ARTICLE IN PRESS

Materials Today: Proceedings xxx (xxxx) xxx

Contents lists available at ScienceDirect

Materials Today: Proceedings

journal homepage: www.elsevier.com/locate/matpr

Bridged concentric circular microstrip patch antenna for C, X and Ku band applications

Emre Kurtulan [a], Vinita Mathur [b,*], Parul Tyagi [b], Ritu Vyas [b], Deepmala [b], Suman Sharma [c]

[a] Ege University, Izmir, Turkey
[b] Jaipur Engineering College and Research Center, Jaipur, India
[c] SKIT, Jaipur, India

ARTICLE INFO

Article history:
Available online xxxx

Keywords:
Microstrip Patch antenna
C band
X band
Ku Band
Circular patch

ABSTRACT

In this paper compact, novel, low profile, low cost, high speed and miniaturized slotted circular Microstrip patch antenna is proposed and designed with defected ground. The antenna's dimensions are 30 mm*30 mm as length*width. The patch is using microstrip feed line as it is simple and it provides better results. Microstrip feed is always taken in the middle of the aerial but in this design its effect on shifting is analyzed. FR-4 (ε_r = 4.4.) has been chosen to design proposed antenna and substrate thickness as 1.59 mm. Proposed aerial has extra two band in lower frequency which are at 3.34 GHz to 3.63 GHz and 5.48 GHz to 18.91 GHz. The antenna's characteristics have been calculated using CST Studio Suite. Partial C band is covered i.e. 5.48 GHz onwards. As maximum value of return loss of more than −60 dB is achieved in this band. Aerial has multiple bands which are located on partial C, X and Ku bands. Detailed parametric studies of the antenna have been carried out.

Selection and peer-review under responsibility of the scientific committee of the International Conference on Advances in Materials Science, Communication and Microelectronics.

1. Introduction

Communication electronics have anew refined a variety of frequencies for lucrative applications. This implies that modernized combination should be considered to contribute for multiple frequency ranges. Consequently demanding the layout of multiband aerial. A prerequisite for present day aerial is to have acceptable multi-directional function so that obligation for circular polarization is there. Besides advancement in light weighted, convenient, and compact accessories have made Microstrip patch antennas as distinguished and requirement for exceptional performance. These aerials are displayed as fundamental type that can be used to address great number of needs.

The framework of the patch antenna incorporates a substrate sandwiched between ground and patch. Patch can have shapes like circular, square, elliptical, rectangular etc. Circular patch are given more preference due to its compact shape [1].However to increase its performance certain amendments are required in the patch structure. This has initiated antenna research in various directions.

Ultra wideband (UWB) range from 3.1 GHz to 10.6 GHz and had been allotted in 2004 by the Federal Communications Commission (FCC) for unlicensed [2–4]. In [5] similar patch was designed but was applicable for 4.96 – 14.55 GHz band. Here in this manuscript amendments were done and performance was improved. Proposed antenna can be used in satellite communication, radar, amateur radio applications, wireless computer networks and Wi-Fi applications.

2. Mathematical modeling

Circular microstrip antennas can be modelled with cavity model approach [6–11]. Wave equation for electric field can be written as in eq.1.

$$\left(\nabla^2 + k^2\right)\vec{E} = 0 \quad (1)$$

Here k is equal to $\omega\sqrt{\mu\varepsilon_r}$ and ∇ is equal to $\frac{\partial}{\partial x}, \frac{\partial}{\partial y}, \frac{\partial}{\partial z}$.

Fields do not vary with z direction because $h \ll \lambda_0$ So we can write $\vec{E}$ field like in equation (2).

$$\vec{E} = \hat{z} E_z \quad (2)$$

* Corresponding author.
E-mail address: vinitamathur12@gmail.com (V. Mathur).

https://doi.org/10.1016/j.matpr.2022.09.327
2214-7853/
Selection and peer-review under responsibility of the scientific committee of the International Conference on Advances in Materials Science, Communication and Microelectronics.

Equation (3) satisfies differential equation which is shown in equation (1).

$$E_z = E_0 J_n \quad (k\rho)\cos(n\varphi) \tag{3}$$

Here $J_n(k\rho)$ are Bessel functions of order n and ε_0 is maximum electric field.

Magnetic field components are.

$$H_\rho = \frac{j}{\omega\mu}\frac{1}{\rho}\frac{\partial E_z}{\partial\varphi} = -\frac{jn}{\omega\mu\rho} E_0 J_n \ (k\rho)\sin(n\varphi) \tag{4}$$

$$H_\varphi = \frac{j}{\omega\mu}\frac{\partial E_z}{\partial\rho} = -\frac{jk}{\omega\mu} E_0 J'_n \ (k\rho)\cos(n\varphi) \tag{5}$$

The other field components are zero inside the cavity.

$$E_\rho = E_\varphi = H_z = 0 \tag{6}$$

Also, the resonance frequency can be calculated using the cavity model in circular patch. Relevant equation are.

$$(f_{rc})_{110} = \frac{1.8412}{2\pi a_e\sqrt{\mu_0\varepsilon_0}\sqrt{\varepsilon_r}} \tag{7}$$

$$a_e = a\left\{1 + \frac{2h}{\pi a\varepsilon_r}\left[\ln\left\{\frac{\pi a}{2h}\right\} + 1.7726\right]\right\}^{1/2} \tag{8}$$

ρ = surface current density.
n = mode of magnetic current distribution.
φ = azimuthal angle.
a = radius of circular patch.
h = height of substrate.
ω = angular frequency.
ε_r = relative permittivity.
ε_0 = space permittivity.
a_e = effective radius.
μ_0 = space permeability.
$(f_{rc})_{110}$ = resonance frequency for TM_{110} dominant.

