A Compact Dual Band Benz Logo Antenna with Staircase Structured Ground for Millimetre Wave (MMW) Applications

Subhash B K, Angulakshmi A, Abhishek K, Om Prakash Kumar, Tanweer Ali

Abstract:In this manuscript a novel design of an asymmetric coplanar a multiband millimeter wave (MMW) antenna is proposed with a size of $0.57\lambda_l \times 0.41\lambda_l \times 0.06\lambda_l$ $(5 \times 7 \times 0.8\,mm^3)$***, at a MMW frequency of 24.76 GHz. The proposed model consists of Benz logo shaped radiator with a staircase structured ground plane which independently controls the band at 24.76 and 37.52 GHz. The proposed model has bandwidth of about 850 MHz (23.85-24.7GHz) and 2740 MHz (36.21-38.95GHz). Acceptable gain with stable radiation patterns and high radiation efficiency are accomplished across the MMW operational bandwidths.***

Keywords—Benz Logo; dual band; staircase structure; MMW.

I. INTRODUCTION

5G system will be launched by 2020 and will be fully operational all over the world by 2025 [1-4].Higher 5Gbandsusesmillimeter wave (MMW) for transmission of high data. 5G system supports hundred to thousand time's higher capacity than 4G system. The size of antenna is reduced due to short wavelength of MMW which leads to reduction in cell size for short range MMW communication [5].To remove the signal loss of millimeter wave, massive MIMO, array and large gain antenna are used. With increasing potential of 5G millimetre wave, there are many challenges such as more number of antenna requirement, complex hardware and more power consumption [6-8]. Nevertheless, the MMW enjoys several advantages such as peak data rate of ten Giga bit per second unlike current 4G of peak data rate of one Giga bit per second;it gives 3 times higher spectrum efficiency compared to 4G system; provides greater mobility of 500 kilometres per hour [10] etc.

In this manuscript a simple configuration, compact microstrip Benz Logo antenna is discussed. The radiator of the discussed antenna consists of Benz logo shape whilethe ground part consists of staircase structure. With the help of aforementioned ground structure higher MMW operations are achieved at 24.76 GHz with a total bandwidth of 850 MHz, and 37.52 GHz with a bandwidth of 2740 MHz. The antenna has a high gain and efficiency with stable radiation pattern.

Revised Manuscript Received on May 9, 2019.

Subhash B K is with School of Electronics and Communication Engineering , REVA University, Bangalore, India

Angulakshmi A is with School of Electronics and Communication Engineering, REVA University, Bangalore, India

Abhishek K is with School of Electronics and Communication Engineering, REVA University, Bangalore, India

Om Prakash Kumaris with the Department of E&C, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal.

Tanweer Ali is with the Department of E&C, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal. (corresponding author-tanweer.ali@manipal.edu)

II. ANTENNA CONFIGURATION AND DESIGN

The Benz logo radiator and the edges of the staircase ground structure contribute in radiating a frequency of 24.76 GHz and the ground contributes proficiently when it radiates a frequency of 35.72 GHz frequency. The detailed parametric analysis of the antenna is conducted and the optimum dimensions have been considered which then results in high gain, good efficiency and efficient radiation pattern.

The main focus of the discussed work in this manuscript is to design a very compact antenna for MMW 5G applications. This objective is achieved by utilizing a Benz Logo Shaped radiator and a staircase structured ground plane. The antenna layout is outlined in Fig.1.The dimensions of the proposed structure is presented in Fig.2. The proposed antenna is modeled on RT Duroid 5880 substrate having δ=0.0009, h= 0.8mm and ε_r= 2.2. Power excitation in the discussed model is achieved by utilizing microstrip feeding which also helps to meet the impedance matching requirement of 50Ω.

