Designing of Patch Antenna: A Review

[1]Sachin Sharma, [2]Kumar Goodwill, [3]Avinash Kumar Dubey,
[4]Ravi Kumar Dhakad, [5]M.V. Kartikeyan
[1,2,3]Dept. of ECE, SET, Sharda University, Gr. Noida, India
[4,5]Dept. of Electronics & Computer Engg., Indian Institute of Technology Roorkee, Uttarakhand, India

Abstract
In this paper we have discussed the design techniques of rectangular, circular and triangular types of Microstrip Patch antennas. Their resonance frequency dependency on the structure of the antennas is also been discussed. Further we have given a thorough explanation of feeding techniques to these microstrip patch antennas and as well as dependency of gain and bandwidth of the antennas to the feeding techniques is also been discussed.

Keywords
Patch Antennas, Co-axial Feed, Aperture Feed, Proximity Coupling, Gap Coupling

I. Introduction

Microstrip antennas, often referred to as patch antennas consists of very thin metallic patch(usually gold or copper) placed a small fraction of a wavelength above a conducting ground plane, separated by a dielectric substrate. While the antenna can be 3-D in structure (wrapped around an object, for example), the element are usually flat; hence their other name, planar antennas. Note that not all planar antennas are always a patch antenna. Fig. 1 shows the basic form of patch antenna: consisting of a flat plate (or patch) of copper or gold over a ground plane. The gap between flat plate and ground plane is filled with substrate having dielectric constant, usually greater than 2. Feed probe is used to couple electromagnetic energy in and /or out of the patch.

The electric field is zero at the center of the patch, maximum (positive) at one side and minimum (negative) on the opposite side. These maximum and minimum sides change their position depending upon the instantaneous phase of the applied signal. At the periphery of the patch, electric field doesn't stop abruptly, while it extends outside the patch upto some degree. These extension fields are known as fringing fields and cause the patch to radiate. Modeling techniques of patch antennas generally used the concepts of leaky-cavity. The fundamental mode of a rectangular patch is often denoted using cavity theory as the TM10 mode.

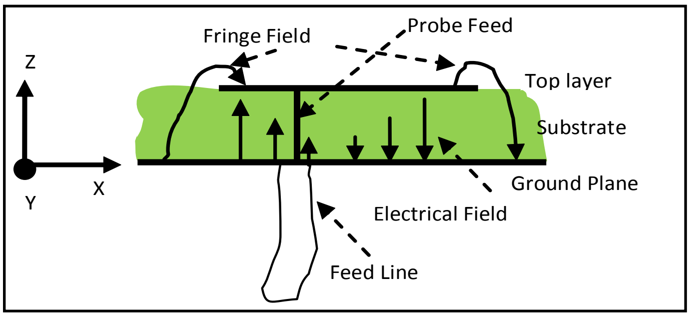


Fig. 1: Basic Form of Patch Antenna

The radiating portion or patch can be rectangle, circle, ring, triangular etc. This patch is printed on the dielectric substrate through the photo etched method like that of PCB making. Microstrip patch antennas have several advantages like, light weight, low manufacturing cost, small in size, easy to manufacture, robust and compatible with microwave monolithic integrated circuits designs. Major setback is, their low efficiency and low operating range (Band Width), which is not quite impressive but there are several methods by which improvement can be done in their efficiency and band width. One such technique, for enhancing band width, is stacking patches either horizontally or vertically [5-7]. The bandwidth of the patch antenna can be increased by increasing the substrate thickness h or with decrease in the dielectric constant εr. However, one cannot increase the h beyond $0.1\lambda 0$ otherwise surface-wave propagation takes place, resulting in degradation in antenna performance. Microstrip antennas can be designed with variable resonant frequency, impedance, polarization and pattern just by adding loads between the patch and the ground plate, such as pins and varactordiodes [1].

Microstrip patch antennas has tremendous applications in military, radar systems, mobile communications, global positioning systems, remote sensing, aircraft, missile and mobile applications where size, weight, cost, performance, ease of installation are constraints, and low profile antennas are required. Patch antennas also used in wireless local area networks to provide high-speed data connections between wireless access points and mobile devices.

