DGS Loaded Broadband Circular Patch Antenna for Satellite Communications

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Abstract —Broadband slotted circular patch antenna with Defective Ground Structure intended for Ku band satellite communications is presented in this communication. The proposed antenna has a fundamental circular radiating element in which a square ring slot is etched along with a circular slot inside it. The ground is etched with a rhombus ring slot at the center and square slots in the corners. The defective ground provides multiple frequencies of operation and the slots in the radiating element act as filters combining the multiple frequencies of operation into broadband. The antenna is fabricated on an FR4 substrate with a volume of 40mm×48mm×1.59mm and a dielectric constant of 4.4. The antenna has been excited using a stripline feed of 50Ω impedance. The proposed antenna has an impedance bandwidth of 1.87GHz ranging from 13.61GHz to 15.48GHz with gain and directivity of 2.2dB and 6.09dB at 13.84GHz, 2.8dB and 5.47dB at 14.48GHz, respectively. The simulated and measured antenna results are in good agreement, showing that the proposed techniques enhance the antenna bandwidth.

Index Terms—Broadband, Circular patch antenna, bandwidth, DGS, Slotted Patch, Satellite Communication

I. Introduction

With the revolution in satellite technology, it is straightforward to establish communication in remote locations where mobile services are not reliable. For this, handheld communication devices are required to communicate with satellites directly, and a microstrip antenna is best suited for this purpose because of their small size and their ability to have multiple frequencies of operation with broad bandwidth and considerable gain in a small size.

Many researchers proposed techniques for enhancing the bandwidth of the antenna and for multiple frequencies of operation. A circular patch [1] with two semi-circular slots with a microstrip feed for a triple frequency operation is considered. Anyhow the bandwidth of the three frequencies is very low. A rectangular stacked patch antenna [2] for developing high gain and wide bandwidth is considered, but it is having a low % of bandwidth ratio. A corner truncated square patch antenna [3] with air space separation between the substrate and ground is considered, but a broadband antenna does not have a wide bandwidth. A corner truncated circular polarized rectangular patch antenna [4] with slots in the radiating element is considered, but it has low gain and efficiency. A triple frequency U slotted patch antenna [5] with multiple slots in the patch with corner truncations is considered for 5G and satellite communications; however, the bandwidth of the antenna at all three frequencies is very low. An edge truncated rectangular patch antenna [6] with co-linear rectangular slots in the two edges for a broad bandwidth of operation is considered. However, it is an antenna array, and the feed network also contribute to the bandwidth. A meandered rectangular patch antenna [7] excited with a coaxial feed is considered to generate wide bandwidth.

Similarly, many techniques were proposed to enhance the bandwidth of antenna-like using defective ground structures, using filtering structures in the patch, using different shapes of slots in the patch, using multiple printed dipole structures [8]-[26]. In addition, many researchers used either DGS or slotted patch or slotted ground techniques for enhancing the antenna parameters. However, in the proposed model, all three techniques are integrated into a single antenna to develop an efficient antenna for satellite communications. This section discusses the introduction of the work and contributions done by various researchers, section 2 details the antenna design considerations, and section 3 discusses antenna parameters and the evolution of the proposed antenna.

The proposed antenna uses the techniques of defective ground, slotted patch, and filtering structures to produce a wide bandwidth. The proposed antenna consists of a fundamental circular radiating element in which a square ring slot has been etched along with a circular slot inside it. The ground is etched with a rhombus ring slot at the center and square slots in the corners. The defective ground provides multiple frequencies of operation. The slots in the radiating element act as filters combining multiple frequencies of operation into broadband, which has an impedance bandwidth of 1.87GHz ranging from 13.61GHz to 15.48GHz, which cover the Ku-band for satellite communications.