A. Antenna Configuration

The proposed antenna has a radiator with Benz logo shaped radiator and a staircase structured ground plane and is depicted in Fig.1. Both the radiator and the ground plane together resonates at 24.76 and 37.52 GHz. The proposed antenna can be used for MMW 5G communication. The overall layout of the discussed antenna model is outlined in Fig.2. Where, L= 7mm, W= 5mm, Wf= 0.4mm, L_f= 2.18mm, R1= 0.6mm, R2= 1.67mm, L1= 1.41mm, L2= 1.55mm, P4=2.7mm, Q3= 0.62mm, P3= 0.8mm, P2= 1mm, Q2= 0.5mm, P1= 0.5mm and Q1= 0.5mm.

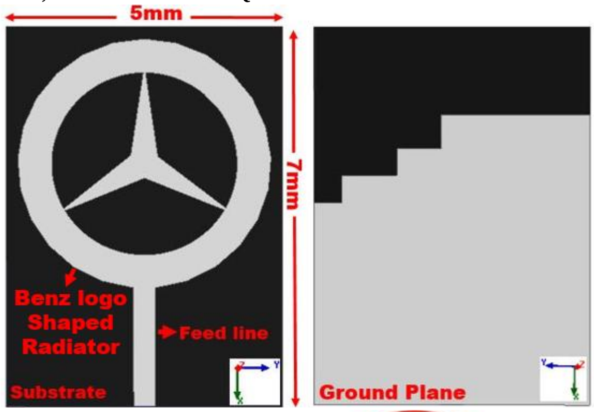

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Fig.1: Discussed antenna model structure layout.

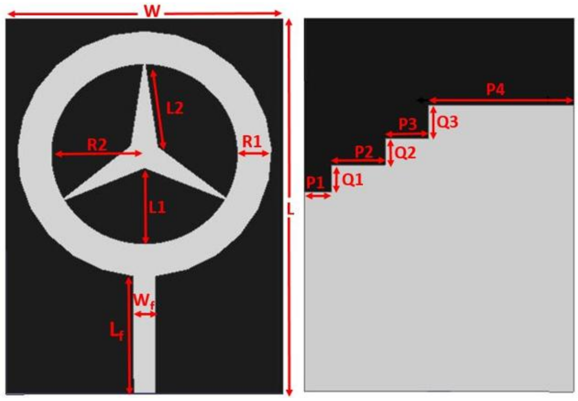

Fig. 2: Detailed layout of the proposed antenna

B. Design Equation

The equation (1)-(2) are used in designing of the antenna [15]. The first operating frequency (f_r) can be calculated as,

$$f_r = \frac{1.8412 \times c}{2\pi \times \text{a} \times \sqrt{\varepsilon_{reff}}} \qquad (1)$$

$$a = r\sqrt{1 + \left\{\frac{4h}{2\pi \times \text{r} \times \varepsilon_r}\left[\ln\left(\frac{2\pi \times \text{r}}{4H}\right) + 1.77\right]\right\}} \qquad (2)$$

The calculated values are further optimized to get the concerned frequency of operation.

III. Analysis Of The Antenna

Antenna analysis is carried out to know and understand the overall surface current flow phenomenon of the antenna. Various factors are taken into consideration and then the optimum dimensions of the antenna is decided. This study is called parametric analysis and this plays a major role in the design of any antenna.

A. Effect of Staircase structure in the ground plane

The ground plane is varied with respect to staircase structure as outlined in Fig. 3and the corresponding $S_{11}$is observed and evaluated in Fig.4. From Fig. 3, Antenna-A without staircase structure at the ground plane is shown which resonates at 34.45 GHz and Antenna-B with staircase structure in the ground plane is responsible for resonating additionally at 24.76 GHz.The etching of staircase structure disturbs the surface current flow of the antenna, thereby increasing its total electrical length path, which in turn make the antenna to achieve additional resonance. Also, one can study that etching of staircase structure tends the initial band at 34.45 GHz to shift at 37.52 GHz, which may be mainly due to the change of electrical size of antenna. Both theradiator and the Staircase ground plane together contributes the operation at 24.76 and 37.52 GHz as outlined in Fig.4.