3. Antenna design

Antenna was designed [3] with slotted annular ring shape and defected ground with applications in X and Ku bands as shown in Fig. 1. To make it applicable for lower frequency range and make its size compact feed point is shifted and two triangles are engrossed. After parametric analysis, we have gained a band from 3.34 GHz to 3.63 GHz and 5.48 GHz to 18.91 GHz which depicts antenna has extra two band in lower frequency.CST Microwave studio is used to check simulation results. Table 1 shows the dimensions used for aerial designing.

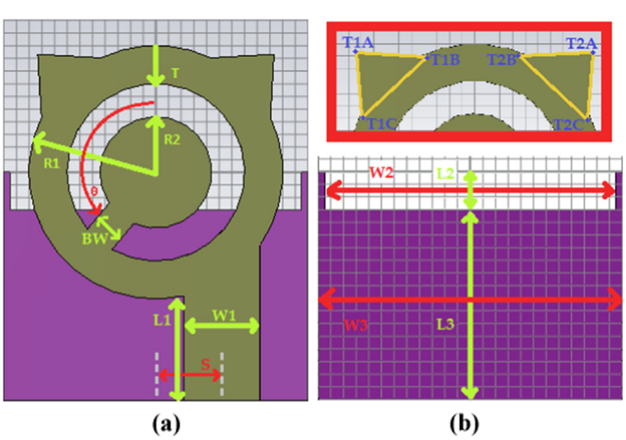


Fig. 1. Proposed antenna (a) Front View (b) Back View.

Table 1
Optimum Dimensions (mm) of proposed antenna.

Parameter	Value
R_1	10
R_2	4.4
T	3
BW	2.5
Θ	140°
L_1	8
W_1	6
S	5.2
L_2	3
W_2	23
L_3	15
W_3	24
h	1.59
Coordinate of T1A	(-9.3, 9.3)
Coordinate of T1B	(-4, 9)
Coordinate of T1C	(-9, 4)
Coordinate of T2A	(9.3, 9.3)
Coordinate of T2B	(4, 9)
Coordinate of T2C	(9, 4)

Initially ring with two slots and notch in defected ground structure is taken as shown in Fig. 2. Gradually microstrip feed is shifted and triangles are added as radiators and notch is also shifted in ground and results are analyzed.

The antenna shown in Fig. 2 is obtained at the beginning of the design process. A wide bandwidth is obtained with it. This antenna became a step for next one. Simulation results of [3] return loss and gain vs frequency are depicted in Fig. 3.

The changes are made to increase the band width and to be effective at low frequencies yielded results. We obtained a continuous band covering the entirety of the X and Ku bands and some of the C band. The width of this band is 13.43 GHz and extends from 5.48 to 18.91 as shown in the Fig. 4. And it has a second dip from 3.34 to 3.63 GHz. Antenna's return loss graph's deepest pit at 12.25 GHz and −42.5 dB in Fig. 4.

Antenna parameters are optimized to give best results. Changes are about feed point, added triangles, reduced number of bridges, reduced plate size, and optimizations in physical parameters were done.

4. Parametric analysis of proposed antenna

According to the design, some parameters have been varied and their effect is analyzed on the patch. It is figured that changes in substrate material, substrate thickness, feed point and feed width bring changes in the performance of the antenna.

4.1. Effect of substrate thickness

Distant extent of substrate material is varied to simulate the performance of aerial. Substrate thickness is varied from 1.25 mm to 1.75 mm. It is observed that with thickness 1.5 mm gives better results. Band at 2.83 GHz, 3.6 GHz and from 5.5 GHz to 18 GHz. As compared to previous design it is observed that bandwidth is increased and multiband characteristics are observed in Fig. 5.

4.2. Effect of substrate material

Substrate material is varied and its effect is observed on return loss characteristics in Fig. 6. Materials like Epoxy Resin, FR-4, G-10