Manuscript received April 2, 2021; revised October 15, 2021.
doi:10.12720/jcm.16.11.485-491

II. Proposed Antenna

The geometry of the broadband antenna is in Figures 1 and 2. Fig. 1 depicts the top view of the antenna and Fig. 2 depicts the rearview of the antenna. It is modeled and fabricated on FR4 material with a volume of 40mm×48mm×1.59mm using HFSS software. The dimension of the basic circular patch and the circular slot is calculated using the formula below. The overall dimensions of the proposed antenna after optimization in HFSS software is presented in Table I below:

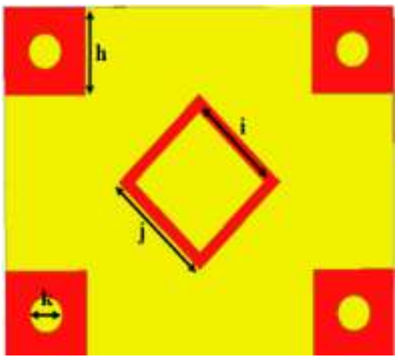


Fig. 1. Top View of the proposed antenna

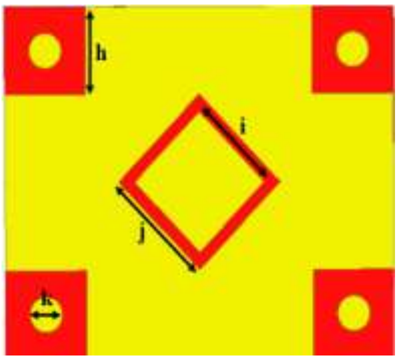


Fig. 2. Rearview of the proposed antenna

The mathematical expression used to derive the dimensions of the antenna are presented below, the width and length of the radiating element are derived using these expressions and are further optimized to realize the required specification for the MIMO antenna. Simulated and fabricated MIMO antenna is presented in Fig. 2, and optimized dimensions are presented in the Table I.

TABLE I: DIMENSIONS OF THE ANTENNA GEOMETRY

Parameter	Value(mm)	Parameter	Value(mm)
a	48	g	2
b	40	h	12
c	17	i	14.14
d	15.5	j	11.3
e	12	k	4.4
f	16		

$$a = F\left\{1 + \frac{2h}{\pi F \varepsilon_r}\left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right]\right\}^{-1/2} \quad (1)$$

$$F = \frac{8.791\times 10^9}{f_r\sqrt{\varepsilon_r}} \quad (2)$$

$$a_e = a\left\{1 + \frac{2h}{\pi a \varepsilon_r}\left[\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right]\right\}^{1/2} \quad (3)$$

Fig. 1 shows the radiating element of the antenna. The overall dimension of the antenna is given by a×b. The primary radiating element of the antenna is a circle of radius f. A circular slot of diameter e is etched in the center of the patch. The circular slot is surrounded by a square ring slot whose inner and outer side dimensions are presented by d and c. The antenna is excited by a microstrip feed with a width presented by g. Fig. 2 shows the antenna's ground plane that consists of a square ring slot at the center, rotated by 90^0 whose inner and outer dimensions are given by i and j. All the four corners of the ground plane are etched with square slots with a side dimension of h. In the center of the square slots at the four corners we placed four circles with a diameter given by k. The defective ground provides multiple frequencies of operation, and the slots in the radiating element act as filters and combines the multiple frequencies of operation into broadband.

III. Results and Discussion

The design optimization and analysis of the proposed antenna are carried out in HFSS software. Fig. 3 below depicts the simulated plot of impedance bandwidth of the antenna a broadband impedance bandwidth of 1.87GHz ranging from 13.61GHz to 15.48GHz which covers the Ku-band for satellite communications can be observed from the plot. A poor impedance matching of -12dB in the frequency range of 14.1 GHz to 14.3 GHz can be improved to -15dB but a compromise is required with the bandwidth as shown in the figure 16 in the evolution of the antenna.