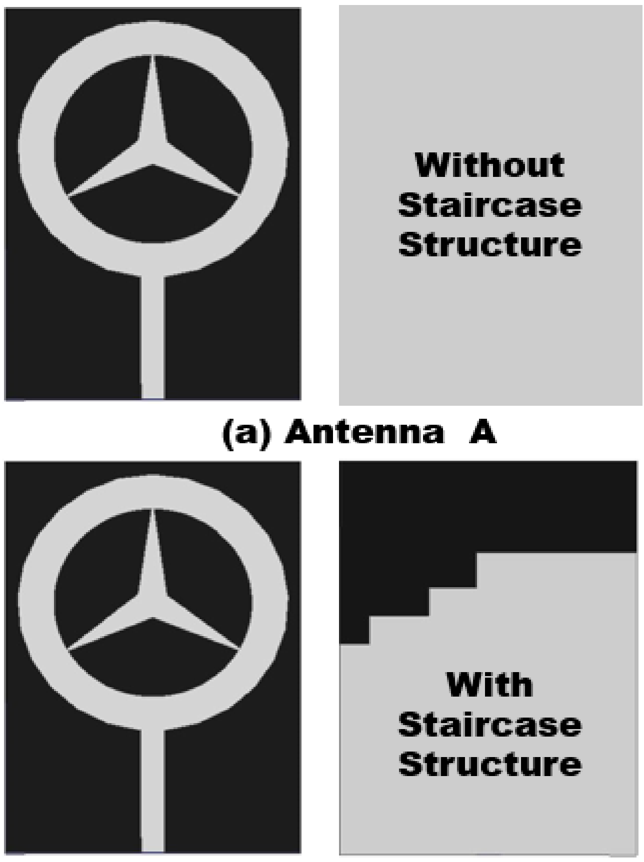

Fig. 3: Effect of Staircase structure in the ground plane (a) Antenna A (b) Antenna B

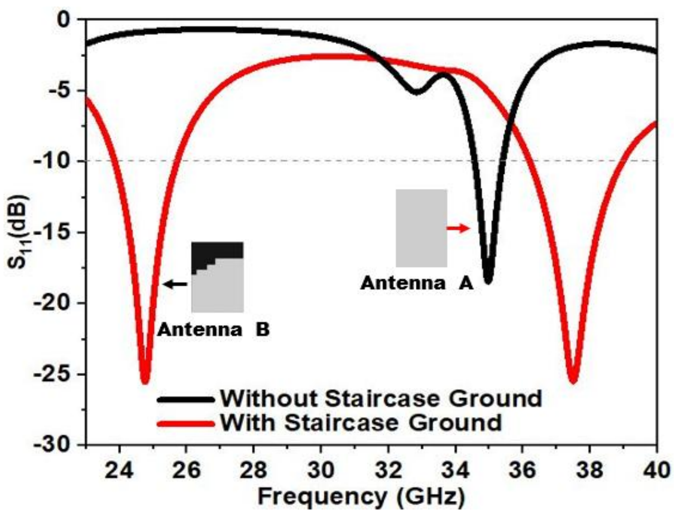

Fig.4: S11 for the Effect of Staircase structure in the ground plane

B. Effect of R1 on the antenna.

The R1 is varied and the corresponding impedance match is observed and evaluated. R1 is modifiedfrom 0.3 to 0.9 mm, as outlined in Fig. 5. It is observed that the best match for both the bands to operate simultaneously is at W_f=0.6mm.