In this paper we have reviewed and briefed about various design techniques used to design different type of patches, their feeding techniques, effect of substrate on the resonant frequency and their radiation pattern. This paper is written specially for the engineering students and teachers for their better understanding of patch antennas and their design techniques.

II. Designing of Different Types of Patch

Transmission line model, leaky cavity model and full wave model provides better results of analyzing the Microstrip patch antennas. The simplest one is transmission line model and it gives good physical insight too. In this paper we will consider the equations based on transmission line model only.

A. Rectangular Patch

This model represents the Microstrip antenna by two slots of width W and height h, separated by a transmission line of length L. The resonant length determines the resonant frequency and is about $\lambda/2$ for a rectangular patch excited in its fundamental mode. Because of fringing fields, the patch is electrically a bit larger than its physical dimensions. This deviation is mainly dependent on the board thickness and dielectric constant. Fig. 1 shows the rectangular patch.

All of the formulas [2] are independent of the feed except for the input resistance formula, which assumes a coaxial feed. All these formulas assumes that patch is operating at the resonance of the TM10 mode.

Because of the quasi-TEM mode and the dominant mode of propagation, effective dielectric constant must be obtained in order to account for the fringing. Effective dielectric constant is slightly less than that of substrate, because the fringing fields are not confined in the dielectric substrate only but are also spread in the air.

 ISSN : 2230-7109 (Online) | ISSN : 2230-9543 (Print)

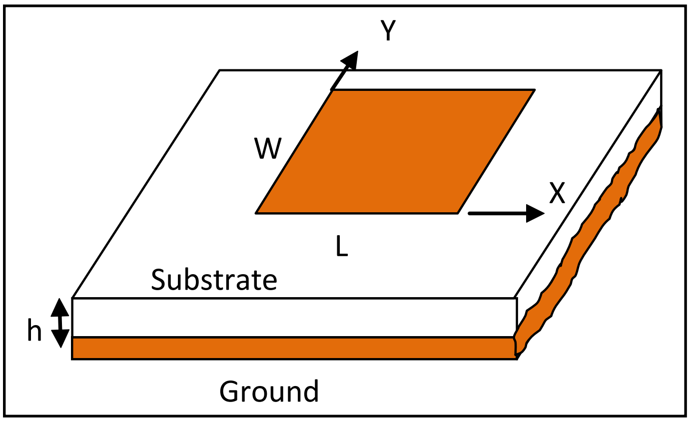


Fig. 2: Dimensions of Rectangular Patch

The expression for effective dielectric constant is

$$\varepsilon_{\text{eff}} = \frac{\varepsilon_r+1}{2} + \frac{(\varepsilon_r-1)\left(1+12\frac{h}{W}\right)^{-1/2}}{2}$$

The fringing extension added to the resonant (L) dimension is given by

$$\Delta L/h = \frac{0.412(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}$$

Resonance frequency is given by [3]:

$$f_o = \frac{c}{2(L+2\Delta L)\sqrt{\varepsilon_{eff}}}$$

where L_{eff}=L+2ΔL
hence patch length L= L_{eff} - 2ΔL.
Patch Width

$$W = \frac{c}{2f_o\sqrt{\frac{(\varepsilon_r+1)}{2}}}$$

Ground plate dimensions are given as:
L_g = 6h+L
W_g = 6h+W

B. Circular Patch

Circular patch is similar to the rectangular patch except the shape of the patch. Fig. 2 shows the shape of the circular patch with its parameters. The formulas for circular patch are derived assuming that the substrate is electrically thin. The resonance frequency of the TM_{11} mode is given by

$$f_o = \frac{c}{2\pi a_e\sqrt{\varepsilon_r}}$$

where c is the speed of light in vacuum and a_e is the effective radius of the patch, given by [4]

