

# Dual Band Minkowski Fractal Antenna for Maritime Radio Navigation Services

Ashwini Kumar, Amar Partap Singh Pharwaha



**Abstract:** A dual band low profile fractal antenna is proposed for Maritime Radio Navigation Services (MRNS). Minkowski fractal geometry is used on both the vertical boundaries of basic patch structure and by adjusting the fractal dimension desired operating frequency is achieved. The effect of antenna dimensions on the bandwidth is determined through the parametric analysis. Proposed antenna operates at 3 GHz and 9.4 GHz with a gain of 6.3 dB and 2.5 dB respectively. Furthermore, the resonating and radiation properties of the proposed antenna are measured experimentally. Measured results of the proposed antenna are highly convincing and in good agreement with simulated results.

**Keyword:** Minkowski Fractal, Bandwidth, Multiband, Maritime Radio Navigation, Gain.

## I. INTRODUCTION

Navigation is the activity of controlling the motion of objects by exactly knowing its position. MRNS is one of the navigation services that is used for the safe operation of ships[1]. MRNS operate in many different frequency bands, in different regions of the world according to ITU specified frequency bands. Some of the specified frequency bands for MRNS are 2900-3100, 5470-5650, 8850-9000 and 9200-9500 MHz. Such kind of communication needs high efficient, multifunctional, and low profile systems. Advancement of such systems depends on the functioning and working of antenna used in the system. Conventional antennas work for single frequency band which leads to an increase in a number of onboard antennas. To reduce the number of antennas, multiband and multifunctional antennas are needed for such kind of communication systems. Microstrip patch antenna with fractal shaped structure is a decent answer to the requirements like small size, low cost, multiband, wideband and application-specificity[2][3]. Fractal is a set of curves or surfaces which have larger Hausdorff Besicovitch dimension than the topological dimension[4]. Incorporation of fractal geometry in patch structure makes it multiband antenna. In the past few years, the use of fractal geometry in the design of the antenna is increased and still, fractals are very popular among antenna engineers because of its phenomenal capabilities. The principle points of interest of fractal antenna over regular

antenna are its multiband operation and diminished size [5-9]. The fractal antenna has valuable applications in various kinds of communications. M. Comisso in [10] reported the resonant behavior of Minkowski fractal and its capabilities of size diminishing. There are a few different strategies reported in [11] [12] to diminish the measure of the microstrip patch antenna, for example, shorting pins, presenting of U-openings, utilizing of high permittivity substrates and fractal geometrical structure. A modified Minkowski rhombic patch fractal antenna is proposed in [13] which has multiband performance and can be used for different wireless applications. However, the size of the antenna is large. In [14] ultra-wideband antenna is reported using Minkowski fractal structure. Fractal structure generates multiple resonances which are used to achieve wideband characteristics. Antenna using different fractal geometries are proposed in [15][16][17] with multiband characteristics which can be used for radio navigation as well as different satellite services in different frequency band. A microstrip patch antenna with the slot is reported in [18] for RADAR, WLAN, fixed satellite services and maritime mobile services. Proposed antenna covers 2-6 GHz frequency range. A microstrip patch antenna working at two frequencies is reported in [19]. Proposed antenna operates at 2.7GHz and 4.57GHz with a peak gain of 1.6dB and 4.9dB respectively. The proposed antenna can be used for fixed satellite, astronomy, aviation and for space research. In [20] fractal antenna array has been designed for MRNS and satellite services which has a tri-band performance with highly convincing results. The antenna element used in the array is optimized using dragonfly optimization. A multiband fractal antenna with large structure has been analyzed in [21] which covers MRNS in S-band and X-band. In [22] a quad-band antenna is reported using Sierpinski fractal operating at 2.12 GHz, 6.6 GHz, 9.33GHz and 13.25 GHz frequencies which has a possible use for different satellite and radio navigation applications. Thus from the literature it is perceptible that there is still a huge possibility of development of dedicated miniaturized multiband antenna using fractal geometry. Therefore, this report intends to provide a straightforward solution to the compact multiband antenna. The proposed antenna has been designed on Roger substrate using simple and easy to fabricate geometrical structure. The most appealing feature of the proposed compact fractal antenna is that it operates specifically only for MRNS at two frequency bands (2900-3100 MHz and 9200-9500 MHz) in S-band and X-band with good resonance and radiation characteristics. Organization of the remaining part of the paper is as follow: Section 2 describes the design and structure of the proposed antenna. Section 3 shows the results and discussion for the simulated and fabricated antenna. Section 4 gives the conclusion.