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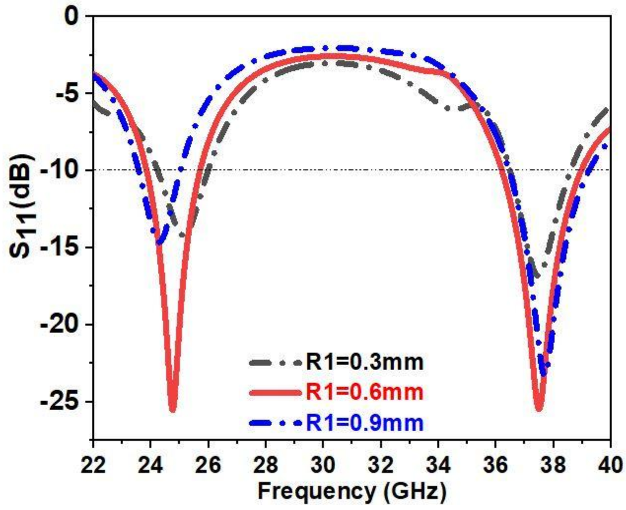

Fig. 5: Effect of R1 on the antenna.

C. Effect of feed width on the antenna.

The feed width is varied and the corresponding impedance match is observed and evaluated. Feed width is modifiedfrom 0.2 to 0.6mm, as outlined in Fig. 6. It is observed that the best match for both the bands to operate simultaneously is at W_f=.40mm.

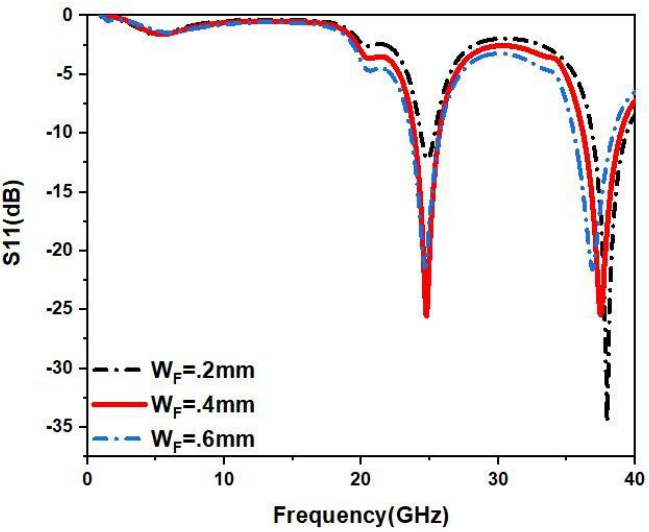

Fig. 6: Effect of feed width on the antenna.

D. Current Distribution

To study the variation of current length path of the antenna, the current distribution is studied and is used to analyze its resonance behavior as outlinedin Fig. 7. At 24.76 and 35.72GHz we can see that the Benz logo radiator and staircase structured ground plane radiate more than the rest of thestructure. Hence, we can say that the entire operation depends on Benz logo radiator and staircase structured ground plane.