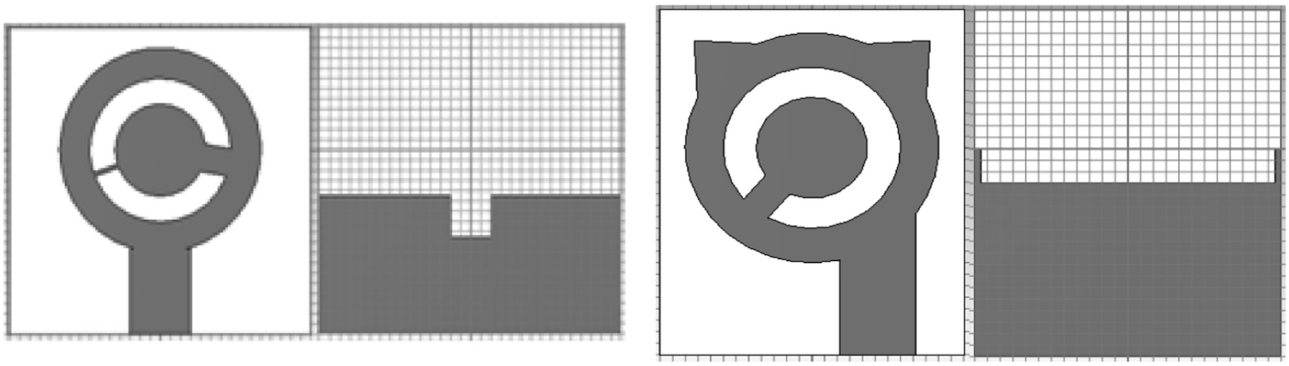
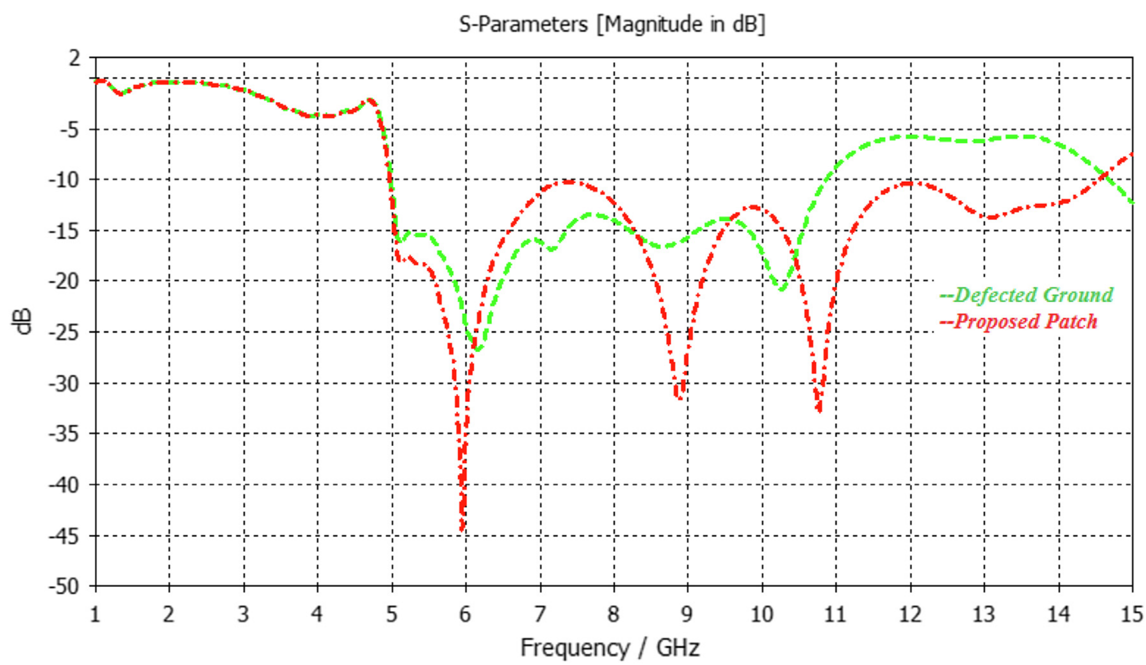
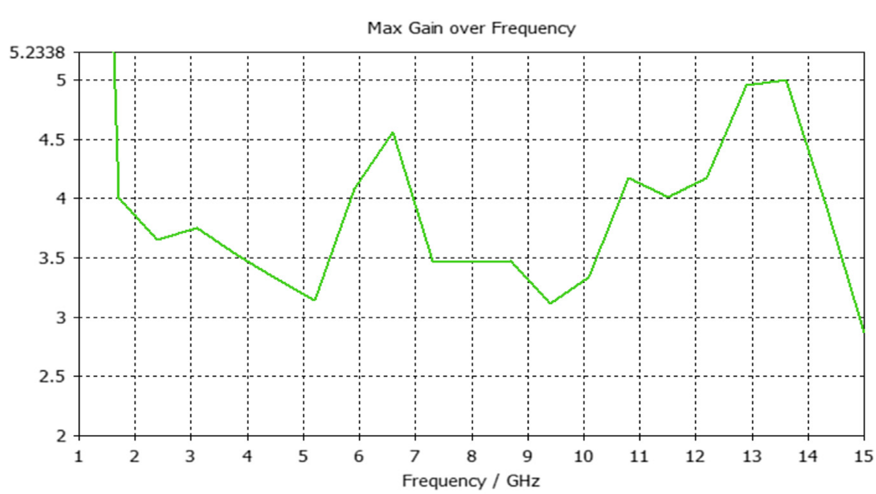


Fig. 2. Previous patch [3].



(a)



(b)

Fig. 3. (a) Return loss of previous patch [3] (b) Gain versus Frequency [3].

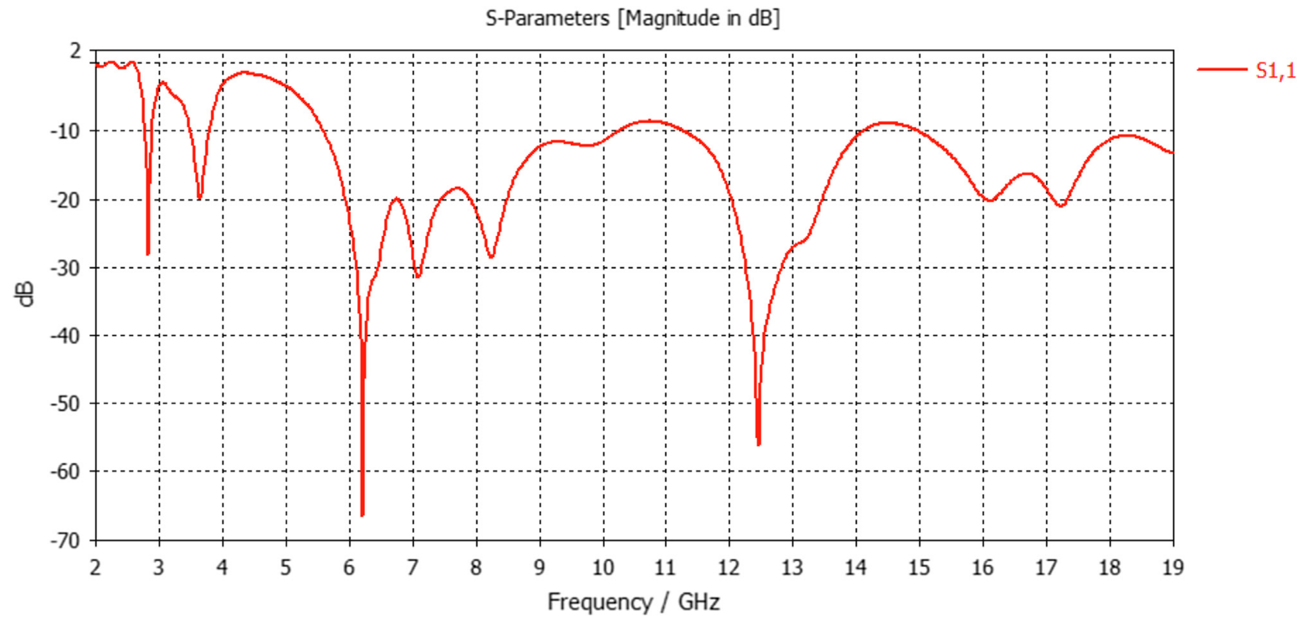


Fig. 4. Return loss of proposed antenna.