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

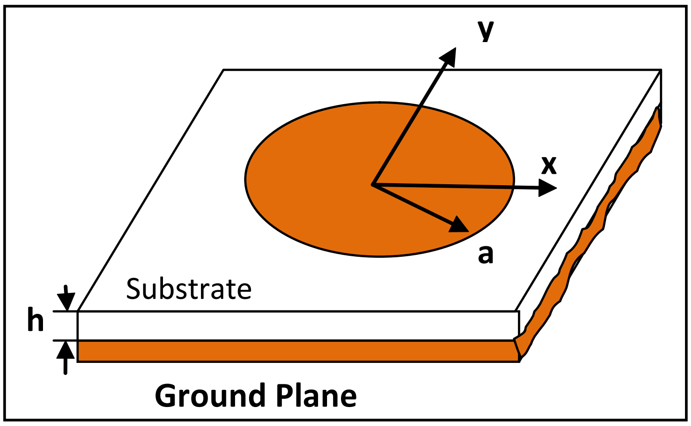


Fig. 3: Circular Patch and Its Parameters

C. Triangular Patch

Although rectangular and circular are most commonly used structures, other geometries can also help in reducing the size and find wide applications in wireless communication systems, where prime concern is compactness. Equilaterally triangular patch configuration is chosen because it has the advantage of occupying less metalized area on the substrate than other existing configurations. Fig. 4 shows the equilateral triangular patch and its dimensions.

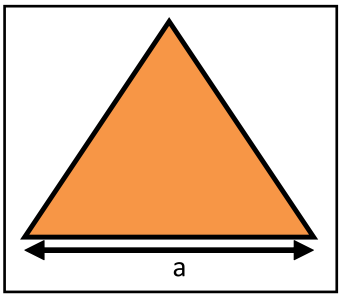


Fig. 4: Equilateral Triangular Patch

This equilateral triangular patch antenna has a side length a of the patch and substrate thickness h with relative dielectric constant ε_r.

The design procedure starts with the determination of the side length of the driven patch using the resonant frequency formula. There are many papers [8-13] published for the resonant frequencies of the equilateral triangular patch antenna. The basic equation for the resonant frequency is given by:

$$f_r = \frac{2\,C\sqrt{m^2+mn+n^2}}{3a\sqrt{\varepsilon_r}}$$

Where c is the velocity of light in free space and K_{mn} is wave number, given by:

$$K_{mn} = \frac{4\,\pi\sqrt{m^2+mn+n^2}}{3a}$$

Thus the fundamental mode resonant frequency of antenna is given by:

$$f_r = \frac{2\,C}{3\,a\,\sqrt{\varepsilon_r}}$$

In above formulas fringing fields are not considered. If ε_r and 'a' in the above equation are replaced by effective dielectric constant 'ε_{eff}' and 'a_{eff}' then accuracy can be increased in determining the resonant frequency.

$$\varepsilon_{eff} = \frac{1}{2}(\varepsilon_r + 1) + \frac{1}{4}\frac{(\varepsilon_r -)}{\sqrt{1 + \frac{12h}{a}}}$$

$$a_{eff} = a + \frac{h}{\sqrt{\varepsilon_r}}$$

Hence, modified formula of resonance frequency is given as:

$$f_r = \frac{2\,C}{3\,a_{eff}\sqrt{\varepsilon_{eff}}}$$

From these equations, it is clear that for high dielectric constant substrate such as alumina, ‘

III. Feeding Techniques

There are many configurations that can be used to feed Microstrip antennas. These configurations can be classified into two categories, contacting and non-contacting. RF power is directly fed to the MSA (Micro Strip Antenna) using a connection such as transmission line or coaxial cable. Electromagnetic field coupling is used to transfer the power from source to the MSA, in non-contacting scheme. The four most popular techniques are Microstrip line, coaxial probe, aperture coupling and proximity coupling [14-20].

Special attention has to be given for the feeding techniques in the view of transferred power to the patch from the source. According to the maximum power transfer theorem, maximum power will be transferred to the load if the source impedance is matched to the load impedance. If there is some mismatch between the source and load than EM waves will get reflect back from the load to the source and standing waves will be formed on the transmission lines and these standing waves increase the power losses. These reflected waves can also damage the source if proper isolation is not provided against them. Hence for the effective radiation from the patch, its impedance should be matched to the load impedance. Generally used wave guide port to deliver the power to patch has the impedance of 50Ω and patch antenna may have different impedance, hence certain techniques must be adopted to match the impedance of the patch to that of waveguide port of the source.

A. Microstrip Feed

Microstrip line feed is much easier to fabricate than other feeding techniques. In this feeding method there is just one conducting strip connecting to the patch and one quarter wave transformer in order to match the impedance of the Microstrip line to that of port impedance. Connecting Microstrip line has impedance 50Ω too, so that resultant impedance of quarter wave transformer and Microstrip patch comes out to be 50Ω only.