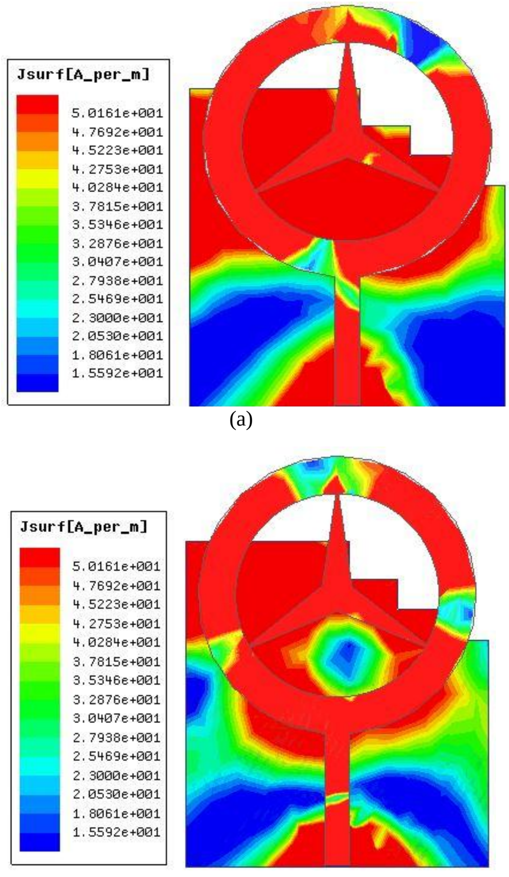

Fig. 7: Surface current distributions at (a) 24.76 and (b) 37.52 GHz

IV. RESULT

The proposed model is simulated on High-frequency Structure Simulator (HFSS) v.13.0 using the FEM method using lumped port excitation. The material substrate used in designing the antenna isRT Duroid 5880 substrate having δ=0.0009, h= 0.8mm and ε_r= 2.2, with total antenna volume of $28mm^3 (7 \times 5 \times 0.8mm^3)$. The simulated S_{11} result of the proposed design is outlined in Fig.8. It is observed that the antenna resonates at 24.76 and 35.72 GHz (dual band) with negligible return loss. The antenna has S_{11}<-10dB bandwidth of about 7.7% (23.85-24.7GHz) and 7.56% (36.21-38.95GHz). The obtained bandwidth can be used to meet the spectrum requirements of MMW 5G wireless applications.

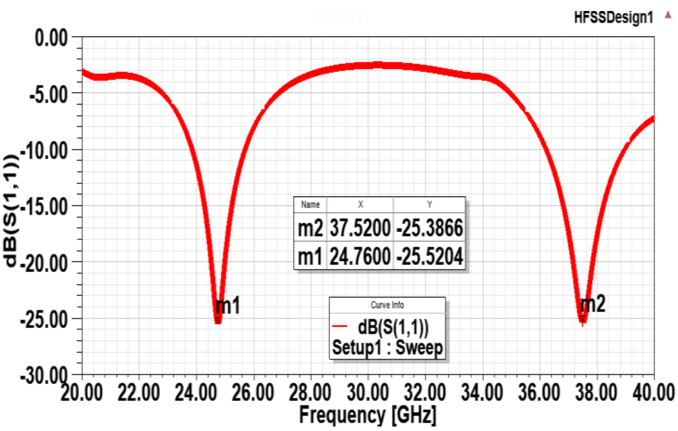

Fig. 8: S_{11} of the modeled antenna

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A. Impedence Matching:

To study the input impedance characteristics of the model, its imaginary and real part is analyzed and outlined in Fig. 9. At 24.76 GHz,it has an input impedance of (55.58-j0.18) ohms (capacitive nature) and at 35.72 GHz it has an impedance of (45.14 + j1.61) ohms (inductive nature).

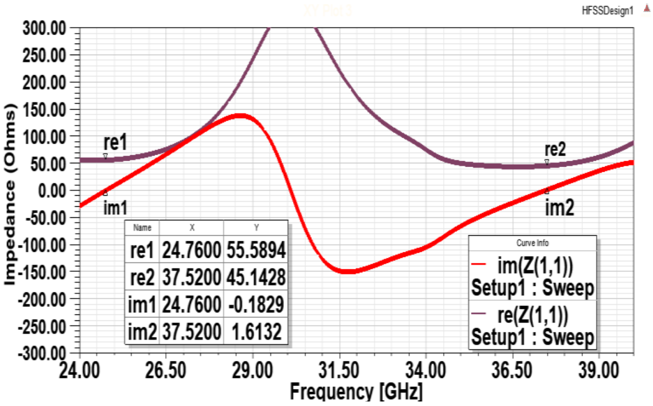
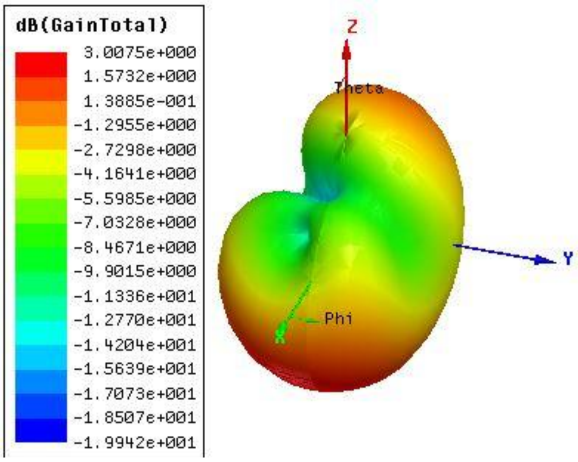


