Design and Analysis of 2X2 MIMO System for 2.4 GHz ISM Band Applications

Harshal Nigam, Mithilesh Kumar

***Abstract*— In, this paper compact antennas have been designed and implemented in a 2X2 Multiple-Input Multiple-Output (MIMO) system. The antennas are compact double-sided printed microstrip patch antennas and fed by a microstrip line designed for a frequency of 2.4 GHz used for industrial, scientific and medical (ISM) band applications. The antennas are designed on CST Microwave studio simulation software with return loss less than -10dB. Furthermore, the MIMO system is designed using polarization diversity of the individual antennas which yields better result in terms of return loss (S_{11} and S_{22}) and mutual coupling (S_{12} and S_{21}). The system is designed for 802.11n Wi-Fi family of standards that has an operation frequency of 2.4 GHz but with MIMO system that offers an increased data rate.**

***Index Terms*— Double-sided Printed, Industrial Scientific and Medical (ISM), Multiple Input Multiple Output (MIMO)**

I. INTRODUCTION

MIMO technology has attracted attention in wireless communications, because it offers significant increases in data throughput and link range without additional bandwidth or transmit power. It achieves this by higher spectral efficiency (more bits per second per hertz of bandwidth) and link reliability or diversity (reduced fading), because of these properties, MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (Wi-Fi), 4G, 3GPP Long Term Evolution, WiMAX and HSPA+, by using MIMO, additional paths can be used to increase the capacity of a link as in [1]. It provides very promising gain in capacity without increasing the use of spectrum, reliability, throughput, power consumption and less sensitivity to fading.

The industrial, scientific and medical (ISM) radio bands are radio bands (portions of the radio spectrum) reserved internationally for the use of radio frequency (RF) energy for industrial, scientific and medical purposes other than telecommunications as in [2]. The 2.4 GHz ISM band is used for many applications like for Wi-Fi family of standards (802.11 a, b,g,n..), cordless phones, wireless medical telemetry equipments and Bluetooth short range wireless applications

In this paper, a simple and compact planar antenna is designed that shows acceptable return loss for 2.4 GHz ISM band frequency. This antenna is further used in the design of a 2X2 MIMO system having two antennas on the transmitting side and two on the receiving side respectively.

When multiple antennas are involved at closer spacing the technical challenges are more pronounced compared to a SISO (Single Input Single Output) system. Hence, the basic aim of MIMO antenna design is to minimize the correlation between the multiple signals as in [3]. The parameter that describes the correlation between the received signals is mutual coupling, as it may affect the performance of the system. By calculating the mutual coupling, one can analyze the electromagnetic field interactions that exist between antenna elements of a MIMO system. The mutual coupling mainly depends on the distance between the elements of an antenna array. The distance between antenna elements in practice cannot be extended beyond a certain level which limits the use of spatial diversity to achieve the desired spectral efficiencies and transmission qualities. As an alternative solution to achieve compactness in MIMO systems, the use of pattern diversity as in [4,5], multimode diversity as in [6], and polarization diversity techniques as in [7] in conjunction with space diversity are discussed in the literature.

In the present design, the orthogonal polarization concept is applied to the proposed multi slot patch antenna yielding better results in terms of return loss and mutual coupling. In a typical case of linear polarization diversity, signals are transmitted and received via horizontally polarized as well as vertically polarized antennas. The orthogonality of two distinct polarizations constructs independent and uncorrelated signals on each antenna and thus, leads to potentially a full-rank MIMO channel and a full rank MIMO channel obviously gives improved channel capacity.

This paper is organized as follows. In Section II, the design methodology and structure of a single antenna is described along with the simulation results. Section III incorporates the use of above antenna to design a MIMO array which is further analyzed for different parameters. In Section IV the above antennas are used in a 2X2 MIMO system, polarization diversity is applied to the above MIMO antennas and simulated results are analyzed further and Section V concludes the analysis of the paper.

II. SINGLE ANTENNA DESIGN

A. Antenna Design

The antenna is designed on a substrate printed on both sides, on one side is the patch and other side is a ground plane. The patch is fed by a micro strip feed line, appropriate matching of the feed line is required to produce desired characteristics of the antenna.

The geometry of the given antenna is illustrated in Fig.1. It is fabricated on a 76.8 X 57.8 mm^2 FR-4 substrate with a dielectric constant of 4.3 and a substrate thickness of 1.6 mm.