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\*Correspondence Author(s)

**Ashwini Kumar\***, Department of Electronics and Communication Engineering, Sant Longowal Institute of Engineering and Technology, Longowal, Sangrur, Punjab, India,

**Amar Partap Singh Pharwaha**, Department of Electronics and Communication Engineering, Sant Longowal Institute of Engineering and Technology, Longowal, Sangrur, Punjab, India,

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II. ANTENNA DESIGN

Rogers RT/duroid 5880(tm) dielectric material having a size of 50.9 mm × 49.9 mm×1.5 mm, a loss tangent of 0.0009 and dielectric constant of 2.2 has been used as substrate for proposed antenna. The dielectric material Rogers RT/duroid 5880(tm) provides high gain and high accuracy in results due to low dielectric constant value [2]. In this work Minkowski fractal geometry is used to change simple patch into a fractal structure, this particular geometry is selected because of its simple and easy to integrate characteristics, another technicality that is observed during analysis is that its dimensions directly affects the resonating frequencies which help in achieving the desired response. Hermann Minkowski introduced first time Minkowski fractals in the year 1885. In this work the two sides of square patch are replaced by Minkowski curve, one begins with the straight line of a unit length called the initiator, than by taking three equal parts of length (1/3) and by replacing middle part with two vertical segment (A) and one horizontal segment (B) of equal length this procedure is repeated to generate fractal geometry as shown in Figure 1. In the reported work, length of the vertical segment (A) is varied in comparison of the horizontal segment (B). This variation provides a design flexibility to modify aspect ratio ( $\eta$ ) of the generator. The patch edges are modified according to Minkowski fractal, in the first iteration as represented A1 and B1; similarly to make the second iteration again edges are modified as A2 and B2. Here the ratio of the A and B factor represents the aspect ratio( $\eta$ ) which is optimized using parametric optimization in HFSS environment and final value for aspect ratio are selected as  $\eta_1$  is equals to 49% and  $\eta_2$  is equals to 19% as given in Eq. (1) and Eq. (2) where the best results are achieved. Basic initiator for the Minkowski fractal and further transformation is shown in Figure 1. Figure 2 shows the basic patch antenna to final transformed Minkowski fractal antenna with modified ground width. Basic patch shown in Figure 2(a) has a dimension of 32.9mm ×32.9mm and dimension of the ground is 50.9mm × 6.6mm. Proposed antenna is fed with an inset feed structure having a dimension of 17.3mm × 1.1mm. Table I shows the all dimensional details of the proposed fractal antenna. The inset feed is used because it provide advantages of both coaxial feed and microstrip line feed simultaneously because it can be connected at the appropriate impedance point and provide the ability to place feeding circuitry near the elements on the same substrate and avoid a multilayer board. Figure 2(b) and Figure 2(c) shows the first and second iteration of the proposed fractal antenna.

$$\eta_1\% = \frac{A_1}{B_1} \times 100 = \frac{5.4}{10.96} \times 100 = 49\% \tag{1}$$



Fig. 2. All iterations of antenna (a) 0<sup>th</sup> iteration (b) 1<sup>st</sup> iteration (c) 2<sup>nd</sup> iteration (d) 2<sup>nd</sup> iteration with modified ground width

$$\eta_2\% = \frac{A_2}{B_2} \times 100 = \frac{0.7}{3.66} \times 100 = 19\% \tag{2}$$

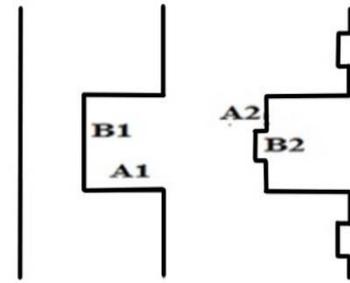


Fig. 1. Basic operator and further transformation for Minkowski fractal

In Figure 2(d) final proposed fractal antenna with optimized ground width is shown. It has been noticed in simulation results that there is a significant variation in the bandwidth of proposed antenna with the change in width of ground which can be observed from the data tabulated in table III.