Quarter wave transformer has strip length λ/4 and its impedance can be altered by changing the width of the strip. Fig. 5 shows the structure of the patch with Microstrip line feed and quarter wave transformer.

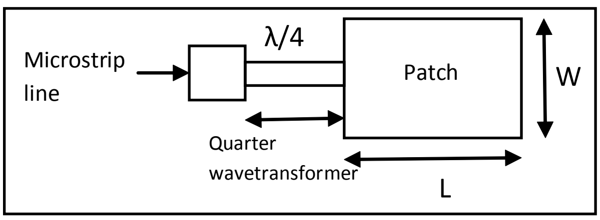


Fig. 5: Patch With Quarter Wave Transformer

B. Inset Cut Feed

In this technique the microstrip line goes upto some depth inside the patch. This is done so, in order to match the impedance of the patch to that of microstrip line, which is 50Ω without using any matching element. The inset cut position need to control properly. The main advantage of this method is, It provide simplicity in modeling, fabrication and impedance matching as well.

However, while increase in the thickness of substrate being used, surface wave and spurious radiation also increased, which results in the hampering of the bandwidth of the antenna. Undesired cross polarized radiation also exists due to the feed radiation. Fig. 6 shows the microstrip patch antenna with inset cut feed.

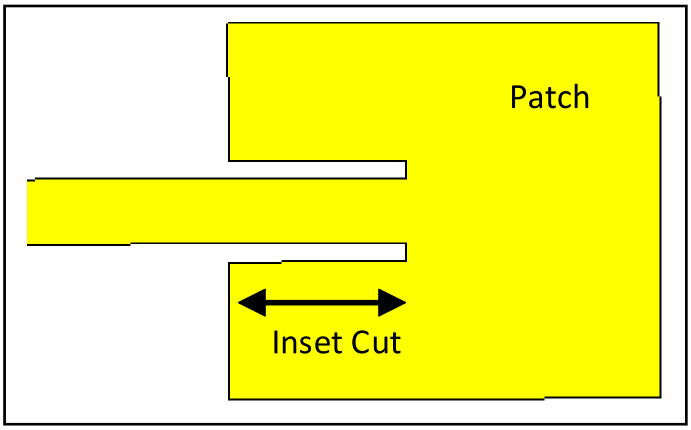


Fig. 6: Rectangular Patch With Inset Cut Feed

V. Co-axial Feed

This feeding technique is very common in microstrip patch antenna feeding. The inner conductor of the co-axial connector goes through the dielectric and is soldered on the radiating patch, while the outer conductor is connected to the ground plane. It can be place at any desired location inside the patch, so that impedance of the patch matches with that of coaxial port.

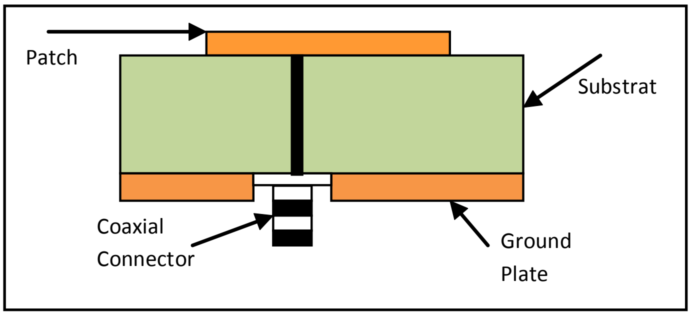


Fig. 7: Side View of Patch Antenna With Coaxial Feed

The main disadvantage in this technique is that antenna has very narrow bandwidth and it is difficult to model as a hole has to be drilled in the substrate. The increased probe length makes the input impedance more inductive which leads to the matching problems. Fig. 7 shows the side view of microstrip patch antenna with co-axial feeding technique.

VI. Aperture Coupled Feed

In the aperture coupled feeding technique, the radiating patch and the microstrip feed line got separated by the ground plate. Power gets coupled to the radiating patch through a slot or an aperture in the ground plane, leading to the name aperture coupled feed.