Manuscript received May, 2014
***Harshal Nigam**, Electronics Engineering Department, University College of Engineering, Rajasthan Technical University, Kota, India*
***Mithilesh Kumar** Electronics Engineering Department, University College of Engineering, Rajasthan Technical University, Kota, India,*

The top and bottom patches printed on the substrate are the radiating structure and the ground plane. The back view is shown in Fig.2.The top patch of the substrate has dimension of 39.4 X 28.9 mm^2 which is fed by a strip line having a width of 3.1 mm. The bottom patch of substrate is just a ground plane. The proposed antenna has been simulated by CST Microwave studio.

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B. Antenna Simulation Analysis

The simulation results of the antenna are shown in Fig.3, from the simulated graph it is observed that for frequency of 2.4 GHz, S_{11}<-10dB. The VSWR plot for the antenna is also shown in Fig.4 which is about 1.04 at 2.4 GHz frequency showing good matching conditions.

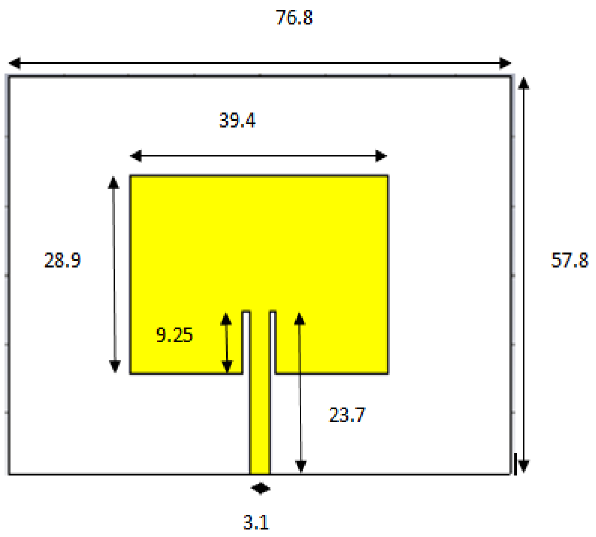

Fig.1. Antenna geometry with dimensions in mm (front view)

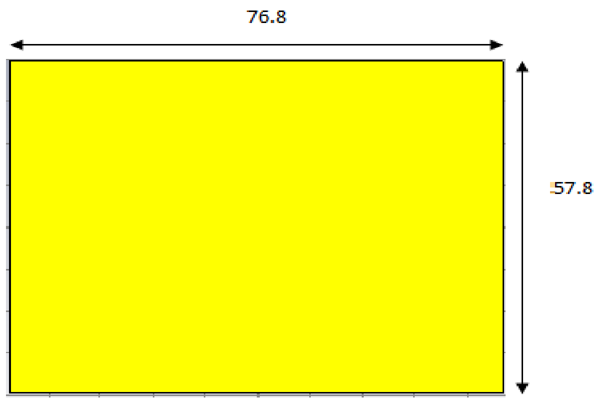

Fig.2. Antenna geometry with dimensions in mm (back view)

