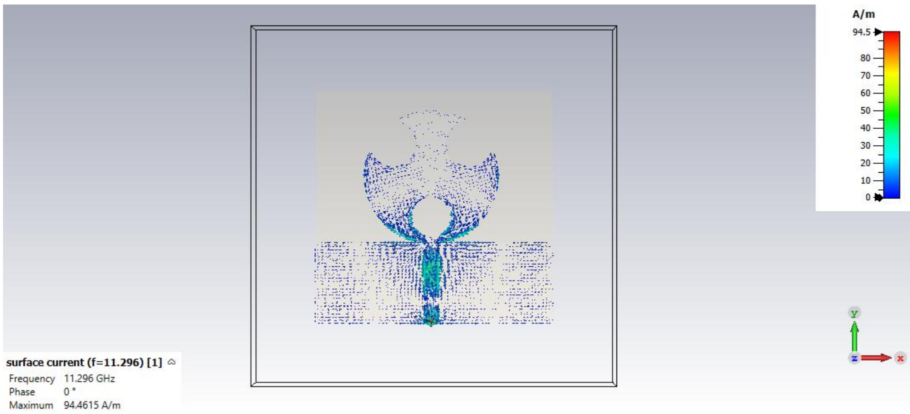
Power flow: It denotes the direction of power flowing in the antenna.



(a) 3.892 GHz.



(b) 5.477 GHz.



(c) 11.296 GHz.

Fig-13. Surface current 3.892 GHz, 5.477 GHz, 11.296 GHz.

Surface current: An electromagnetic field is used to induce the actual electric current.

7. CONCLUSION

In this study, a tri-band microstrip antenna has been proposed with tri band frequencies which operate in 3.892GHz, 5.477GHz, 11.296 GHz resonant which works in the 3.5 GHz WiMAX band for 5G purpose for longer range but less speed. The radiation performances of the microstrip antenna were studied. The performance indicates that the antenna had a greater gain, a better front-to-back ratio, and good bandwidth. The suggested antenna, in addition to triple-band antennas, has a sufficient bandwidth, high gain, and better bandwidth and it works with wearable technology and wireless body area networks. for multiband applications and can be used for satellite communication, 5G, and radar application for target identification and discrimination.

8. FUTURE SCOPE

In the future, this design can be fabricated and tested on a human phantom to know its SAR value and effects on the human body so that it can be used for wearable applications and also on other applications. The design can be further used for the exchange of information between different devices over a cloud network and satellite connectivity can be achieved from it, tracking, navigation fetching of data, and communication.

REFERENCES

[1] Seyedi, M.; Kibret, B.; Lai, D.T.H.; Faulkner, M. A survey on intrabody communications for body area network applications. IEEE Trans. Biomed. Eng. 2013, 60, 2067–2079. [CrossRef] [PubMed]

[2] Seneviratne, S. A survey of wearable devices and challenges. IEEE Commun. Surv. Tutor. 2017, 19, 2573–2620. [CrossRef]

[3] Ashyap, A.Y.I.; Bin Dahlan, S.H.; Abidin, Z.Z.; Abbasi, M.I.; Kamarudin, M.R.; Majid, H.A.; Dahri, M.H.; Jamaluddin, M.H.; Alomainy, A. An overview of electromagnetic band-gap integrated wearable antennas. IEEE Access. 2020, 8, 7641–7658. [CrossRef]

[4] Song, L.N.; Rahmat-Samii, Y. A systematic investigation of rectangular patch antenna bending effects for wearable applications. IEEE Trans. Antennas Propag. 2018, 66, 2219–2228. [CrossRef]

[5] Singh, R.K.; Michel, A.; Nepa, P.; Salvatore, A.; Terraroli, M.; Perego, P. Compact and wearable yagi-like textile antennas for near-field UHF-RFID readers. IEEE Trans. Antennas Propag. 2021, 69, 1324–1333. [CrossRef]

[6] Agarwal, K.; Guo, Y.-X.; Salam, B. Wearable AMC backed near-endfire antenna for on-body communications on latex substrate. IEEE Trans. Compon., Packag. Manuf. Technol. 2016, 6, 1113–1124. [CrossRef]

[7] Alemaryeen, A.; Noghanian, S. On-body low-profile textile antenna with artificial magnetic conductor. IEEE Trans. Antennas Propag. 2019, 67, 3649–3655. [CrossRef]Micromachines 2022, 13, 1938 12 of 12

[8] Velan, S.; Sundarsingh, E.F.; Kanagasabai, M.; Sarma, A.K.; Raviteja, C.; Sivasamy, R.; Pakkathillam, J.K. Dual-band EBG integrated monopole antenna deploying fractal geometry for wearable applications. IEEE Antennas Wirel. Propag. Lett. 2015, 14, 249–252. [CrossRef]

[9] Gao, G.P.; Hu, B.; Wang, S.F.; Yang, C. Wearable planar inverted-F antenna with stable characteristic and low specific absorption rate. Microw. Opt. Technol. Lett. 2018, 60, 876–882. [CrossRef]

[10] Jiang, Z.H.; Brocker, D.E.; Sieber, P.E.; Werner, D.H. A compact, low-profile metasurface-enabled antenna for wearable medical body-area network devices. IEEE Trans. Antennas Propag. 2014, 62, 4021–4030. [CrossRef]

[11] Le, T.T.; Yun, T.-Y. Miniaturization of a dual-band wearable antenna for wban applications. IEEE Antennas Wirel. Propag. Lett. 2020, 19, 1452–1456. [CrossRef]

[12] Atrash, M.E.; Abdalla, M.A.; Elhennawy, H.M. A wearable dual-band low profile high gain low SAR antenna AMC-backed for WBAN applications. IEEE Trans. Antennas Propag. 2019, 67, 6378–6388. [CrossRef]

[13] AlSabbagh, H.M.A.; Elwi, T.A.; Al-Naiemy, Y.; Al-Rizzo, H.M. A compact triple-band metamaterial-inspired antenna for wearable applications. Microw. Opt. Technol. Lett. 2019, 62, 763–777. [CrossRef]

[14] Sambandam, P.; Kanagasabai, M.; Natarajan, R.; Alsath, M.G.N.; Palaniswamy, S. Miniaturized button-like WBAN antenna for off-body communication. IEEE Trans. Antennas Propag. 2020, 68, 5228–5235. [CrossRef]

[15] Le, T.T.; Kim, Y.-D.; Yun, T.-Y. A triple-band dual-open-ring high-gain high-efficiency antenna for wearable applications. IEEE Antennas Wirel. Propag. Lett. 2021, 9, 118435–118442. [CrossRef]

[16] Yang, S.H.; Zhang, L.Y.; Wang, W.S.; Zheng, Y.J. Flexible tri-band dual-polarized MIMO belt strap antenna toward wearable applications in intelligent internet of medical things. IEEE Trans. Antennas Propag. 2022, 70, 197–208. [CrossRef]

[17] Dey, A.B.; Mitra, D.; Arif, W. Design of CPW fed multiband antenna for wearable wireless body area network applications. Int. J. RF Microw. Comput. Aided Eng. 2020, 30, e22459. [CrossRef]

[18] Alam, M.; Siddique, M.; Kanaujia, B.K.; Beg, M.T.; Kumar, S.; Rambabu, K. Meta-surface enabled hepta-band compact antenna for wearable applications. IET Microw. Antenna Propag. 2019, 13, 2372–2379. [CrossRef]

[19] Langley, R.J.; Parker, E.A. Double-square frequency-selective surfaces and their equivalent circuit. Electron. Lett. 1983, 19, 675–677.[CrossRef]