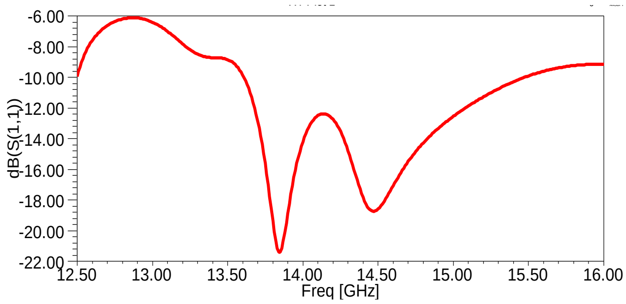


Fig. 3. Return loss

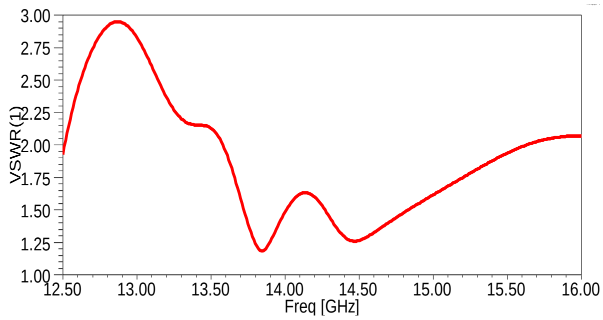


Fig. 4. VSWR

Fig. 4 below depicts the simulated plot of VSWR bandwidth of the antenna a broadband impedance bandwidth of 1.87GHz ranging from 13.61GHz to 15.48GHz which covers the Ku-band can be observed from the plot. A poor SWR of value higher than 1.5dB in the frequency range of 14.1 GHz to 14.3 GHz can be improved to lesser value but have to compromise with the bandwidth.

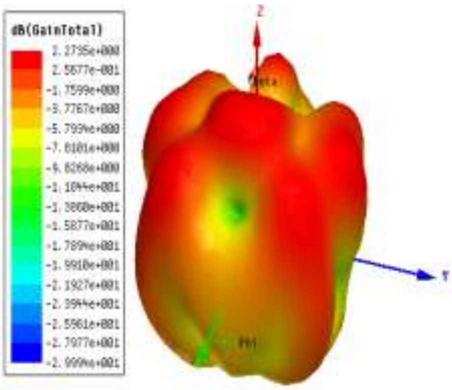


Fig. 5. Gain at 13.84GHz

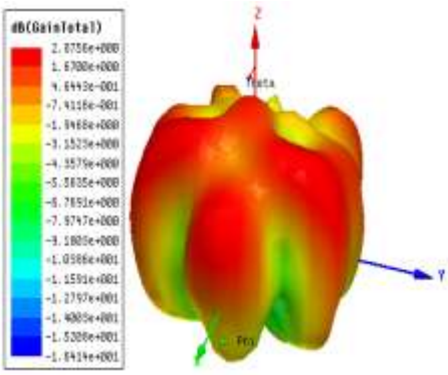


Fig.6. Gain at 14.48GHz

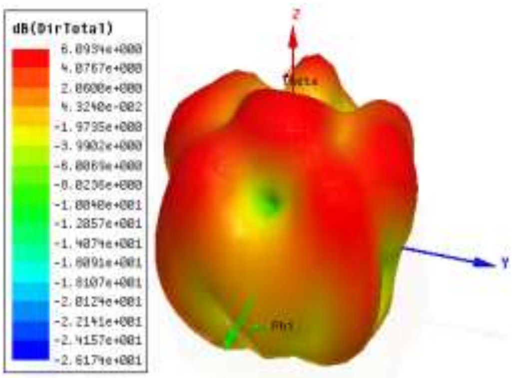


Fig. 7. Directivity at 13.84GHz

Antenna gain at two intermediate frequencies of 13.84GHz and 14.48GHz is presented in Fig. 5 and Fig. 6, respectively. Fig. 5 depicts the antenna gain at 13.84GHz, which is around 2.27dB, and Fig. 6 depicts the antenna gain at 14.48GHz, which is around 2.87dB. It is observed that the proposed antenna is having a considerable gain throughout the impedance bandwidth. Directivity at two intermediate frequencies of 13.84GHz and 14.48GHz is presented in Fig. 7 and Fig. 8. Fig. 7 depicts the antenna directivity at 13.84GHz, which is around 6.09dB, and Fig. 8 depicts the antenna directivity at 14.48GHz, which is around 5.47dB. It is observed that the proposed antenna has a considerable directionality in radiation throughout the impedance bandwidth.