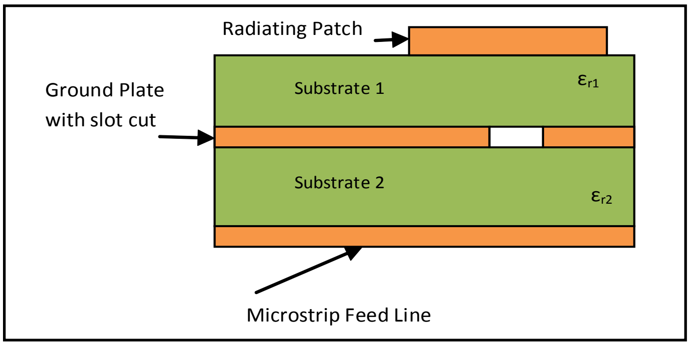


Fig. 8: Microstrip Patch Antenna With Aperture Coupled Feed

In order to reduce cross-polarization, which occurs due to symmetry of the configuration, the coupling aperture is usually centered under the radiating patch. Shape of the aperture, size of the aperture and location of the coupling aperture determines the amount of coupling from the feed line to the patch. Generally, a high dielectric material is used for bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch [21]. Due to the separation of patch and the feed line through ground plate, spurious radiation is minimized. The disadvantage of this feed technique is that it is very difficult to fabricate due to multiple layers. Bandwidth is also reduced due to this feeding technique.

E. Proximity Coupled Feed

This is also the type of electromagnetic coupling scheme. In this technique, the microstrip feed line is sandwitched between the two substrates and radiating patch remain at the top of the upper substrate. By this method bandwidth got increased by 13% (approx), due to increase in the thickness of the patch antenna and it eliminates the spurious feed radiations. Fig. 9 shows the microstrip patch antenna with Proximity Coupling.

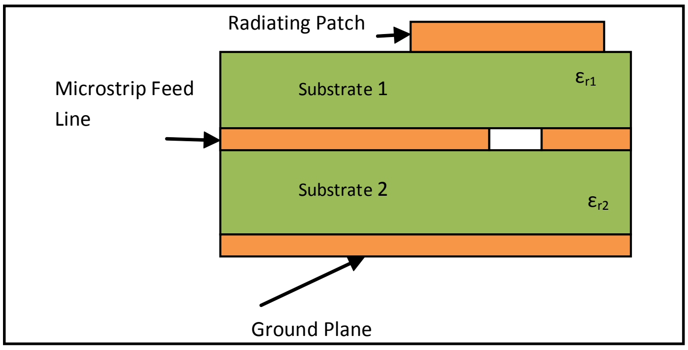


Fig. 9: Microstrip Patch Antenna with Proximity Coupling

F. Gap Couple Feed (Gap Coupling)

Power feeding to the antenna can be done in such a way that microstrip line doesn't get in contact with the microstrip patch. This introduces a gap between microstrip feed line and microstrip patch antenna. Hence giving the name as gap coupled feeding.

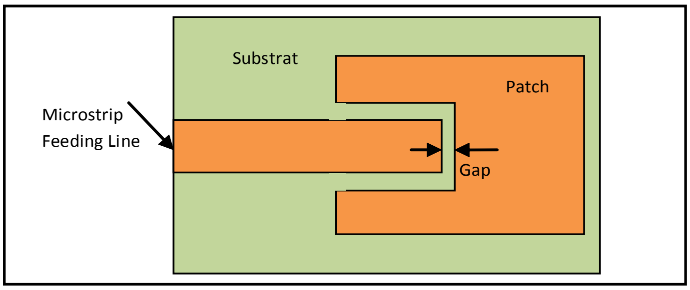


Fig. 10: Microstrip Patch Antenna with Gap Coupling

The gap coupling provides an extra degree of freedom to the design of antenna. This gap introduces some capacitance into the feed which can cancel out the inductance added by the probe feed. Improvement of results in terms of increase bandwidth and gain is being demonstrated in this paper [27]. In this paper gap coupling was used for dual band operation while via connects ground to patch.

VI. Conclusion

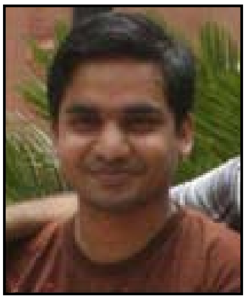
In this paper we have discussed various types of patch antennas e.g. rectangular, circular and triangular. We have also discussed the equation which relates the resonance frequency of these antennas to the dimension of the patch antenna. Further various design techniques which are used to feed the main patch has been discussed. The effect of feeding techniques on the B.W. and Gain of the antenna has also been discussed.