Table-1: Different dimension of proposed antenna

Parameter	Value (mm)
Length of substrate	49.9
Width of substrate	50.9
Height of substrate	1.5
Length of patch	32.9
Width of patch	32.9
Length of feed	17.3
Width of feed	1.1
Length of ground	6.6
Width of ground	28.9
A1	5.4
B1	10.96
A2	0.7
B2	3.66

A. Effect of aspect ratio ( $\eta$ ) on the resonance frequency of the antenna Submission of the paper

A critical analysis is done to relate the aspect ratio ( $\eta$ ) of Minkowski Fractal geometry and resonance frequency of the proposed antenna. Various dimensions of Minkowski fractal antenna has been parametrically analyzed using HFSS simulation tool to find the optimum solution. Table II shows the performance parameter for the different values of  $\eta$  at different stages of design. It has been observed in the simulation results that  $\eta$  affects the resonant frequency and bandwidth of the antenna significantly as shown in table II.  $\eta$  is varied for both of the iterations, for first iteration  $\eta_1$  is varied from a value of 38% to 60% and after observing the

**Table-II: Parametric study of aspect ratio at first and second iteration**

Iteration	$\eta\%$	Resonant frequency (GHz)	Bandwidth (MHz)
First	$\eta_1\%=38$	3.0, 9.8	117, 500
	$\eta_1\%=44$	3.0, 9.7	126, 400
	$\eta_1\%=49$	3.0, 9.5	95, 284
	$\eta_1\%=55$	3.0, 9.4	67, 288
	$\eta_1\%=60$	3.0, 9.1	93, 160
Second	$\eta_2\%=11$	3.0, 9.6	120, 680
	$\eta_2\%=19$	3.0, 9.4	121, 720
	$\eta_2\%=35$	3.0, 9.3	131, 250
	$\eta_2\%=49$	3.0, 9.2	118, 205
	$\eta_2\%=65$	9.1	120

results for the targeted application the best value for  $\eta_1$  that is 49% is selected, similarly  $\eta_2$  is varied from value of 11% to 65% and best value for  $\eta_2$  is selected as 19% where the proposed antenna provides the best results in terms of resonant frequency and bandwidth for desired application.

**B. Effect of ground width on the bandwidth of the antenna**

When the width of the ground is varied, it has been observed that there is a significant impact on the bandwidth of the antenna. To study the effect of ground width on bandwidth and to find optimum bandwidth a parametric analysis is done for the ground width. The ground width is varied from 22.9 mm to 50.9 mm and at each variation, the effect on bandwidth is observed. Optimum result in terms of bandwidth at desired frequencies is found at a ground width of 28.9 mm. Table III shows the effect of ground width variation on antenna's bandwidth. The final design of antenna resonates at 3.0 GHz and 9.4 GHz with a bandwidth of 189 MHz and 850 MHz respectively.

**C. Analysis with different substrate**

The proposed antenna is analyzed with different substrate materials. For the analysis of proposed fractal antenna four substrates are taken Rogers RT/duroid 5880(tm) ( $\epsilon_r= 2.2$ ), Roger TMM3 ( $\epsilon_r= 3.27$ ), FR4 ( $\epsilon_r= 4.4$ ) and Rogers RT/duroid 6006 (tm) ( $\epsilon_r= 6.15$ ). The resonant behavior of fractal antenna with different substrate is shown in table IV. It has been noticed that the lower resonating band shift to higher resonating frequency when the dielectric constant is increased as well as the bandwidth is also reduced for upper resonating band. Desired results for targeted application of MRNS is achievable using the Rogers RT/duroid 5880(tm) ( $\epsilon_r= 2.2$ ) only as it provide resonance at 3 GHz and 9.4 GHz with a bandwidth of 189 MHz and 850 MHz respectively. Gain for the targeted frequency bands is 6.3 dB and 2.5 dB which are also good.