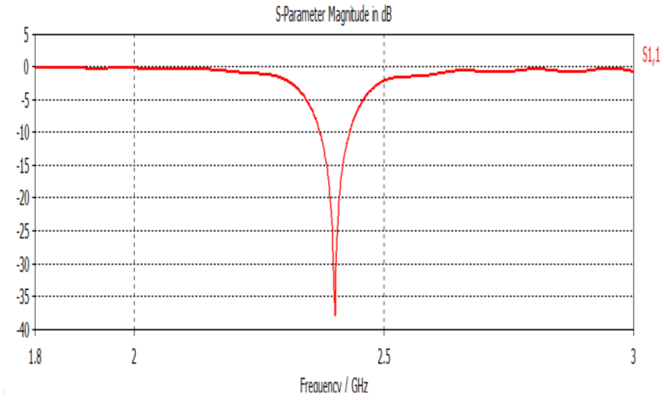

Fig.3. Return loss for the antenna

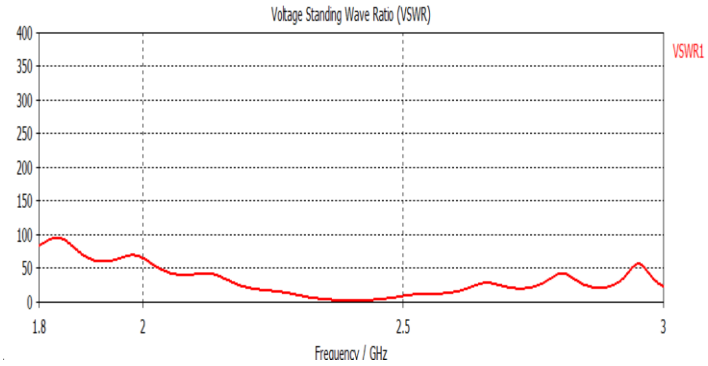

Fig.4. VSWR plot for the antenna

III. MIMO ARRAY DESIGN AND ANALYSIS

The main criteria for MIMO system design is mutual coupling, which mainly arises due to the smaller spacing between the two antennas, when multiple antennas are involved at closer spacing the design issues are more complicated. The mutual coupling mainly depends on the distance between the elements of an antenna array, by increasing the distance between the elements of the antennas, the mutual coupling can be reduced. However, the distance between the antennas cannot be maintained too large, since MIMO systems have their major applications in mobile terminals, laptops, MODEMs, WLAN Access Points etc., where miniaturization is the main task. Hence, we can achieve less mutual coupling by another means known as diversity concept. There are various diversity techniques like, spatial diversity, polarization diversity and pattern diversity for MIMO systems. In all these techniques, the mutual coupling can be mitigated more with the use of polarization diversity. The orthogonality of two distinct polarizations constructs independent and uncorrelated signals on each antenna.

In the design of our system to achieve orthogonal polarization, one antenna is rotated to 90^0 with respect to its adjacent element as shown in the Fig.5.The separation between the antennas is 18.75 mm which is 0.15 λ. The antennas in the array have the same dimensions as mentioned in Section II. The antennas are mounted on a substrate symmetrically with εr = 4.3, which in turn is mounted on a ground plane. The above two port system is simulated on CST Microwave Studio simulation software. The array is further analyzed for the following parameters.

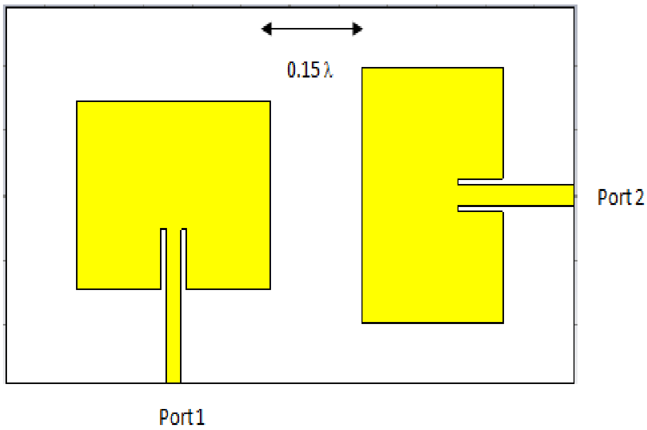

Fig.5. MIMO array of two antenna

A. Return Loss

The plots in Fig.6 and Fig.7 show the S_{11} and S_{22} plots respectively after simulation. We can observe that S_{11}<-10 dB for the 2.4 GHz ISM band frequency and also S_{22}<-10 dB for this frequency. Thus, both antennas are meeting the specified requirement of return loss.

B. VSWR

The plots in Fig.8 and Fig.9 show the corresponding VSWR at the two ports for the two antennas. We can observe that VSWR1=1.23 and VSWR2 =1.08 for the 2.4 GHz ISM band frequency which are less than 2 indicating improved matching conditions.

C. Mutual Coupling

The plots in Fig.10 and Fig.11 show the S_{12} and S_{21} plots for the two port system, we can observe that both S_{12} and S_{21}<-15 dB for the 2.4 GHz ISM band frequency, thus the two antennas are nearly independent of each other and value of mutual coupling between the two antennas is very low.

