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Design and Analysis of Cavity Backed Annular Ring Microstrip Antenna for Personal Wireless Communication

Anil Kumar Singh[1,2] · **Ravi Kumar Gangwar**[1] ·
Binod Kumar Kanaujia[3] · **Abhishek Sharma**[3]

Abstract Effect of cylindrical metallic cavity enclosure on resonant frequency of the annular ring microstrip antenna (ARMSA) having air-gap between substrate and ground plane is studied. The proposed antenna is analyze theoretically using modal expansion cavity model and circuit theory concept and verified by simulated results using Ansoft HFSS simulation software and experimental results. Theoretical and measured result of input characteristics shows good agreement with simulated results. Effect of cylindrical metallic cavity backing on resonance frequency of ARMSA is investigated for different air gap height and inner patch radius. The patch miniaturization of about 15 % is achieved using cavity backed ARMSA.

Keywords Microstrip antenna · Annular ring microstrip antenna · Cavity backing · Air-gap

1 Introduction

Microstrip antennas (MSAs) are attractive due to their unique feature like light weight, ease of fabrication etc., it is used extensively in modern communication systems [1, 2]. Annular ring microstrip antenna (ARMSA) with a proper selection of the radius, have

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✉ Binod Kumar Kanaujia
bkkanaujia@yahoo.co.in

Anil Kumar Singh
anilei76@gmail.com

Ravi Kumar Gangwar
ravi8331@gmail.com

[1] Electronics Engineering, Indian School of Mines, Dhanbad 826004, India

[2] Electronics and Instrumentation Engineering, Institute of Engineering and Technology, M.J.P. Rohilkhand University, Bareilly 243006, India

[3] Electronics and Communication Engineering, AIACTR, Geeta Colony, Delhi 110031, India

longer current path as compare to the circular patch of the same radius, which leads to substantial miniaturization of the antenna and it also provide the broader bandwidth [3–6].

Bluetooth devices, Wi-Fi antenna, cordless phones and radio controlled toys are using the 2.4 GHz band. The IEEE 802.11 wireless standard specifies WLAN computer communication at 2.4 GHz. MSAs is compact in size, further so many researchers are trying to minimize and design more compact antenna. A compact antenna can be realized by increasing dielectric constant of the substrate, by using shorting plate/pins, or by cutting slots in the radiating patch or in ground plane [7]. These methods will either distort the patch geometry or degrade the performance of the antenna. One of the suitable choices is cavity backing, where patch antenna was placed on the top of a metal cavity with cavity radius close to the patch radius. It also provides an extra feeding option compared to a conventional microstrip patch antenna. The cavity loading improves the performance of the antenna [8]. The cavity having some characteristic dimensions affects the fringing electric fields surrounding the patch which is responsible for radiation. The resonant fields in the cavity help to reducing the size of the antenna without greatly affecting the antenna performance [9]. Thus, cavity backed MSAs have gained significant importance over the last few decades due to their advantages like rigid shape, compact configuration, enhanced gain and bandwidth, improves radiation efficiency, and suppress surface waves in thick substrate [10–13]. Cavity backed rectangular MSA with annular slot antenna was investigated by [14] for dual-band circular polarization. Effect of cylindrical cavity enclosure on the resonance frequency of circular patch and inverted circular patch are analyzed [15–19].

In this paper, the authors have investigates the effect of cylindrical cavity enclosure on the resonance frequency of the ARMSA using the commercial simulation software HFSS, theoretical calculation using modal expansion cavity models and circuit theory concept and experimental results.