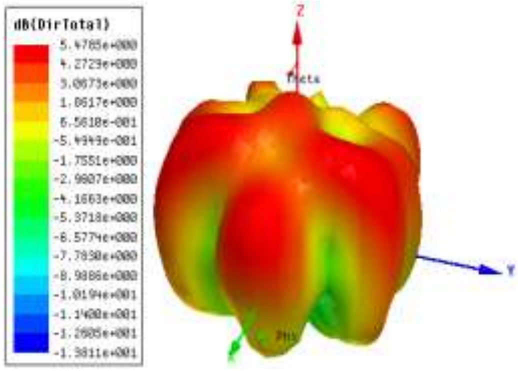
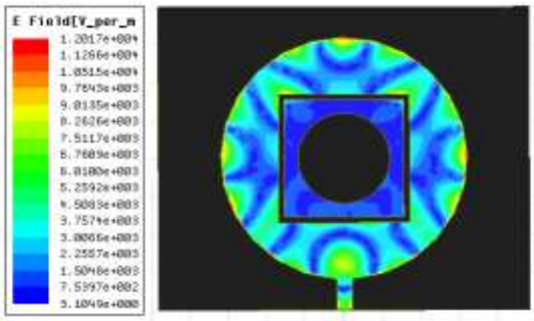
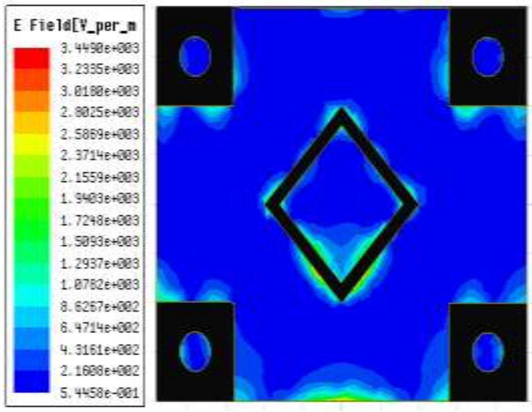