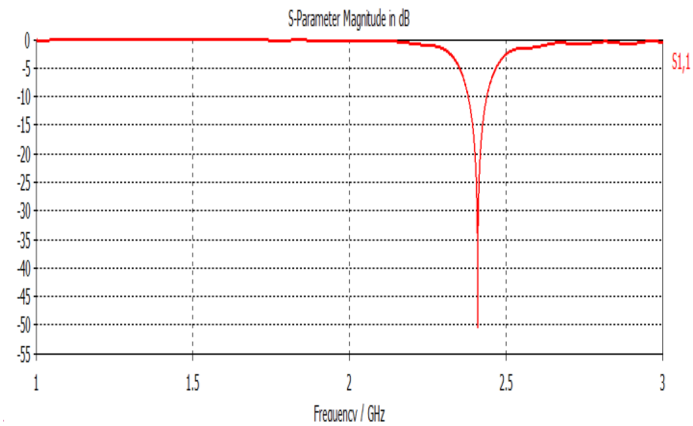

Fig.6. Plot for S_{11}

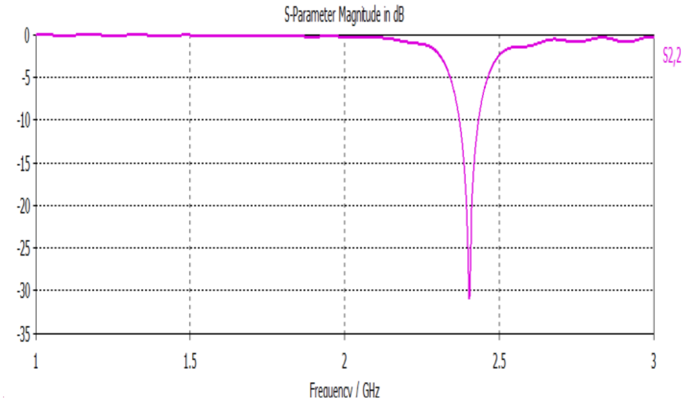

Fig.7. Plot for S_{22}

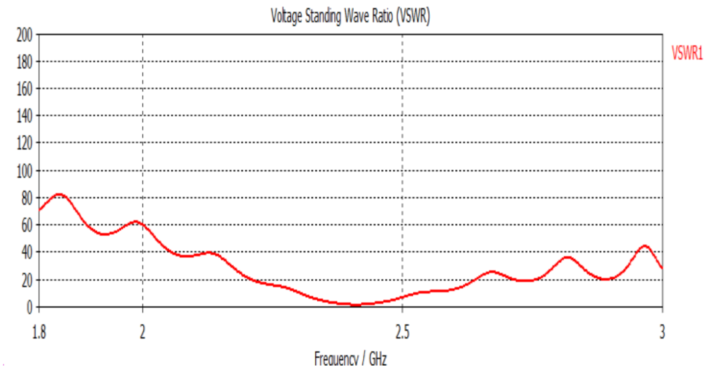

Fig.8. VSWR plot for 1st port

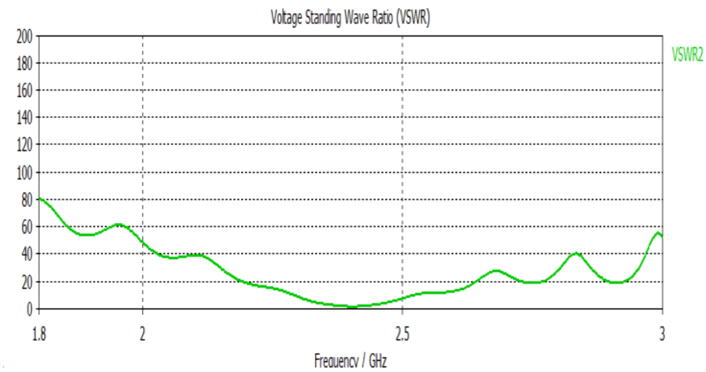

Fig.9. VSWR plot for 2nd port

D. Correlation Coefficient and Diversity Gain

We also calculate the correlation coefficient and diversity gain for the two antenna array. Correlation coefficient formula using S parameters is given as in (1)

$$\rho = \frac{\left|S11^{*} S12 + S21^{*} S22\right|^{2}}{\left(1 - \left|S11\right|^{2} - \left|S21\right|^{2}\right)\left(1 - \left|S22\right|^{2} - \left|S12\right|^{2}\right)} \quad (1)$$