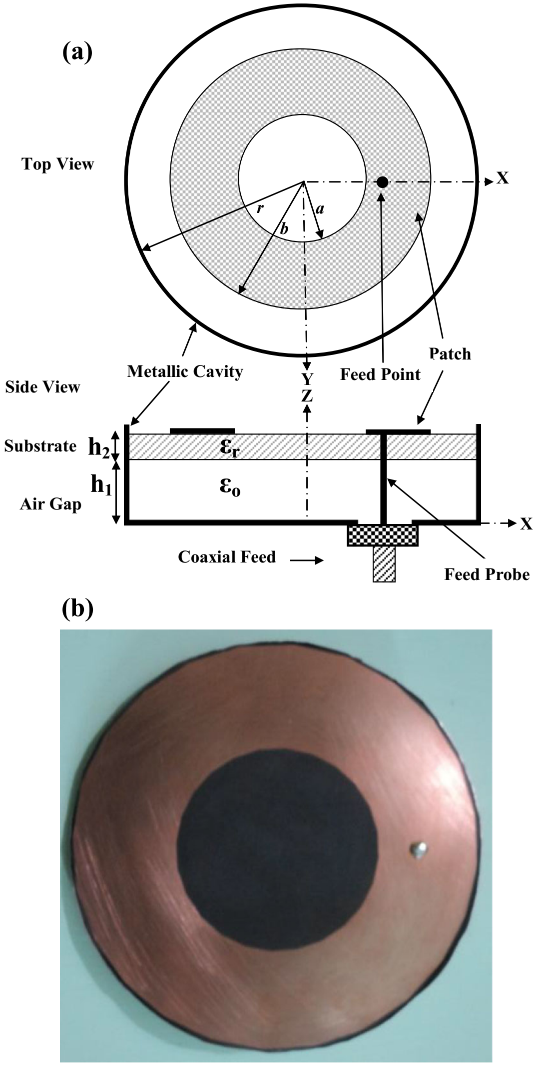
2 Design Consideration

Geometry and photo of prototype fabricated antenna is shown in Fig. 1. The patch is residing in a cylindrical Aluminum metal cavity of radius r and height $h_t = h_1 + h_2$, where h_1 is the air gap height and h_2 is the substrate (Rogers RT/duroid 5880) height. The radius of the substrate is equal to the radius of metallic cavity whereas the outer radius of ARMSA is less than metallic cavity in such a way that the effective radius of the patch is always less than metallic cavity, because effective outer radius of annular patch is always greater than actual or physical outer radius due to the presence of fringing fields generation at the outer edge of annular patch. The antenna is fed using co-axial probe. The equivalent dielectric constant of the medium below the patch which comprises of substrate of thickness h_1 and air gap of height h_2 and in [20] $\varepsilon_{re} = \varepsilon_r\,(1 + h_1/h_2)/(1 + \varepsilon_r\,h_1/h_2)$, where ε_r is the dielectric constant of the substrate. The antenna design parameters are listed in Table 1.

3 Results and Discussion

Commercial simulation software HFSS is used to study the influence of cavity enclosure on the resonance of the ARMSA. Figure 2 shows the variation of resonant frequency with air gap height with and without cavity for two values of inner radius, a (with condition that

Fig. 1 **a** Geometry. **b** *Top view* of proposed fabricated antenna (the *drawing is not in the scale*)



$b = 2a$). From Fig. 2, it can be observed that the increase of the resonant frequency of the ARMSA with increase the air gap height, without cavity is mainly due to the sharp decline in effective dielectric constant ε_{eff} of the air-dielectric interface. On the other hand, for the cavity enclosed patch, resonant frequency of the ARMSA increases but not with the same degree as that of free space case and saturates for larger air gap height. The above facts also verify in Fig. 3, which show the variation in resonance frequency of antenna with substrate height, keeping air gap height constant at 1 mm. It is also observed that the rate of change in resonance frequency of antenna is higher for higher side of substrate height and lower on the lower side of substrate height. Variation of resonant frequency with inner radius of annular ring is depicted in Fig. 4. It can be observed that on increasing the radius of inner radius, resonant frequency decreases and it is lower in case of cavity backed ARMSA.

Table 1 Antenna design parameters

Antenna parameter	Value
Inner radius of annular ring (a)	30 mm
Outer radius of annular ring (b)	60 mm
Substrate material used	Rogers RT/duroid 5880
Dielectric constant (ε_r)	2.2
Thickness of substrate (h_2)	1.59 mm
Height of air-gap (h_1)	3 mm
Height of patch ($h_1 + h_2$)	4.59 mm
Metal of cavity	Aluminum
Height of cavity	4.59 mm
Radius of cavity (r)	60.5 mm