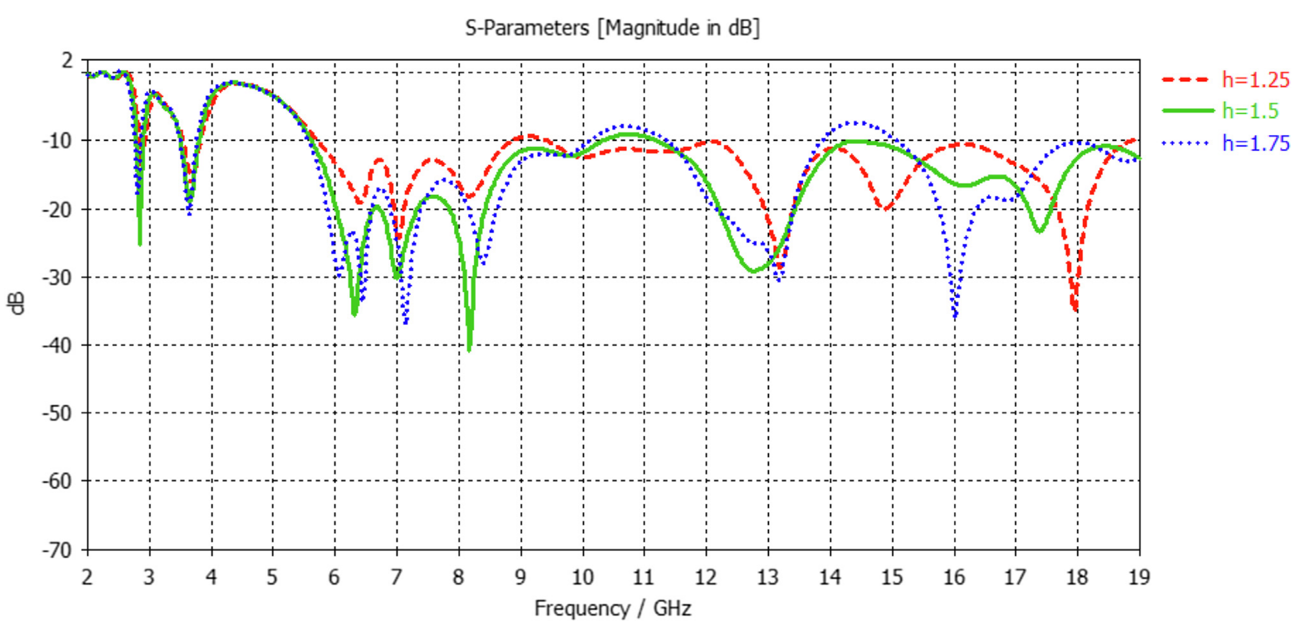


Fig. 5. Return loss variation with different substrate thickness (h).

and Rogers 5880 are taken into consideration. FR-4 material is considered because of low cost, cheap and easily available.

4.3. Effect of variation of slot thickness in annular ring

Annular slot thickness is varied and its effect is observed in Fig. 7 on return loss. Thickness is varied from 2 mm to 3 mm. It is observed that at 2.5 mm better results are observed as value of S_{11} is towards more negative.

4.4. Effect of position of Microstrip feed line

Microstrip feed line position is varied from −5.2 mm to 5.2 mm as seen in Fig. 8. It is observed that width of feed is taken as 3 mm. Right side shows better results as compared to left and middle positions. As can be seen from the Fig. 9.

5. Result analysis

Return Loss of proposed antenna is shown in Fig. 10. Broad band width is obtained from 5.5 GHz to 18 GHz. This band is suitable for

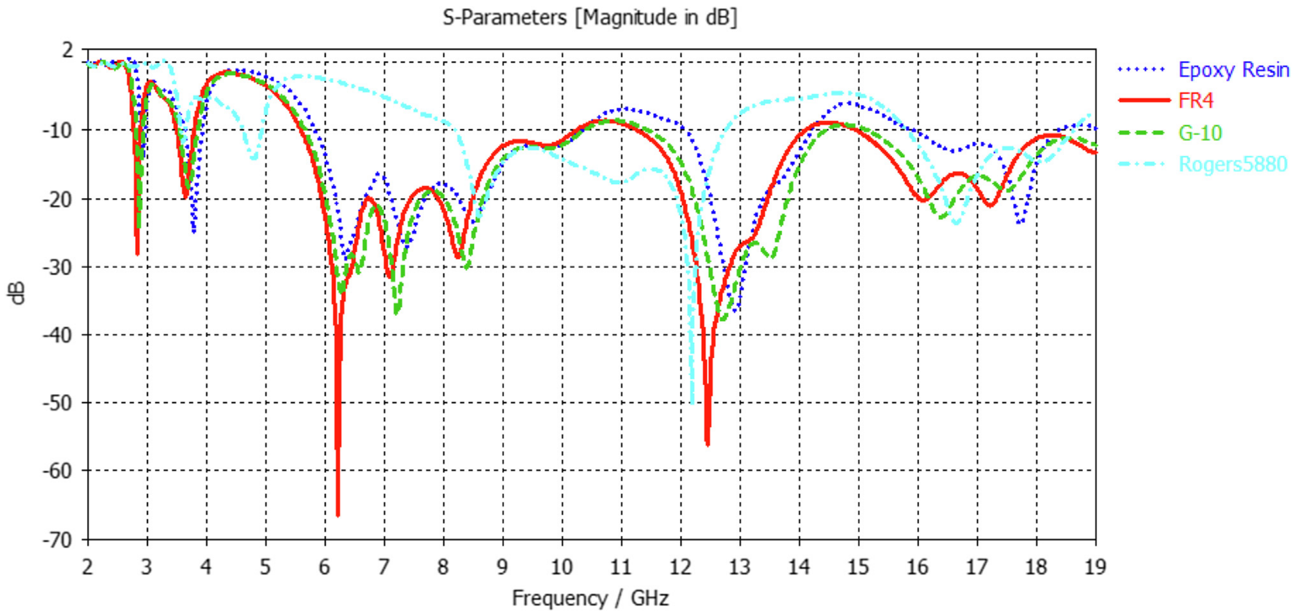


Fig. 6. Return Loss of different substrate materials.