Fig. 8. Directivity at 14.48GHz

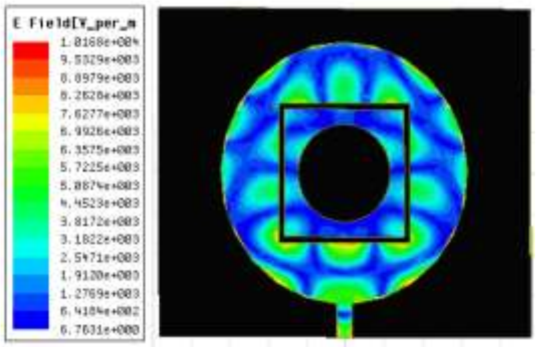


(a) Patch

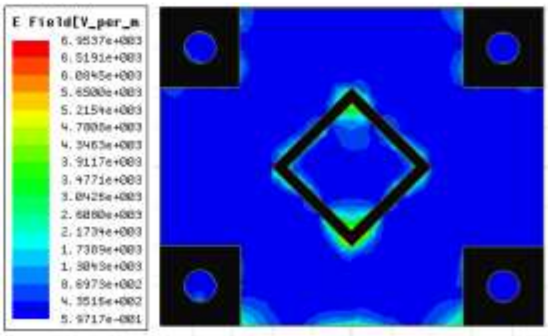


(b) Ground plane

Fig. 9. Current distribution 13.84GHz



(a) Patch

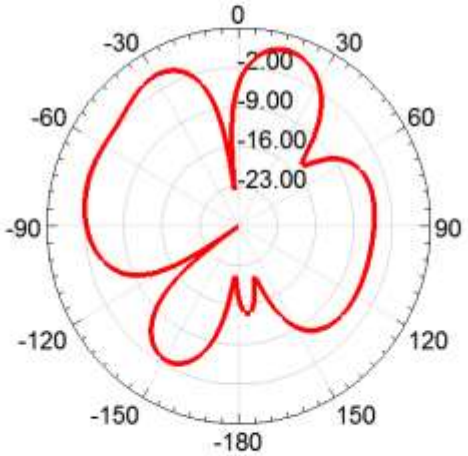


(b) Ground plane

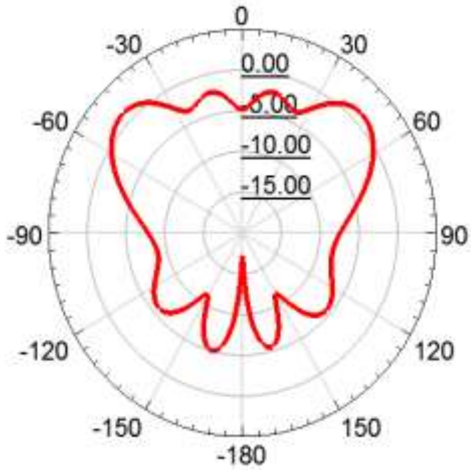
Fig. 10. Current distribution 14.48GHz

Fig. 9 and Fig. 10 below depict the antenna current distributions for the two intermediate frequencies of 13.84GHz and 14.48GHz. The contribution of patch and ground plane for radiation at both frequencies can be observed from the plots.

Fig. 11 to Fig. 14 below depict the proposed antenna's radiation characteristics at two intermediate frequencies of 13.84GHz and 14.48GHz. Both the elevation plane and the azimuthal plane of the antenna are depicted in Fig. 11 and Fig. 12. Fig. 11(a) and 12(a) depicts the elevation plane of the antenna and Fig. 11(b) and 12(b) depicts the azimuthal plane of the antenna.

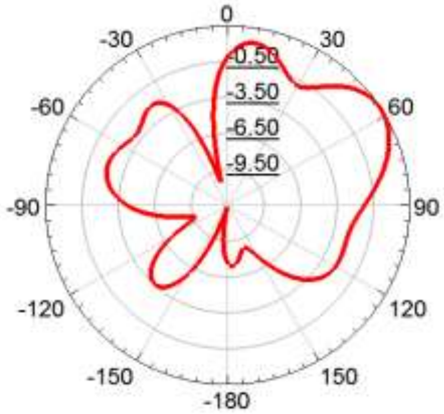


(a) Elevation Plane

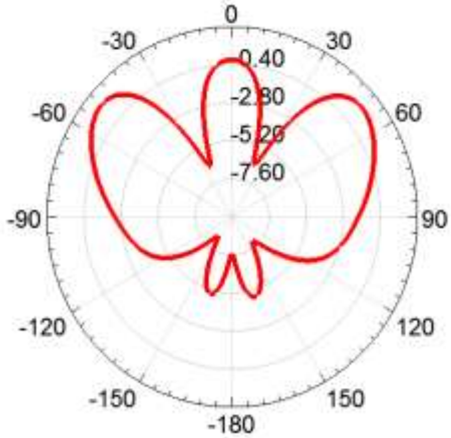


(b) Azimuthal Plane

Fig. 11. Radiation pattern at 13.84GHz



(a) Elevation Plane



(b) Azimuthal Plane

Fig. 12. Radiation Pattern at 14.48GHz

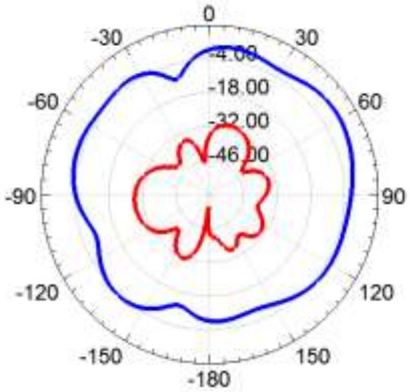


Fig. 13. Co pole and Cross pole Patterns at 13.84GHz

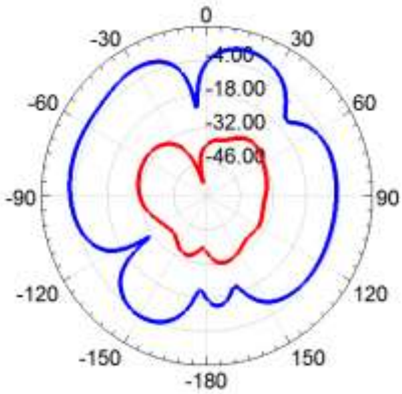


Fig. 14. Co pole and cross pole patterns at 14.48GHz

Fig. 13 and Fig. 14 depict the co pole and cross pole patterns of the antenna at the two intermediate frequencies of 13.84GHz and 14.48GHz. It represents the level of difference between the antenna’s radiation in the required direction and unwanted directions.