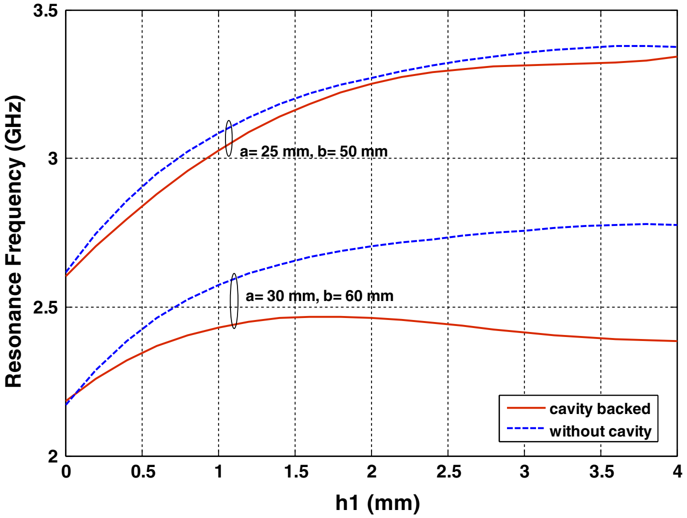


Fig. 2 Variation in resonant frequency with air-gap height (h_1) of cavity enclosed and without cavity of the proposed antenna. $\varepsilon_r = 2.2$, $r = 60.5$ mm, $h_2 = 1.59$ mm

Figure 5 shows the simulated result of surface current distribution of the ARMSA enclosed in a metallic cylindrical cavity at the operating frequencies of 2.4 GHz, and the same surface current distribution was observed for the ARMSA without cavity at 2.82 GHz. This is due to the effect of cavity enclosure. The cavity enclosure provides an extra ground around the edge of the patch antenna results in increased fringing fields on the edge of the patch antenna, whereas the same amount of fringing field generates in a patch antenna without cavity required larger radius. A reduction of resonant frequency is about 15 % of the conventional patch. This reduction in the size of the patch antenna is due to the patch diameter is inversely proportional to the resonant frequency.

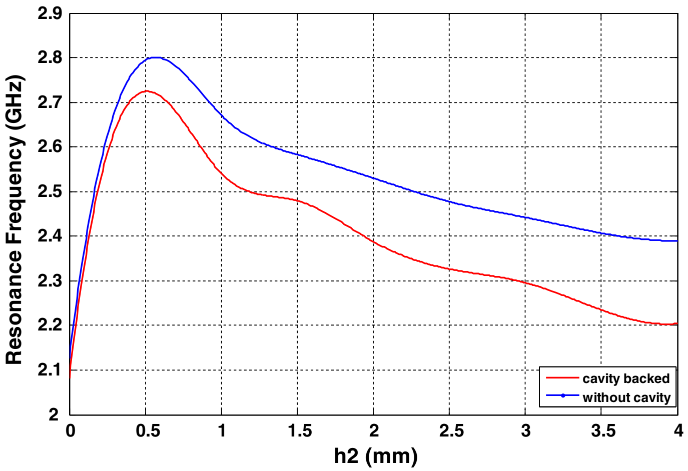


Fig. 3 Variation in the resonant frequency with substrate height (h_2) of cavity enclosed and without cavity of the proposed antenna. $\varepsilon_r = 2.2$, $r = 60.5$ mm, $a = 60$ mm, $h_1 = 1$ mm

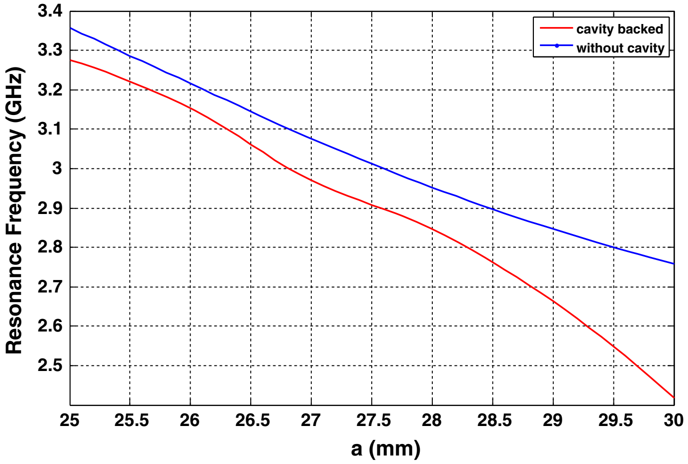


Fig. 4 Variation in the resonant frequency with radius of annular ring of cavity enclosed and without cavity of the proposed antenna. $\varepsilon_r = 2.2$, $r = 60.5$ mm, $h_1 = 3$ mm, $h_2 = 1.59$ mm