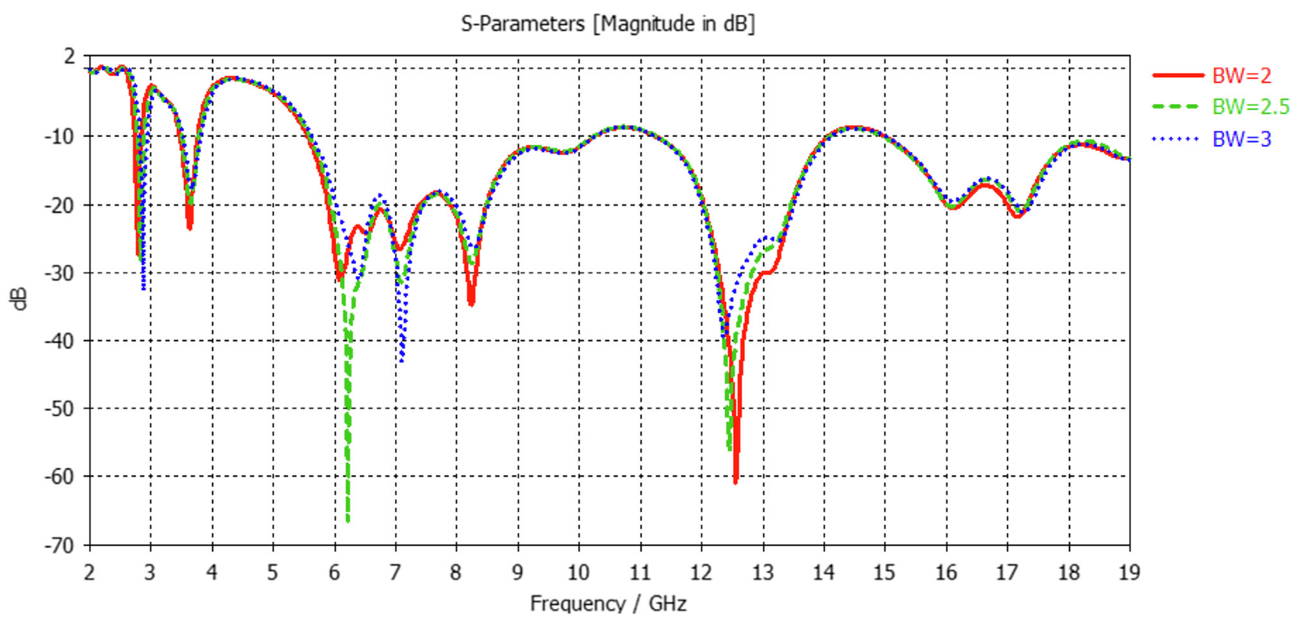


Fig. 7. Return loss of different bridge widths.

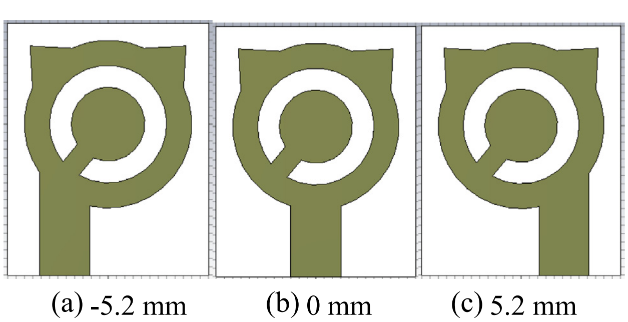


Fig. 8. Shifting of feed point.

satellite communications. VSWR curve is shown in Fig. 11. Which depicts a value of less than 2 in broadband range.

Table 2 shows the proposed aerial results at resonant frequencies. Table 3 shows the comparative analysis of proposed antenna with already manufactured antenna in terms of size and applications.

Fig. 12 shows the surface current distributions of the proposed design at resonant frequencies.

Gain plot mainly depends on the material used. To make it cost effective FR-4 material is used. Rogers 8550 material gives better results but is costly. Fig. 13 shows the results now.