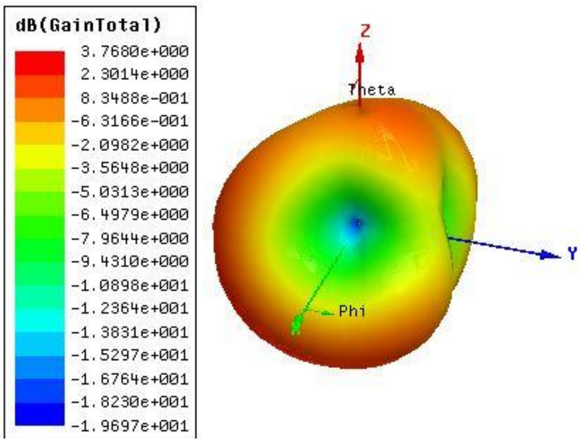
Fig. 9: Impedance matching of the proposed design

B. Gain:

The 3-D gain plot of the dual band model is studied and outlined in Fig.10. At 26.74 GHz, antenna has a gain of 3 dB and at 35.72 GHz antenna has a gain of 3.76dB.



(a)



(b)

Fig. 10: 3-D gain plot of the model at (a) 24.76 and (e) 35.72 GHz.

C. Radiation Efficiency:

To know how well the antenna radiates in the given environment,its radiation efficiency is studied and is outlined in Fig. 11. The antenna has a radiation efficiency of 98% at 24.76 and 99% at 37.52 GHz.

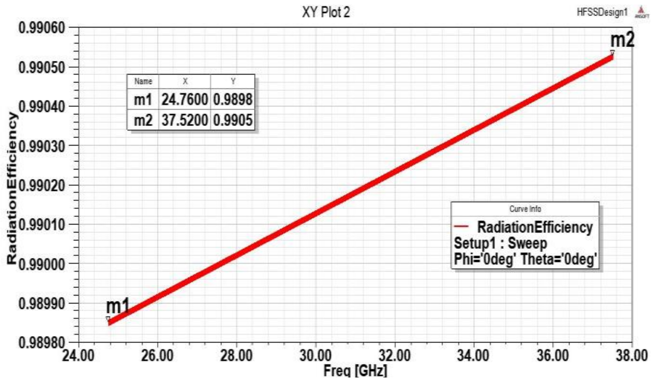
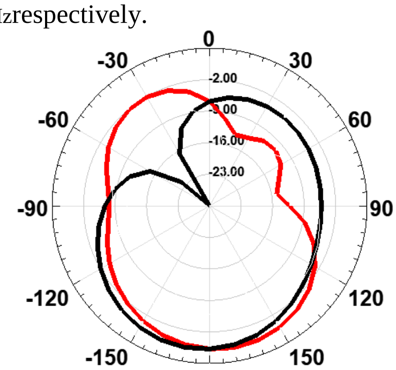