The $|S_{11}|$ was measured at frequencies over 1.0–3.0 GHz range using Agilent$^{\text{TM}}$ Vector Network Analyzer PNA-L Series (Model No.). Figure 6 shows the $|S_{11}|$ curve of ARMSA with and without cavity. The antenna is excited without cavity in TM_{31} mode at 2.82 GHz and TM_{21} mode at 2.21 GHz. After enclosing the ARMSA with a metal cylindrical cavity, the above mentioned modes are shifted to 2.4 and 1.72 GHz, respectively. From Fig. 5, it can be observed that ARMSA with cavity resonates at 0.4 GHz lower frequency than ARMSA without cavity.

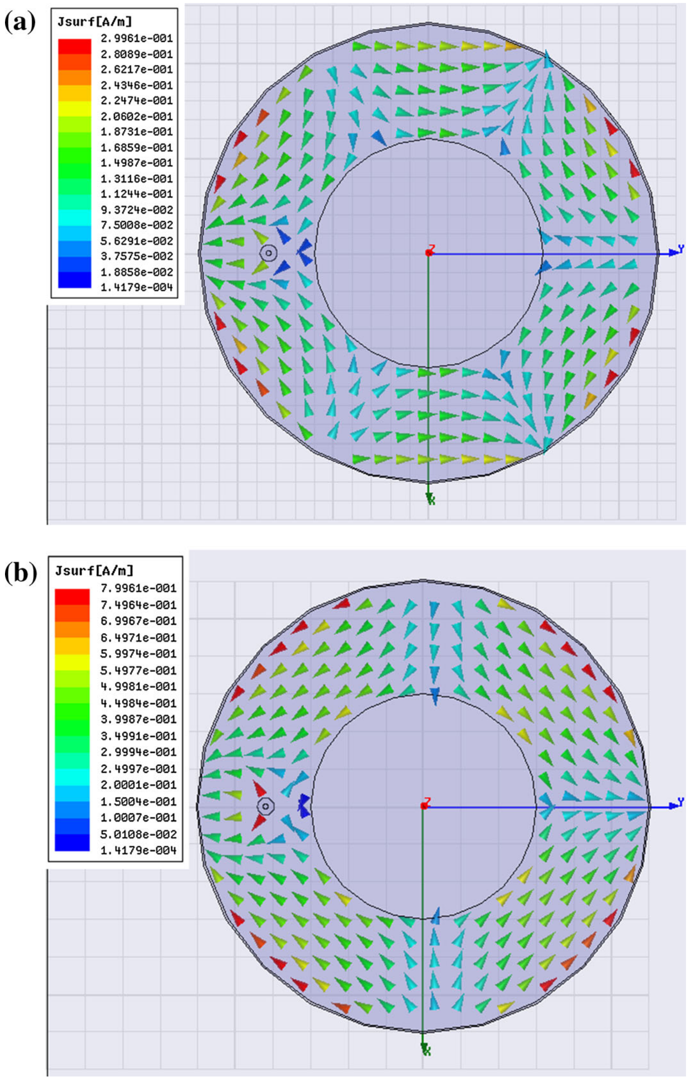


Fig. 5 Simulated surface current distribution at **a** 2.4 GHz and **b** 1.72 GHz of the proposed antenna

The far-field radiation characteristics of the proposed antenna for both *E* and *H* planes were calculated at 2.4 GHz, and the co-polar and cross-polar characteristics are shown in Fig. 7. The cross-polar level is below −28 and −45 dB in E-plane and H-plane respectively at 2.4 GHz. Figure 8 shows the variation of maximum gain of the antenna with and without cavity. As cavity improves matching, antenna gives dipper return loss at 2.4 GHz hence gain is highest at this point. Measured results of antenna gain are close agreement with simulated results. Gain of cavity backed antenna is greater than that of antenna without cavity.