**Table-III: Variation in bandwidth with ground width**

Ground width (mm)	$f_r$ (GHz)	$f_i$ (GHz)	$f_h$ (GHz)	Bandwidth (MHz)
50.9	3	2.94	3.06	121
	9.4, 9.8	9.23	9.95	720
48.9	3	2.94	3.05	106
	9.4, 9.9	9.25	9.925	675
46.9	3	2.95	3.05	98
	9.4, 9.8	9.303	9.985	682
44.9	3	2.94	3.06	120
	9.4, 9.8	9.31	9.94	630
42.9	3	2.95	3.052	102
	9.4, 9.9	9.31	9.99	680
40.9	3	2.94	3.06	120

38.9	9.4	9.31	9.54	230
	9.8	9.68	9.98	300
	3	2.944	3.056	112
36.9	9.4	9.36	9.48	120
	9.8	9.63	9.92	290
34.9	3	2.944	3.056	112
	9.5	9.38	9.55	170
	3	2.93	3.06	129
32.9	9.4	9.28	9.49	210
	9.8	9.65	9.93	280
	3	2.949	3.054	105
30.9	9.4	9.28	9.5	220
	9.8	9.67	9.95	280
	3	2.958	3.048	90
28.9	9.4	9.18	9.59	410
	9.9	9.75	10.05	300
26.9	3	2.905	3.094	189
	9.4	9.13	9.98	850
24.9	3	2.92	3.07	150
	9.7	9.27	10.03	760
22.9	3	2.95	3.04	90
	9.8	10.04	9.4	640
22.9	3	2.960	3.049	89
	9.9	9.71	10	290

**Table-IV: Analysis of proposed antenna with different substrate**

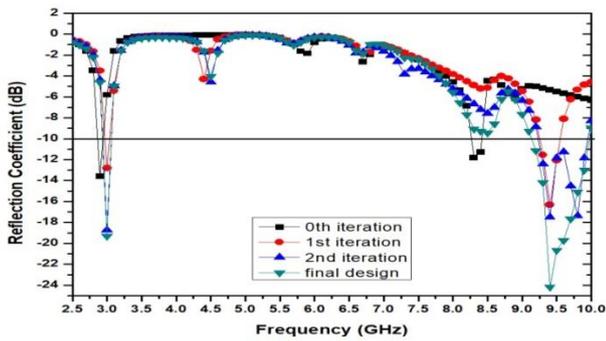
Dielectric Constant	Loss tangent	Resonant frequencies (GHz)	Reflection coefficient (-ve)	Bandwidth (MHz)	Input Impedance (Ohms)	Gain (dB)
2.2	0.0009	3.0	19.3	189	106.9	6.3
		9.4	24.2	850	91.7	2.5
3.27	0.002	7.9	19.2	461	71.2	1.8
		9.45	22.8	373	79.2	8
4.4	0.02	7.025	31.8	490	71.7	0.06
		8.2	24.3	250	74.4	3.5
		5.775	12.9	42	89.5	1.1
6.15	0.0019	6.15	18.5	104	48.5	2.3
		6.975	13.5	95	49.7	6.9
		8.025	13.1	51	122.7	0.2
		8.825	16.8	125	111.9	7.6

**III. RESULT AND DISCUSSION**

Observation of simulated results shows that as the number of iteration increased the performance parameter such as Reflection coefficient, gain, and bandwidth of the antenna is improved considerably as given in Table V. In Figure 3 Reflection coefficient of the proposed antenna for all iterations are shown which includes from 0<sup>th</sup> iteration result to the final iteration result. The result of proposed antenna shows that there are two resonating frequencies 3.0 GHz and 9.4 GHz which covers bandwidth ranging from 2.905 GHz to 3.094 GHz and from 9.13 GHz to 9.98 GHz respectively and Reflection coefficient value at these two resonating frequencies are -19.3 dB, and -24.2 dB respectively which are well below -10 dB ensuring proper impedance matching and reception of the antenna. The proposed antenna is fabricated on Roger 5880<sup>TM</sup> dielectric material using standard etching process. The fabricated antenna is tested using Vector Network Analyzer made of Anritsu (Model No.MS46322A). Figure 4 shows the fabricated antenna and experimental set up



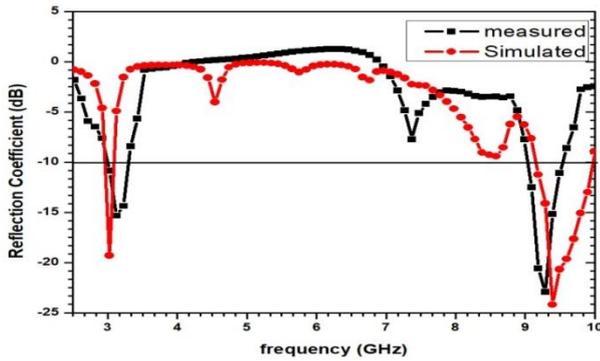
for measurement of radiation characteristics in anechoic chamber. In figure 5 simulated as well as measured reflection coefficients are shown for the proposed antenna.