Fig. 15 depicts the different stages in the antenna's evolution, and the antenna's key features that are responsible for the broad bandwidth are presented.

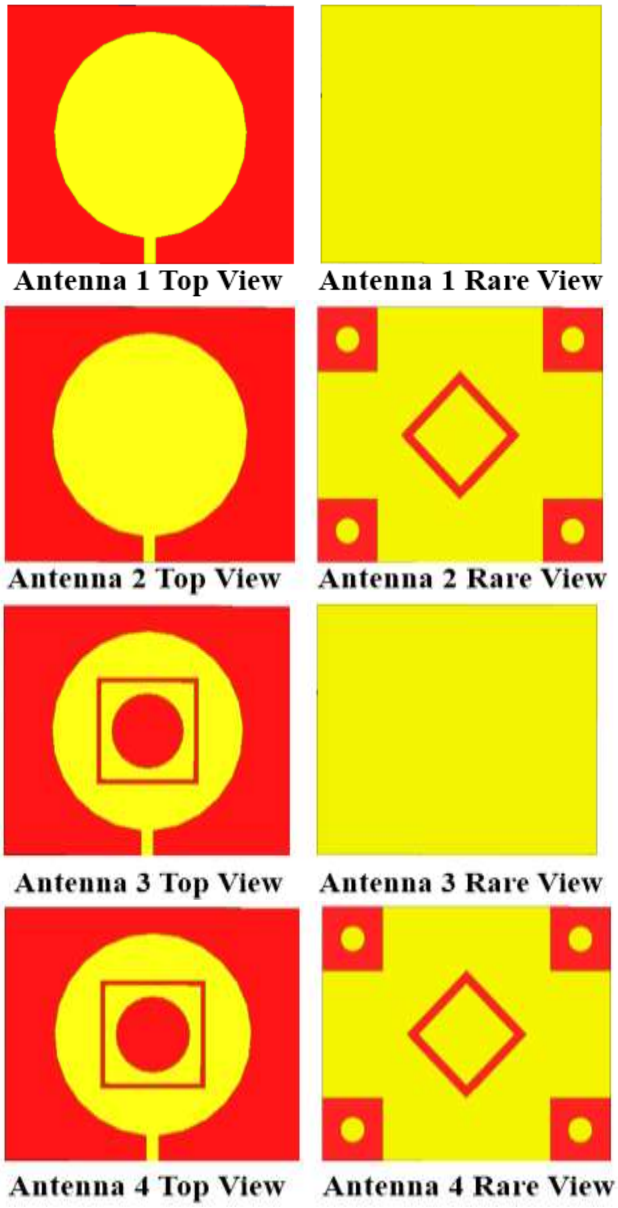


Fig. 15. Evolution of the antenna design

The first antenna is a basic one with a normal circular patch and a uniform ground plane which do not have a good resonance. The second antenna has a normal circular patch and a ground plane with a defective ground structure with multiple frequencies of resonance. The third antenna has a slotted circular patch and a uniform ground plane with a wide bandwidth. The fourth antenna has a slotted circular patch and ground plane with a defective ground structure with a broad bandwidth. The positioning of the slots plays a crucial role in the antenna resonance and the dimensions of the slots, their positioning are considered based upon the required frequency of operation. The impedance response of the proposed antenna at different stages of the evolution is presented in Fig. 16.

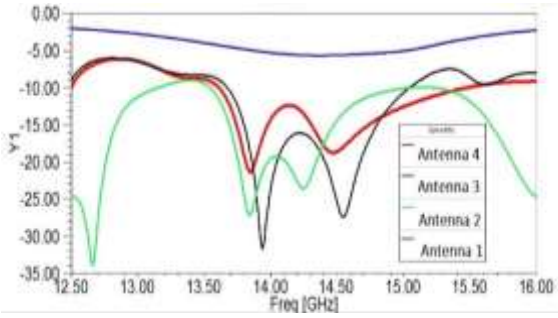


Fig. 16. Return loss

Fig. 17 below depicts the measurement setup of the fabricated antenna for the return loss plot in Keysight ENA Series Network Analyzer E5063A. We can observe a good agreement in-between the simulated and measured results. Figure 18 below depicts the fabricated prototype model of the proposed antenna. Fig. 18(a) presents the top view of the antenna and Fig. 18(b) presents the rare view of the antenna.