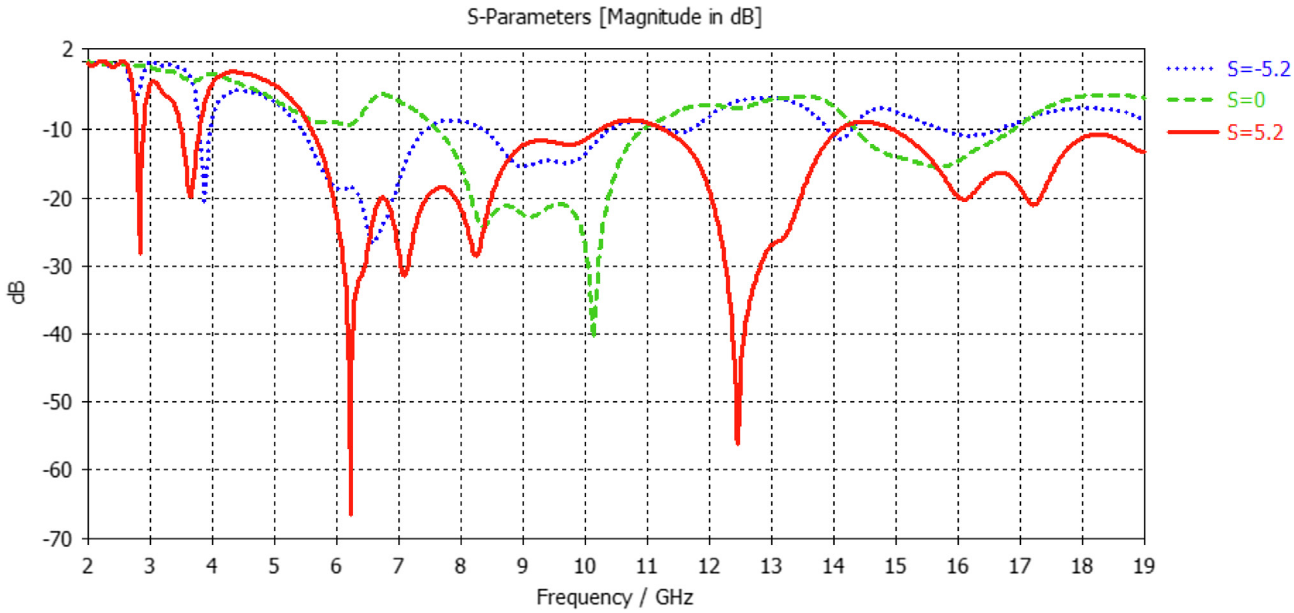


Fig. 9. Return loss of different feed point.

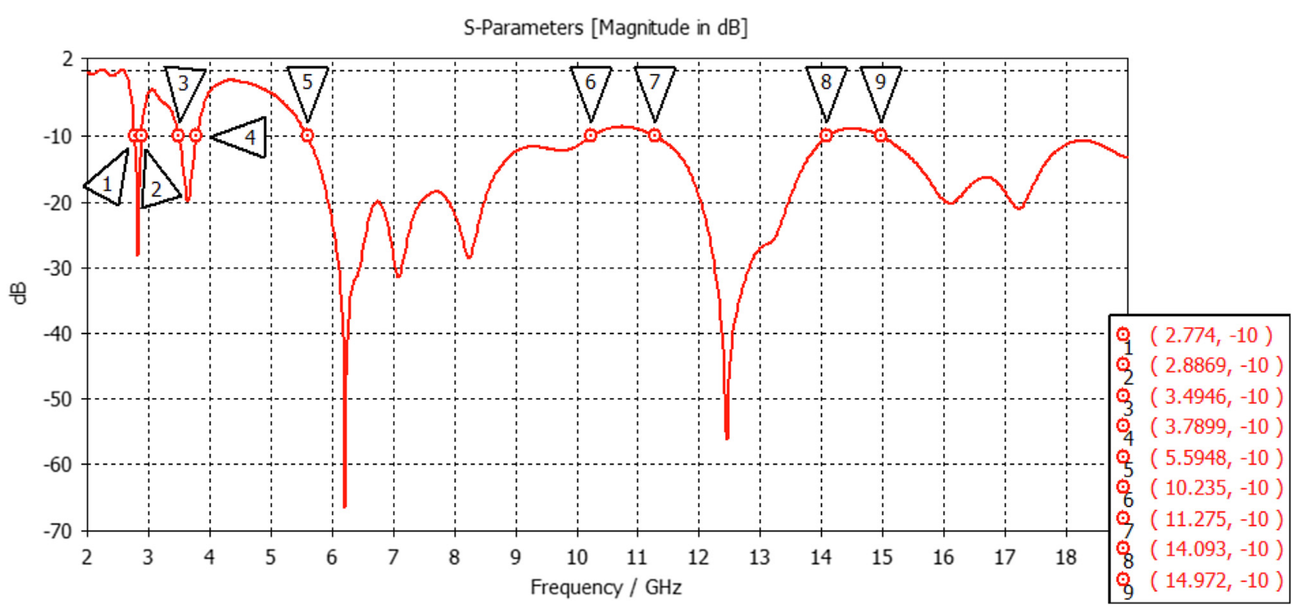


Fig. 10. Return loss of proposed antenna.