**Fig. 3. Reflection coefficient of all iteration of proposed antenna**



**Fig. 4. Proposed antenna (a) In the anechoic chamber (b) Connected to VNA**



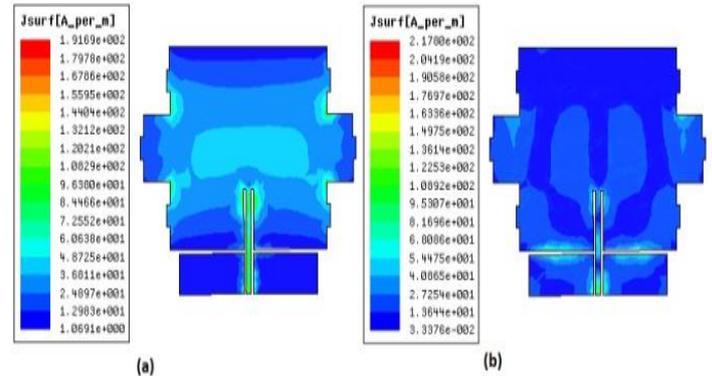
**Fig. 5. Simulated and the Measured Reflection coefficient of the proposed antenna**

**Table-V: Performance parameter of proposed fractal antenna**

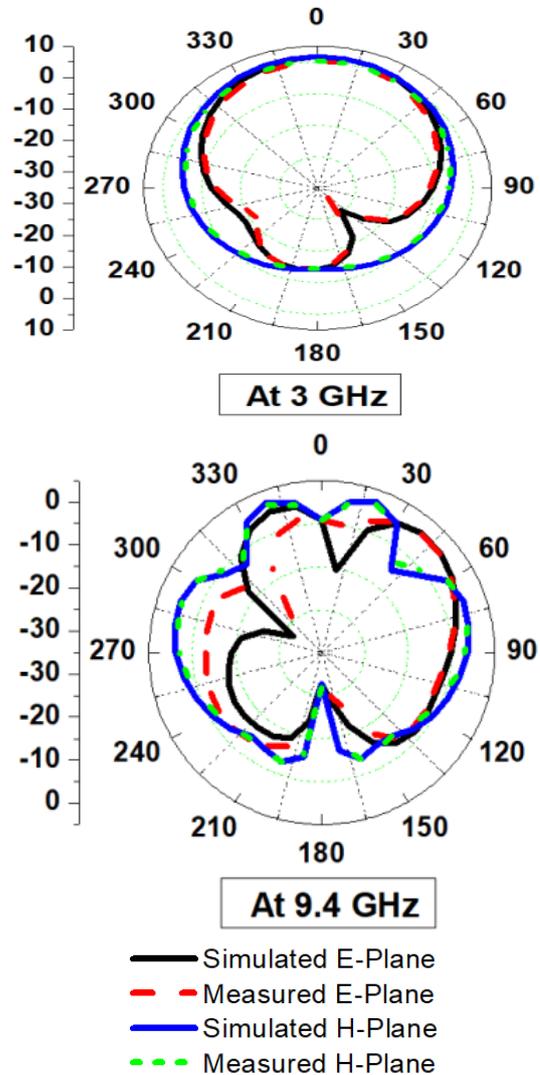
Number of Iteration	Resonant frequencies (GHz)	Reflection coefficient (-ve)	Bandwidth (MHz)
0 <sup>th</sup>	2.9	13.6	81
	8.3	11.8	155
1 <sup>st</sup>	3.0	15.2	95
	9.5	14.9	284
2 <sup>nd</sup>	3.0	18.7	121
	9.4	17.5	720
Proposed antenna	3.0	19.3	189
	9.4	24.2	850
Measured result	3.12	15.3	260
	9.29	22.9	480

Measured results are tabulated in table V and as expected, the measured Reflection coefficient is in good agreement with the simulated Reflection coefficient values except a small deviation which may be due to scattering from surrounding area, copper loss, and soldering bumps. Current distribution plot of the designed antenna is demonstrated in Figure 6 for the two resonating frequencies. Figure 6(a) represents the current distribution at 3.0 GHz and Figure 6(b) at 9.4 GHz.