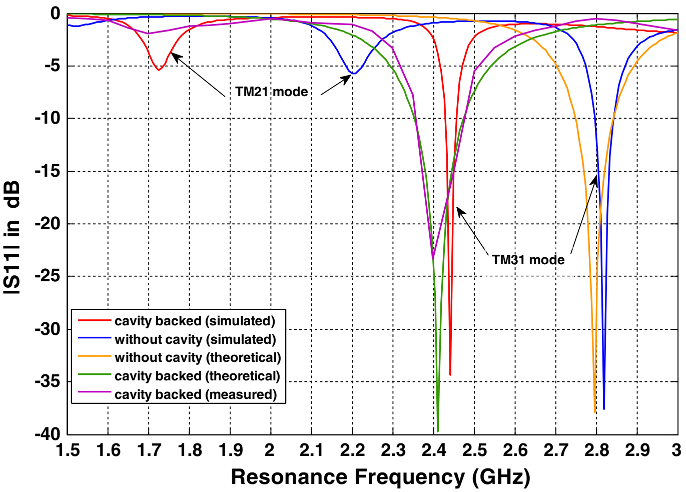


Fig. 6 Variation in the $|S_{11}|$ parameter with frequency of cavity enclosed and without cavity annular ring microstrip antenna at $\varepsilon_r = 2.2$, $r = 60.5$ mm, $h_1 = 3$ mm, $h_2 = 1.59$ mm

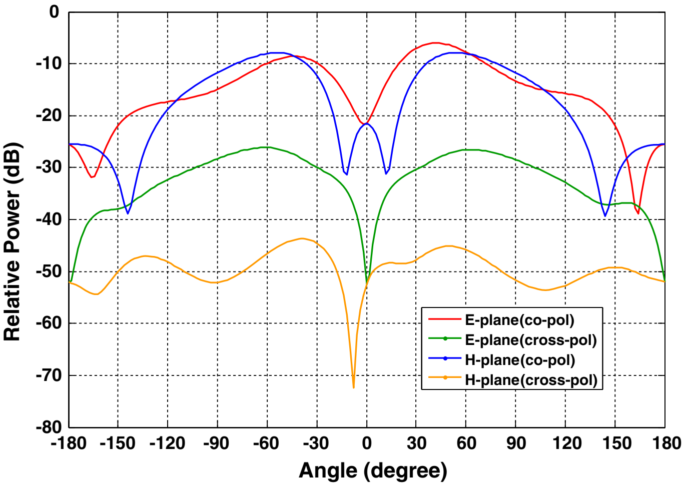


Fig. 7 E-plane and H-plane radiation pattern at 2.4 GHz of the proposed antenna

4 Conclusion

The proposed ARMSA with cylindrical metallic cavity backing has been designed, simulated and fabricated. The effect of cylindrical aluminium metal cavity on resonance of ARMSA has been studied using HFSS simulation software and theoretical modelling is carried out using cavity model and circuit theory concept. Theoretical and measured result shows close agreement with simulated results. The patch miniaturization in the presence of cavity has been proved. A size reduction of about 15 % has been achieved using cavity

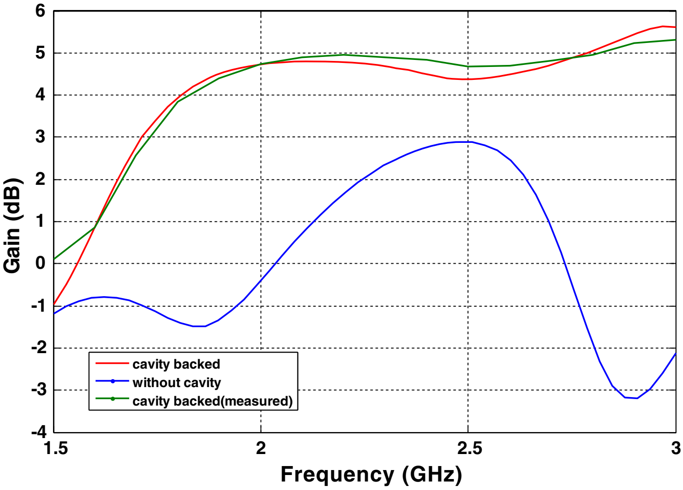


Fig. 8 Variation of antenna gain against frequency of the proposed microstrip antenna

with a properly chosen radius of 60.5 mm, which is very close to outer patch radius and thus influences the fringing fields associated with the antenna. The proposed compact antenna can be used for Wi-Fi, Bluetooth, WLAN computer communication, Zig-Bee, cordless phones, radio controlled toys, and alarm systems etc. Which are using the 2.4 GHz band.