References

[1] Constantine A. Balanis," Antenna Theory: Analysis and Design", John Wiley & Sons, Inc., pp 722-783, 1997.
[2] K. F. Lee (ed.),"Advances in Microstrip and Priinted Antennas", John Wiley & Sons, Inc, 1997.
[3] E. O. Hammerstad," Equations for Microstrip Circuit Design", Proc. 5th European Microwave conference, pp. 268-272, 1975.
[4] D. M. Pozar,"Microwave Engineering", 3rd Edition, John wiley & Sons, 2005.
[5] Dahele, J. S., Tung, S. H., Lee, K.F.,"normal and Inverted Configurations of the Broadband Electromagnetically Coupled Microstrip Antennas", IEEE AP-S International Symposium Digest, 1986, pp. 841-844.
[6] Smith, H. K., Mayes, P.E.,"Stacking Resonators to Increase the Bandwidth of Low Profile Antennas", IEEE Transaction on Antennas and Propagation, 1987, Vol. AP-35, pp. 1473-1476.
[7] Al-Charchafchi, S.H., Loukrezis, F.,"Electromagnetically Coupled Stacked Patch Antenna", Microwave Journal, June 1995, Vol. 38, No. 6, pp. 76-79.
[8] Dahele, J.S., Lee, K. F.,"On the resonant frequencies of the triangular patch antenna", IEEE transactions antennas and propagation, 1987, Vol. AP-35, No. 1, pp 100-101.
[9] Gang, X.," On the resonant frequencies of Microstrip Antennas", ibid., 1989, Vol. AP-27, No. 2, pp. 245-247.
[10] Garg, R., Long, S.A.,"An Improved Formula for the Resonant Frequencies of the Triangular Microstrip Patch Antenna", ibid., 1988, Vol. AP-36, No. 4, pp. 570.
[11] Suzuki, Y., Chiba, T.,"Computer Analysis Method for Arbitrarily Shaped Microstrip Antenna with Multiterminals", ibid., 1984, Vol. AP-32, No. 6, pp. 585-590.
[12] Singh, R., De, A. Yadava, R.S.,"Comments on an improved formula for the resonant frequency of the triangular microstrip patch antenna", ibid., 1991, Vol. AP-39, No. 9, pp. 1443-1444.
[13] Kumprasert, N., Kiranon, W.,"Simple and Accurate Formula for the Resonant Frequency of the Equilateral Triangular Microstrip Patch Antenna", ibid., 1994, Vol. AP-42, No. 8, pp 1178-1179.
[14] I. J. Bahl, P. Bhartia,"Microstrip Antennas", Artech House, Dedham, MA, 1980.
[15] K. R. Carver, J. W. Mink,"Microstrip Antenna Technology", IEEE transactions antennas propagation, Vol. AP-29, No. 1,