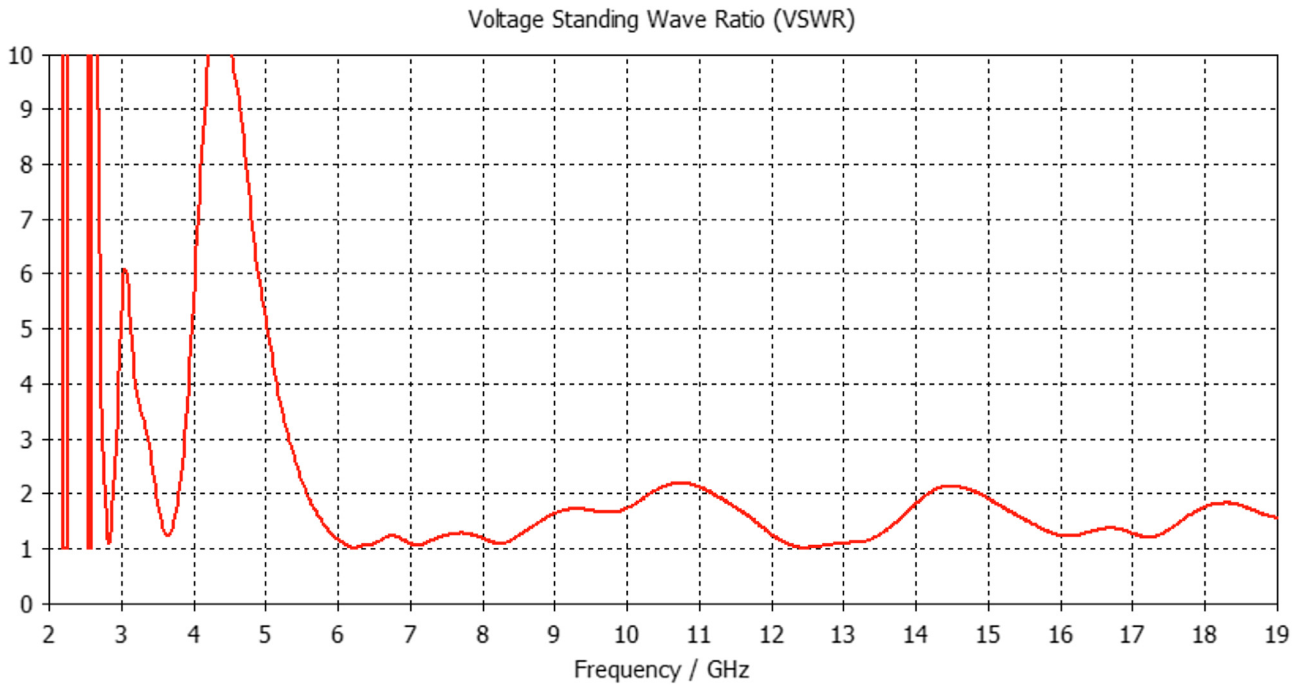


Fig. 11. Voltage Standing Wave Ratio of proposed antenna.

Table 2
Proposed antenna's results.

Frequency	3 GHz	7 GHz	8 GHz	12 GHz	13 GHz
Gain (dB)	8.48	4.802	3.972	2.077	2.122
Directivity (dBi)	4.14	4.695	5.071	3.877	4.407
Angular width(3 dB)	178.5	106.2	90.6	128.7	125.6
Main lobe mag. (dB)	7.98	0.431	−1.56	−0.040	−0.344
E-field (dBv/m)	20.36	19.22	18.59	16.79	15.69
H-field (dBA/m)	−31.16	−32.30	−32.93	−34.73	−35.83

Table 3
Comparative Results.

Reference	Antenna Size (L*W) mm^2	Circular Patch (Radius mm)	Applicable Band
[11]	40*40	8	X and Ku Band
[12]	36*32	10.1	Bluetooth (2.4 to 2.485), Wi- Fi (2.4 to 5.8 GHz), Ultra wideband (UWB) (3.1 to 10.6 GHz) and X-band
[13]	50*50	23	UWB Band
[14]	70*70	24	2.4 GHz
Proposed	30*30	10	Partial C, X and Ku Band

6. Conclusions

The objective of the manuscript is to come up with a novel microstrip patch antenna design that covers part of ultra wideband range, partial C, X and Ku bands. That provides versatile applications to aerial. Bridges' number, angle and width have given us flexibility to design wide bandwidth and compact antenna. The antenna is useful for military, radar, and satellite applications since higher frequencies are used to detect the long distance object so as the frequency increases it is easy to detect the object. Partial C band is covered i.e. 5.48 GHz onwards. As maximum value of return loss of more than −60 dB is achieved in this band.

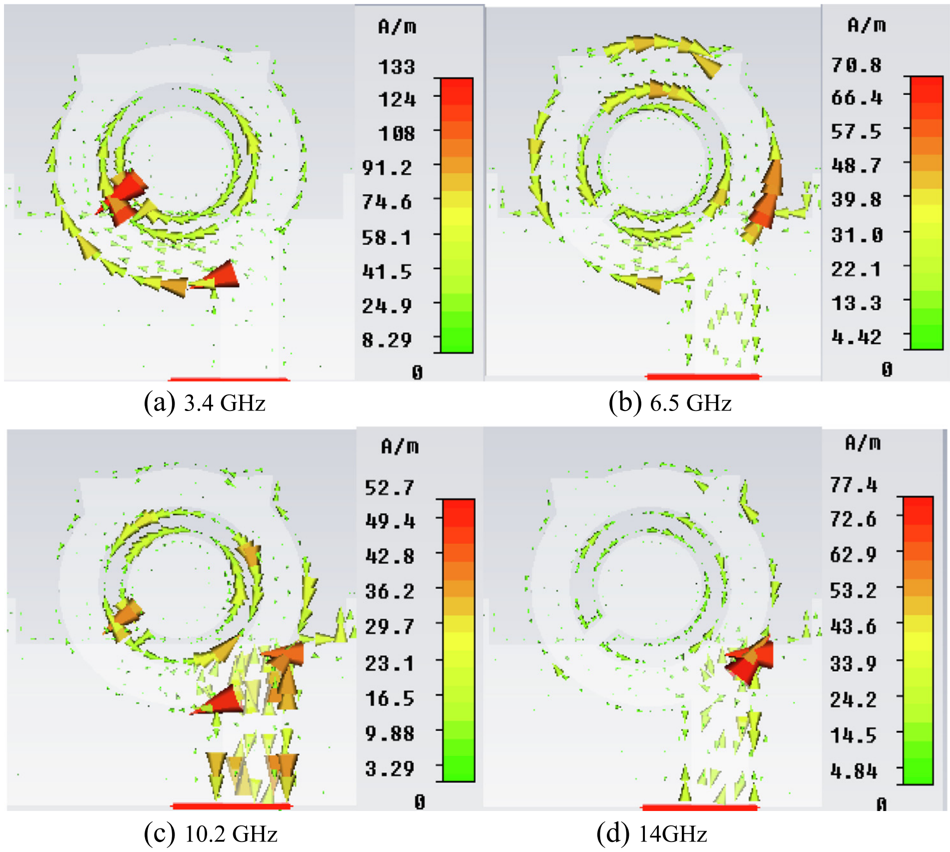


Fig. 12. Surface current distributions proposed antenna (a) 3.4 GHz (b) 6.5 GHz (c) 10.2 GHz (d) 14 GHz.