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Anil Kumar Singh was born in Jamalpur, Mirzapur (UP), India on 10 July 1976. He received the M.Tech. degree in Instrumentation and Control Engineering from NITTTR Chandigarh, India in 2011. He is currently working towards the Ph.D. degree on some study on annular ring microstrip antenna from Electronics Engineering Department, Indian School of Mines (ISM), Dhanbad (India). He joined the Department of Electronics and Instrumentation Engineering, Institute of Engineering and Technology, M.J.P. Rohilkhand University, Bareilly as lecturer in 2002. He has published more than 20 papers in national and international journals and conferences. His current research interest includes design and analysis of microstrip antennas. He is a graduate student member of IEEE.

Ravi Kumar Gangwar received the B.Tech. degree in Electronics and Communication Engineering from U.P. Technical University, and Ph.D. degree in Electronics Engineering from the Indian Institute of Technology, Banaras Hindu University (IIT-BHU), Varanasi, India in 2006 and 2011, respectively. He is currently assistant Professor in Department of Electronics Engineering, Indian School of Mines, Dhanbad, India. He has authored or coauthored over 40 research papers in international/national journals/conference proceedings. His research interest includes dielectric resonator antenna, microstrip antenna, metamaterial and bio-electromagnetics. He is a member of the Antenna and Propagation Society and Communication Society, Institute of Electrical and Electronics Engineers (IEEE), USA. He is a reviewer of progress in Electromagnetic Research, International Journal of Electronics, International Journal of Microwave and Wireless Technology, Wireless Personnel Communication, Indian Journal of Radio and Space Physics (IJRSP), Indian Journal of Pure and Applied Physics (IJPAP) journals.

Binod Kumar Kanaujia joined Ambedkar Institute of Technology (AIT) Government of N.C.T. Delhi, Delhi-31 as Assistant Professor, Electronics and Communication Engineering in January 2008 through selection by Union Public Service Commission New Delhi. Before joining this institute he has served in the M.J.P. Rohilkhand University, Bareilly as Reader from 26 February 2005 to 30 January 2008 and Lecturer from 25 June 1996 to 25 February 2005 in Electronics and Communication Engineering Department and also served as Head of Department E&CE from 25 July 2006 to 30 January 2008. He has been an active member of Academic Council and Executive Council of the M.J.P. Rohilkhand University and played a vital role in the academic reforms. Prior to his career in the academics, Dr. Kanaujia has been working as Executive Engineer in the R&D division of M/s UPTRON India Ltd. Presently, Dr. Kanaujia is working as associate Professor in E&CE Dept. At Ambedkar Institute of Technology, Delhi and served on various key portfolios i.e. Head of Department of E&CE from 21 February 2008 to 05 August 2010, In-charge Central Library from March 2008 to Aug 2010. He under took to modernize and upgrade the Library with the introduction of fully automatic book issue and receiving, on-line journal, on-line retrieval of catalogue of the library and establishment of E-Library. Apart from this, he has been discharging the duty of head of office of this institute since 09 August 2008 and always exploring for good administration in the institute. Dr. Kanaujia has completed B.Sc. from Agra University, Agra, India in 1989 and B.Tech. in Electronics Engineering from KNIT Sultanpur, India in 1994. He did M.Tech. and Ph.D. in 1998 and 2004, respectively from Electronics Engineering Department IIT BHU Varanasi. He has been awarded Junior Research fellow by UGC Delhi in the year 2001–2002 for his outstanding work in his field. His has keen research interest in design and modelling of microstrip antenna, dielectric resonator antenna, left handed metamaterial microstrip antenna, shorted microstrip antenna, wireless communication and microwave engineering, etc. He has been credited to publish more than 80 research papers in peer-reviewed journals and conferences. He is member of IEEE, life members of the Institution of Engineers (India), Indian Society for Technical Education and The Institute of Electronics and Telecommunication Engineers of India.

Abhishek Sharma was born in Alwar, Rajasthan, India on 15 August 1988. He received the B.Tech. degree from Shri Mata Vaishno Devi University, Jammu and M.Tech. degree from Guru Gobind Singh Indraprastha University, Delhi both in Electronics and Communication Engineering, in 2010 and 2013, respectively. He is currently a research scholar at Indian Institute of Technology Kanpur, Kanpur. His current research interest includes Microstrip Antennas, Dielectric Resonator Antennas, Computational Electromagnetics. He is a graduate student member of IEEE and student member of European Microwave Association.