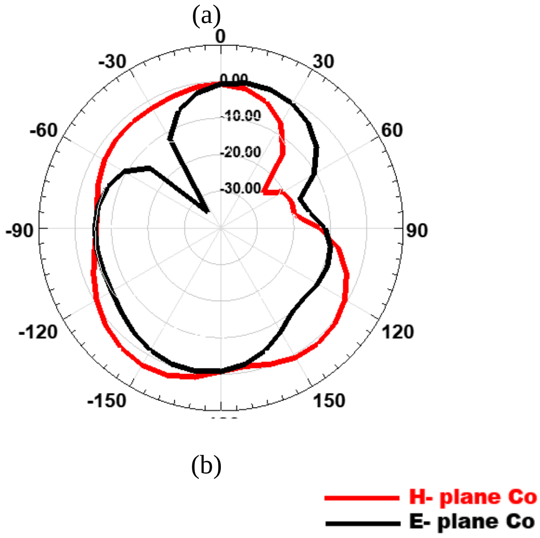
Fig. 11: Radiation efficiency of the model at 24.76 and 35.72 GHz

D. Radiation pattern:

For an antenna with good radiation characteristics it must have a stable radiation pattern. The proposed model has omni-directional pattern in H-plane and bi-directional pattern in E-planeis depicted in Fig.12. for 24.76 and 37.52 GHzrespectively.



(a)



(b)

Fig. 12. Radiation pattern of the model at (a) 24.76 and (b) 37.52 GHz

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V. CONCLUSION

A dual band antenna for MMW 5G wireless application is studied and designed. The proposed model has a volume of 28mm^3 and is highly compact and can be easily integrated with wireless portable terminal devices. The operating frequencies have acceptable gain and shows good radiation efficiency. Parametric analysis reveals that the current distribution is maximum at the Benz logo radiator and the staircase structured ground plane which helps in achieving the operation at 24.76 and 35.72 GHz. The proposed model has the advantage of miniaturized size, simple configuration, planar structure, high radiation efficiency, good impedance matching and acceptable gain thereby, making it highly suitable for MMW 5G applications.

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AUTHORS PROFILE

Subhash B Kis an Assistant Professor in the School of Electronics and Communication Engineering, REVA University, India. He worked as Junior Research Fellow in the field of Antenna design. He is currently continuing his research on microstrip patch antenna. His research area includes Multiband antenna, Metamaterial - based antenna, Reconfigurable antennas, Ultra wide band antenna and millimeter wave 5G antennas. He has over 18 research publications in reputed international journals and IEEE Scopus indexed conferences. His research articles have been published in the journals like Microwave Optical Technology Letters (MOTL) Wiley; Progress in Electromagnetic Research C (PIER Cambridge, USA) and IEEE Xplore Digital Library.

Angulakshmi A, B.TECH. School of Electronics and Communication Engineering, REVA University, Bangalore, India. Her research area includes Multiband antenna and millimeter wave 5G antennas.

Abhishek K, B.TECH. School of Electronics and Communication Engineering, REVA University, Bangalore, India. His field of interest is in data communication and networking.He has over 2 research publications in reputed international journal and IEEE Scopus indexed conferences.

Om Prakash Kumaris an Assistant Professor in the Dept. of Electronics & Communication Engineering at Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal. His research field includes UWB Antennas, Multiband antennas and metamaterial antennas.

Dr. Tanweer Ali is an Assistant Professor in the Dept. of Electronics & Communication Engineering at Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal. He is an active researcher in the field of microstrip antennas, wireless communication and microwave Imaging. He has published more than 55 papers in reputed peer reviewed international journal and conferences. He is a senior member IEEE (SMIEEE), and Associate Member of IETE India. He is on the board of reviewers of journals like the IEEE Transactions on Antennas and Propagation, IEEE Antennas and Wireless Propagation Letters, IET Microwaves, Antennas & Propagation, IET Electronics letter, Wireless Personal Communication (WPC), Springer, AEU-International Journal of Electronics and Communications, Microwave and optical Technology letters (MOTL), Wiley, International Journal of Antennas and Propagation, Hindawi., Advanced Electromagnetics, Progress in Electro Magnetics Research (PIER), KSII Transaction of Engineering Science, Korea, International Journal of Microwave and Wireless Technologies, Frequenz, Radioengineering etc.