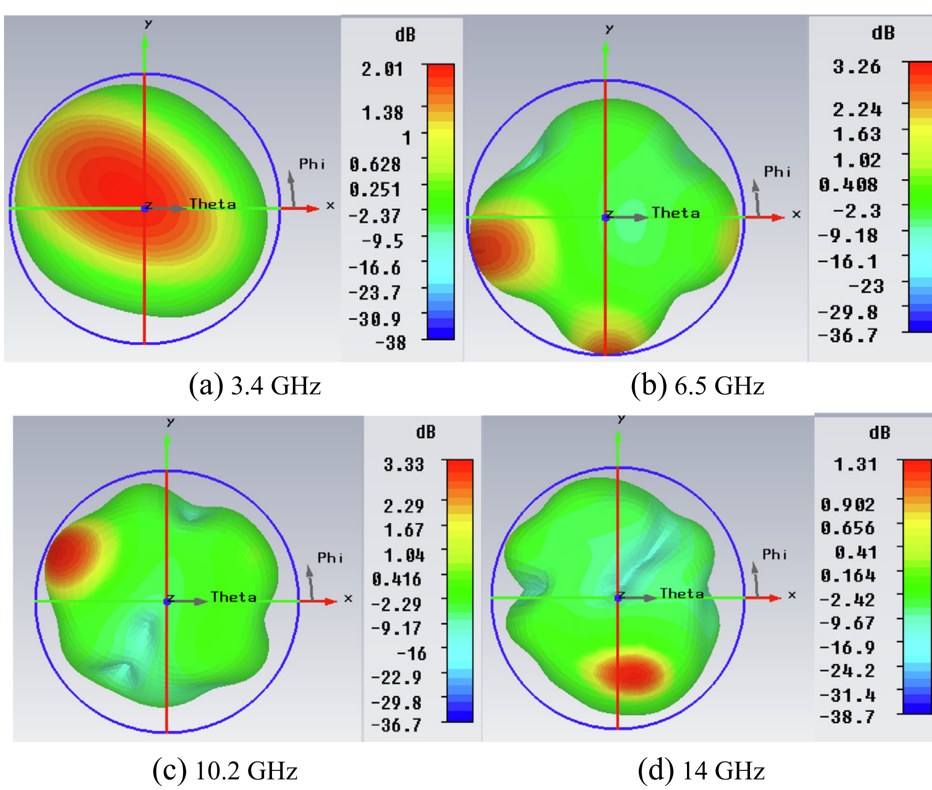


Fig. 13. Radiation Pattern of the proposed patch at resonant frequencies (a) 3.4 GHz (b) 6.5 GHz (c) 10.2 GHz (d) 14 GHz.

Data availability

Data will be made available on request.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dr. Vinita Mathur reports a relationship with Jaipur Engineering College & Research Centre that includes: employment.

References

[1] Manisha Gupta, Vinita Mathur, Wheel shaped modified fractal antenna realization for wireless communications, Int. J. Electron. Commun. (2017).

[2] IEEE Aerospace & Electronic Systems Society, *IEEE Standard Letter Designations for Radar-Frequency Bands,* IEEE Std 521tm-2002(R2009) (Revision of IEEE 521-1984), Radar Systems Panel, 17 June 2009.

[3] International Telecommunication Union, Radio Communication Study Groups, *Framework for the introduction of devices using ultra-wideband technology,* Document 1/85(Rev. 1)-E, 09, Nov. 2005. 2.

[4] R. Garg, P. Bhartia, I.J. Bahl, A. Ittipiboon, Microstrip antenna design handbook, Artech House, Norwood, Mass, USA, 2001.

[5] E. Kurtulan, V. Mathur, P. Tyagi, N. Singh, Bridged Circular Microstrip Patch Antenna for UWB Applications, Mater. Today: Proc. 46 (2021) 5742–5747.

[6] Constantine A. Balanis, *"Antenna Theory: Analysis and Design"*, third edition, ISBN: 0-471-66782-X.

[7] P. Khanna, K. Shinghal, A. Kumar, Multi-band Annular Ring Microstrip Antenna with Defected Ground Structure for Wireless Communication, Int. J. Comput. Appl. 135 (2) (2016).

[8] *Chafaa Hamrouni, Chafai Abdel Hamid, HediSakli, Abdelnaceur Kachouri, and NaceurAbdelkrim, "Design of Ring-shaped Circular Microstrp Antenna for ULB Application"*, 2017 Progress In Electromagnetics Research Symposium, Spring (PIERS), St Petersburg, Russia, 22–25 May.

[9] A.H.M. ZahirulAlam, Md. Rafiqul Islam and Sheroz Khan, *"Design and Analysis of UWB Rectangular Patch Antenna"*, 2007 Asia-Pacific Conference on Applied Electromagnetics Proceedings, 4-6 December 2007.

[10] Dinesh Yadav, Mahes P. Abegaonkari Shiban Koul, "Compact band-notched UWB antenna with CSRR for portable wireless communication", 2017 IEEE Applied Electromagnetics Conference (AEMC).

[11] Suman Sharma, Mukesh Kumar, Harshal Nigam, Monika Mathur, "Dual Band Circular Patch Coplaner Microstrip Patch Antenna for X band and Ku band Applications, 2021 IEEE Indian Conference on Antennas and Propagation (InCAP).

[12] Praveen Kumar Rao ECE, KM Jyoti Singh, Rajan Mishra, "A Circular Shaped Microstrip patch Antenna for Bluetooth/Wi-Fi/UWB/X-band Applications, 2018 International Conference on Power Energy, Environment and Intelligent Control (PEEIC) G. L. Bajaj Inst. of Technology and Management Greater Noida, U. P., India, Apr 13-14, 2018.

[13] Rahul Kumar Garg Department, Smrity Dwivedi, Raghuvir Tomar, "A Wide Band, Highly-Efficient Circular Patch Antenna with Split Triangular Shape Slit.

[14] A. Motevasselian, W.G. Whittow, Miniaturization of a Circular Patch Microstrip Antenna Using an Arc Projection, IEEE Antennas Wireless Propagation Lett. 16 (2017) 517.