ISSN: 2278 – 1323

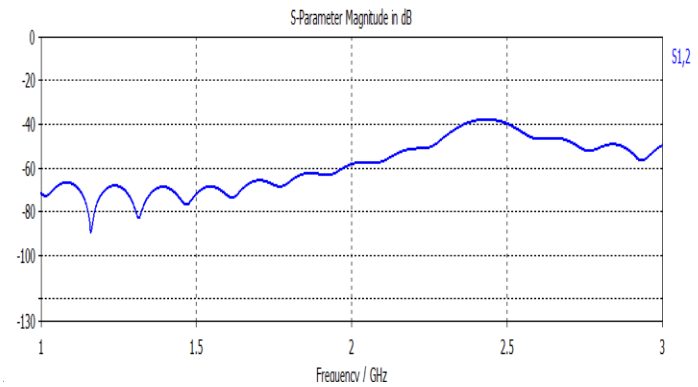

Fig.10. Plot for S_{12}

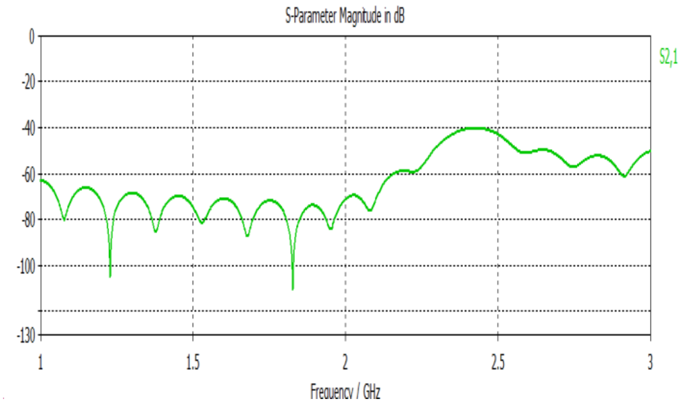

Fig.11. Plot for S_{21}

The plot of correlation coefficient with frequency is shown in Fig.12. We can observe that the value of correlation coefficient is very low for the frequency of 2.4 GHz. This is good because coefficient correlation should be < 0.1 for MIMO antenna. Diversity gain is the increase in signal to noise ratio due to the diversity scheme which is given by the formula as in (2)

$$DG = 10 * \sqrt{1 - (0.99 * \rho)^2} \quad (2)$$

It comes out to be 9.9 dB, which shows an acceptable gain in terms of diversity.

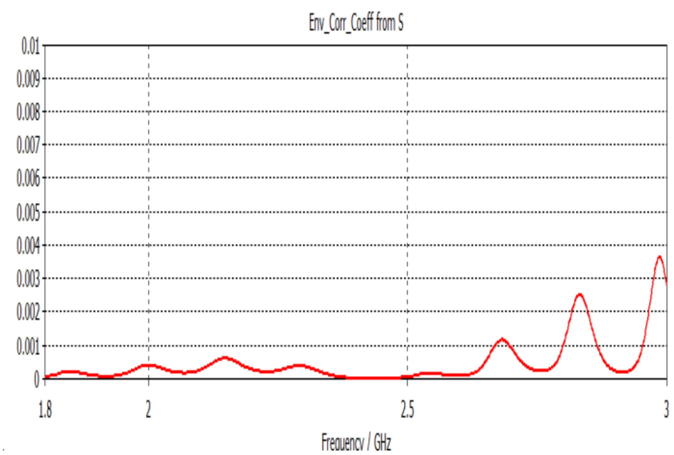

Fig.12. Plot for correlation coefficient

IV. DESIGN OF 2x2 MIMO SYSTEM

We have designed the transmitting section, having two antennas that are mutually independent of each other, now for the receiver side we again take the same two antennas separated by the same distance as the transmitting antennas with ports numbered 1 and 2 for transmitting side and ports 3 and 4 for the receiving side as shown in Fig.13. The distance between transmitting and receiving sides is taken to be 30mm which is greater than the far field distance of the antennas.

The four port system is simulated on CST Microwave Studio and the channel matrix for the system can be calculated by observing S_{31}, S_{32}, S_{41} S_{42} from the simulation plot of the four port system as in Fig.14, at a frequency of 2.4 GHz, these will be the coefficients of the channel matrix, as the S parameters simply denote the ratio of received and transmitted voltages, these ratios denote channel matrix coefficient. The channel matrix for the 2X2 system is as in (3)

$$H = \begin{matrix} S31 & S32 \\ S41 & S42 \end{matrix} \quad (3)$$

This channel matrix can be used for transmission and reception on this MIMO system.