Figure 6(a) it has been noticed that the current is almost zero near to the edges and maximum current density is at the center of the antenna which signifies a strong radiation at 3 GHz and similarly in Figure 6(b) the maximum current density is noticed in the fractal area of the antenna which produce a strong radiation at the 9.4 GHz.



**Fig. 6. Current Distributions at (a) 3GHz (b) 9.4GHz**



**Fig. 7. Simulated and Measured 2D radiation pattern at 3 GHz and at 9.4 GHz**

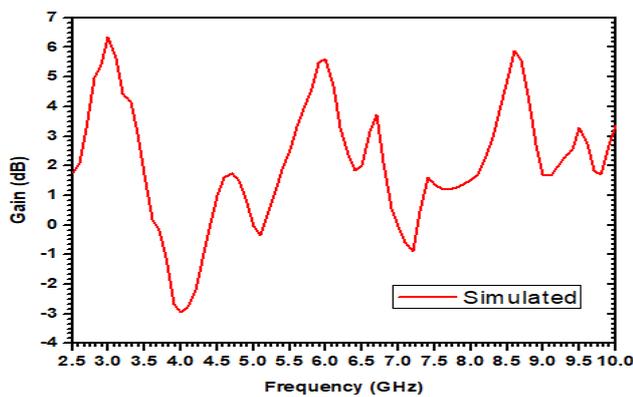


Fig. 8. Gain v/s Frequency plot of proposed antenna

Radiation properties of the antenna have been shown in the form of 2-D radiation pattern. It is a two-dimensional representation of radiated energy from the antenna in E-plane (YZ-plane) and H-plane (XZ-plane) which describe the antenna's radiation performance. Simulated and measured radiation pattern for the proposed antenna at 3.0 GHz and 9.4GHz is shown in Figure 7. It has been noticed that simulated and measured radiation pattern in both the XZ-plane and YZ-plane are in good agreement with each other. In XZ-plane radiation patterns are nearly Omni-directional. Figure 8 shows the simulated gain plot for the proposed fractal antenna. The simulated gain for the proposed antenna at two resonating frequencies is 6.3 dB and 2.5 dB at 3 GHz and 9.4 GHz respectively. From the gain versus frequency plot it can be noticed that at 3 GHz the proposed antenna has high gain and for 9.4 GHz the gain value is moderate which signify good radiation property of the antenna.

#### IV. CONCLUSION

This paper presents a dual band inset fed Minkowski fractal antenna. The proposed antenna is tuned at a desired frequency by adjusting the aspect ratio of Minkowski fractal geometry. Ground width is parametrically optimized to find optimum bandwidth in desired bands. The antenna is optimized to resonate at 3.0 GHz (2.905 GHz to 3.094 GHz) and 9.4GHz (9.13 GHz to 9.98 GHz) with an impedance bandwidth covering frequency bands for maritime radio navigation services. The designed antenna has nearly omnidirectional radiation pattern, and it has high gain of 6.3 dB at 3.0 GHz and a moderate gain of 2.5 dB at 9.4 GHz. Resonating and radiation characteristics of the proposed fractal antenna have been measured which are highly convincing.

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#### AUTHORS PROFILE



**Ashwini Kumar** has received his B.Tech Degree from Kurukshetra University, Kurukshetra and M.Tech degree from Guru Jambheshwar University of Science & Technology, Hisar. At present, he is pursuing his Ph.D degree in the field of microstrip patch antennas from Sant Longowal Institute of Engineering and Technology, Longowal, Sangrur, Punjab, India. His research includes Microstrip patch antennas and Fractal antennas Design.

## Dual Band Minkowski Fractal Antenna for Maritime Radio Navigation Services



**Dr. Amar Partap Singh Pharwaha** was born in Sangrur, Punjab in 1967 and received his BTech degree in ECE from GNDU, Amritsar in 1990. He received his MTech degree from REC, Kurukshetra in 1994 and PhD degree in 2005. Presently, he is a professor of ECE as well as part-time chief vigilance officer (appointed by the Govt. of India) at SLIET, Longowal. Dr Singh is credited with a professional experience of more than 24 years. He has guided seven PhD thesis. He has published more than 180 research papers in various national and international journals/conferences and received various awards including IETE Students Journal Award-2006 by IETE, New Delhi, Certificate of Merit in 2006, KF Antia Award in 2009, Sir Thomas Ward for the year 2010, and again KF Antia Award in 2014 by the Institution of Engineers (India).