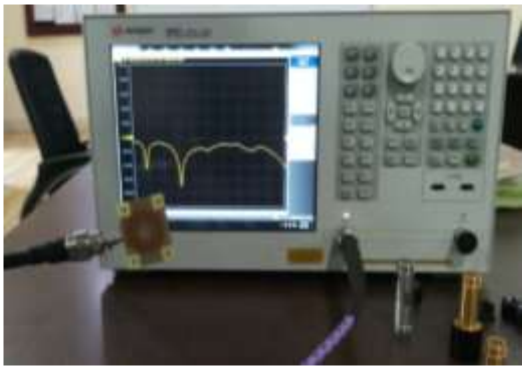
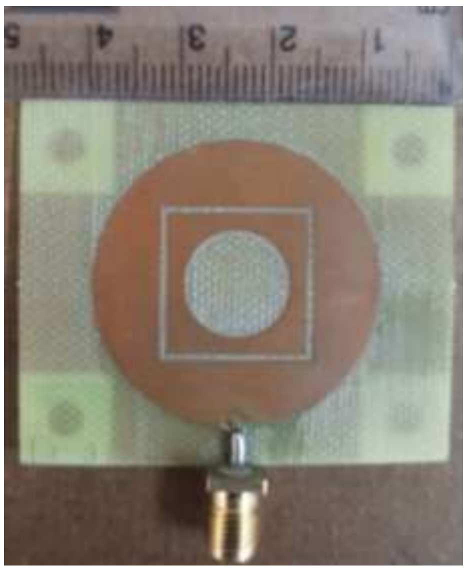
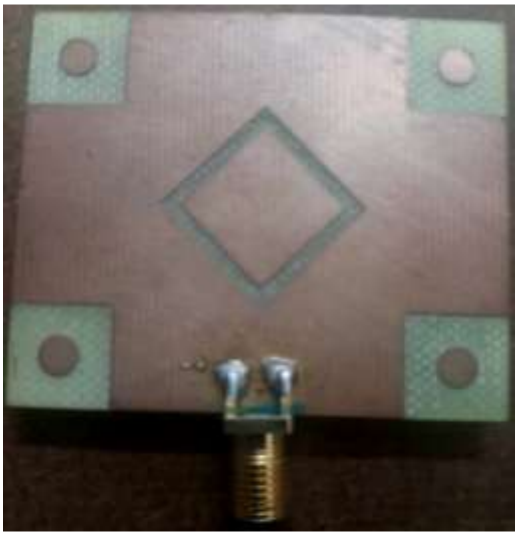


Fig. 17. Measurement setup



(a) Top View



(b) Rare View

Fig. 18. Fabricated antenna

IV. Conclusion

Broadband slotted circular patch antenna with Defective Ground Structure for Ku band satellite communications is presented in the communication. The proposed antenna has a basic circular radiating element in which a square ring slot has been etched along with a circular slot inside it. The ground is etched with a rhombus ring slot at the center and square slots in the corners. The defective ground provides multiple frequencies of operation and the slots in the radiating element act as filters and combines the multiple frequencies of operation into broadband. The antenna is fabricated on an FR4 substrate with a volume of 40mm×48mm×1.59mm and a dielectric constant of 4.4. The antenna has been excited using a stripline feed of 50Ω impedance. The proposed antenna has an impedance bandwidth of 1.87GHz ranging from 13.61GHz to 15.48GHz with gain and directivity of 2.2dB and 6.09dB at 13.84GHz, 2.8dB and 5.47dB at 14.48GHz, respectively. The results of both simulated and measured antenna are in good agreement, showing that the proposed techniques enhance the antenna bandwidth. Proposed antenna characteristics can be further extended by enhancing the antenna's bandwidth or by achieving circular polarization of operation.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Author 1 & 2 have performed the literature survey and identified the drawbacks. Design and analysis of antenna is done and simulation studies were performed at various stages. Author 3 has fabricated the antenna and performed the measurement analysis. Author 4 has prepared the manuscript.

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