pp. 2-24, January 1981.
[16] P. B. Katehi, N.G. Alexopoulos,"On the modeling of Electromagnetically Coupled Microstrip Antennas-The Printed Strip Dipole", IEEE Transactions Antennas Propagation, Vol. AP-32, No. 11, pp. 1179-1186, November 1984.
[17] D.M. Pozar,"Microstrip Antennas", Proceedings IEEE, Vol. 80, No. 1, pp. 79-81, January 1992.
[18] H. G. Oltman, D. A. huebner,"Electromagnetically Coupled Microstrip Dipoles", IEEE transactions Antennas Propagation, Vol. AP-29, No. 1, pp. 151-157, January 1981.
[19] D. M. Pozar," A Microstrip Antenna Aperture Coupled to a Microstrip Line", Electronic Letters, Vol. 21, pp. 49-50, January 1985.
[20] G. Gronau, I. Volff,"Aperture-Coupling of a Rectangular Microstrip Resonator", Electronic Letters, Vol. 22, pp. 554-556, May 1986.
[21] S K Behera,"Novel Tuned Rectangular Patch Antenna As a Load for Phase PowerCombining", Ph.D Thesis, Jadavpur University, Kolkata.
[22] C.K. Wu, K.L. Wong,"Broadband microstrip antenna with directly coupled and gap-coupled parasitic patches", Microwave and Optical Technology Letters, Vol. 22, No. 5, pp. 348-349, 1999.
[23] K.P. Ray, V. Sevani, R.K. Kulkarni,"Gap coupled rectangular microstrip antennas for dual and triple frequency operation", Microwave and Optical Technology Letters, Vol. 49, No. 6, pp. 1480-1486, 2007.
[24] P. Kumar, G. Singh, S. Bhooshan, T. Chakravarty, "Gap-coupled microstrip antennas", Proceedings of International Conference on Computational Intelligence and Multimedia Applications, pp. 434-437, 2007.
[25] R.B. Konda, G.M. Pushpanjali, S.N. Mulgi, S.K. Satnoor, P.V. Hunagund,"Multi-frequency operation technique using slot loaded gap-coupled microstrip antenna", The Icfai University Journal of Electrical & Electronics Engineering, Vol. 1, No. 3, pp. 7-14, 2008.
[26] Amit A. Deshmukh, A. Joshi, T. Tirodkar, K.P. Ray, "Broadband Gap-Coupled Slot Cut Rectangular Microstrip Antennas", IEEE explore, 2013.
[27] Malik, J., M. V. Kartikeyan,"Metamaterial inspired patch antenna with L-shape slot loaded ground plane for dual band (WiMAX/WLAN) applications", Progress In Electromagnetics Research Letters, Vol. 31, 35-43, 2012.

Sachin Sharma was born at Dadri, Uttar Pradesh, India on 5 July, 1987. Currently, He is working as an Asst. Professor at Dept. of ECE, Sharda University. He did his M.Tech in Instrumentation and Control Engineering from NIT Jalandhar and B.Tech in Electronics and Communication Engineering from GLA Institute of Technology, Mathura. He has published several papers in International conferences and International journals. His area of interests includes Microstrip Patch Antenna designing, embedded systems and system designing.



Kumar Goodwill was born at Sarnath, Varanasi, Uttar Pradesh, India on 1st July, 1986. Currently, he is working as an Asst. Professor in Dept. of ECE, Sharda University. He did M.Tech in RF & Microwave from IIT Roorkee and B.Tech in Electronics & Communication Engg. From Galgotia College of Engineering and Technology, Gr. Noida. He has more that 1.5 years of teaching experience and has published several papers in International and National conferences. His area of research includes Antenna Designing, Planar Antenna Design and UWB MIMO Antennas.

Avinash Kumar Dubey was born at Gorakhpur, U.P., India on 22 September, 1986. Presently he is teaching in Dept. of ECE, Sharda University, Gr. Noida. He did his M.Tech degree in Control System from NIT Kurukshetra and B.Tech in Electronics and Communication Engg. From GLA Institute of Technology & Management, Mathura. He has Published several papers in International Conferences and Journals. His area of research includes Microstrip Patch Antennas and Control System

M.V. Kartikeyan was born inNellore (Andhra Pradesh), India, in1961. He received the M.Sc. and Ph.D. degrees in 1985 and 1992 in Physics and Electronics Engineering, respectively from the Banaras Hindu University, India. Dr., Kartikeyan is the recipient of a Hildegard-Maier Research Fellowship for ElectricalSciences of the Alexander von Humboldt Foundation andthe Alexander von Humboldt Research Fellowship forlong-term Cooperation and worked at the Institut fu¨rHochleistungsimpuls-und Mikrowellentechnik, Karlsruhe Institute of Technology, Karlsruhe, Germany. He joinedthe Department of Electronics and Computer Engineering,Indian Institute of Technology, Roorkee, India, in 2003 asan Associate Professor and at present he is working as aFull-Professor. His research interests include Millimeter Wave Engineering (Electron Cylotron Masers and other High Power Devices and Components), Microstrip Antennas for communications, Computational Electromagnetics, Microwave Integrated Circuits, and RF& Microwave Design with soft computing techniques. Dr. Kartikeyan is a fellow of Institution of Electronics and Telecommunications Engineers (IETE), Fellow of the Institution of Engineers (IE), India, and Senior Member of IEEE.