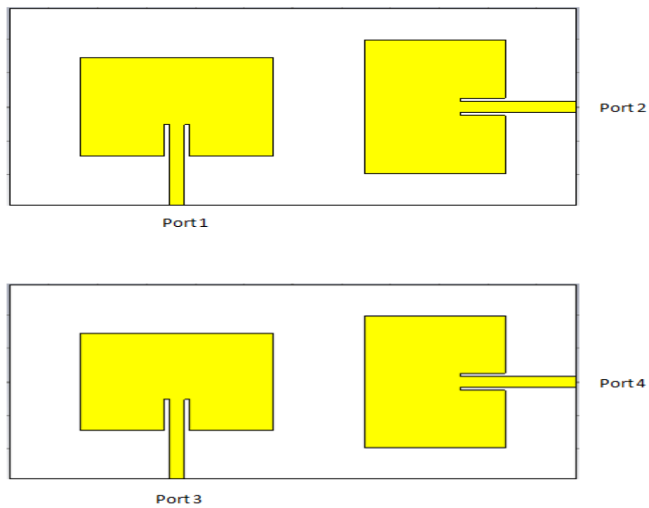

Fig.13. 2X2 MIMO system with four ports

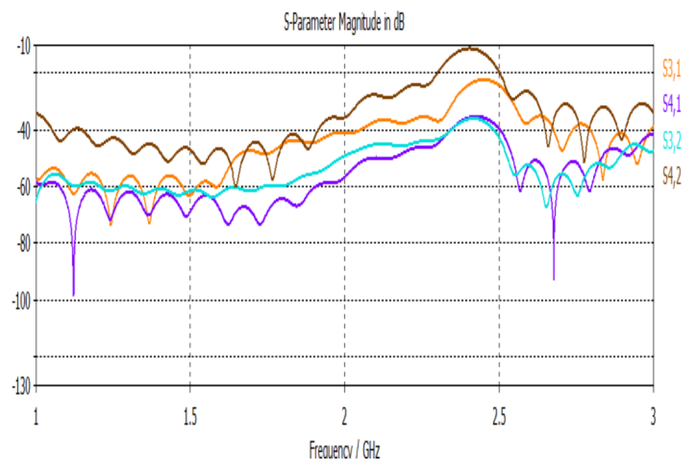

Fig.14. Simulation result for the 2X2 MIMO system

V. CONCLUSION

A new methodology has been defined by designing practical 2X2 MIMO system along with the design considerations. The system is operating on 2.4 GHz ISM band frequency using practical antennas designed on CST Microwave studio. We have analyzed various parameters of the MIMO array and found that the antennas in the MIMO system are operating independently of each other which is a necessary requirement for MIMO system design. MIMO systems offer an increased capacity but this requires a complex design and problems associated with mutual coupling need to be taken care of otherwise they create huge interference, also the cost for designing the system is high.

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Harshal Nigam (B.E 2011) received the B.E degree in Electronics and Communication Engineering from College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur, Rajasthan, India in 2011. Currently, he is pursuing his Masters degree in Digital Communication from University College of Engineering, Rajasthan Technical University, Kota, Rajasthan India. He is the author of 2 research papers in International Conferences technically sponsored by IEEE. His research interest focuses on RF Communication, UWB antenna system design and also in the field of Wireless communications. He became a student member of IEEE in 2013.

Mithilesh Kumar (B.E. 1992–M.Tech. 1999–Ph.D. 2011) received the B.E degree in Electronics and Communication Engineering from Government Engineering College, University of Rajasthan, Kota, Rajasthan, India in 1992, M.Tech. degree in Communication and Radar Engineering in 1999 and Ph.D. degree in RF Communication Engineering from the Indian Institute of Technology Delhi, India in 2011. He served as a Lecturer (1993-2000), Sr. Assistant Professor (2000-2008) and Associate Professor (2008-2013) at Rajasthan Technical University, Kota, Rajasthan, India. Currently he is a Professor (2013-till date) at the same university. He is author/ co-author of 85 Research papers in referred Journals, International and National conferences. His current research interests include RF Communication, UWB Active Antenna, Microstrip Antenna and Microwave Device Designing Technology. Dr. Kumar received " First prize best student paper platinum award" in 2009 at the IEEE International Conference on Antennas, Propagation and Systems (INAS-2009) held at Johor Bahru, Malyasia from December 3-5, 2009.

