A Review of Antenna Design and Development for Indian Regional Navigational Satellite System

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***Abstract* - The Indian regional navigational satellite system (IRNSS) developed by the Indian Space Research Organization (ISRO) is an autonomous regional satellite navigation system which is under the complete control of Government of India. The requirement of indigenous regional navigational satellite system is driven by the fact that access to Global Navigation Satellite System, like GPS is not guaranteed in hostile situations. Design of IRNSS antenna at user segment is mandatory for Indian region. The IRNSS satellites will be placed at a higher geostationary orbit to have a larger signal footprint and minimum satellites for regional mapping. IRNSS signals will consist of a Special Positioning Service and a Precision Service. Both will be carried on L5 band (1176.45 MHz) and S band (2492.08 MHz). As it is be long range communication system needs high frequency signals and high gain receiving antennas. So, different antennas can be designed to enhance the gain and directivity. Based on this the rectangular Microstrip patch antenna, planar array of patch antennas and planar, wideband feed slot spiral antenna are designed by using various software simulations. Use of array of spiral antennas will increase the gain position. Spiral antennas are comparatively small size and these antennas with its windings making it an extremely small structure. The performance of the designed antennas was compared in terms of return loss, bandwidth, directivity, radiation pattern and gain. In this paper, Review results of all antennas designed for IRNSS have presented.**

Keywords - Microstrip Patch Antenna, Antenna Array, Spiral antenna, Return loss, Gain, Directivity, Radiation Pattern.

I. INTRODUCTION

GNSS maintained by the United States government is the standard generic term for Global Navigation Satellite Systems, GNSS provide autonomous global geo-spatial positioning. GNSS allows the user, with a small electronic receiver, to locate longitude, latitude and altitude position of desired place by using time signals transmitted from a constellation of satellites with some accuracy. The Global Positioning System (GPS) is a space-based satellite system provides information of position and time of any desired place on or near the Earth is available in all weather conditions. At present Global Positioning System (GPS) is freely accessible to anyone with a GPS receiver [1].

The limitation is if GPS system of US fails then in all over the world navigation system may not function due to the dependency on GPS. The requirement of such an independent navigation system is driven by the fact that in hostile situations access to foreign government-controlled global navigation satellite systems is not guaranteed [2]. Hence, A distinct but pioneer proposal of using geo-stationary satellite applications through Regional Satellite System has been adopted executed by India for India and the said Regional Satellite System has been named as (IRNSS) Indian Regional Navigational Satellite System [3][4]. Figure 1 shows the IRNSS constellation architecture.

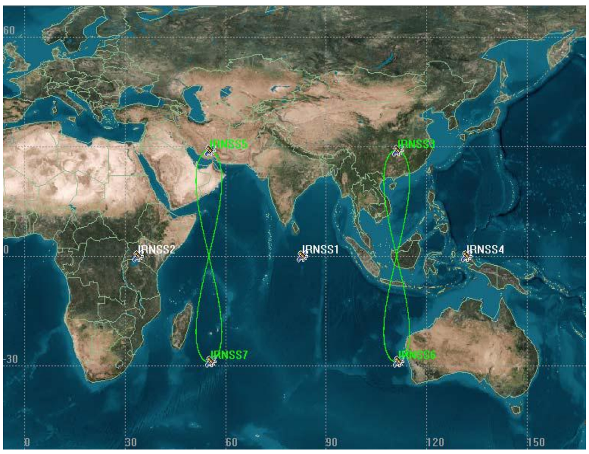

Figure.1 IRNSS Constellation Architecture

IRNSS is a regional, autonomous, 24 hour operating satellite navigation system operating over the Indian region's land, air and sea users. The IRNSS is under the total control of the government of India. The IRNSS afford two services are Standard Positioning Service (SPS) will be open for civilian use and the other service is the Restricted Service (RS), encrypted only (Military purpose and/or authorized users). Both

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(SPS) & (RS), Service will have operating frequency on L5 band (1176.45 MHz) and S band (2492.08 MHz). It consist of 7 constellation satellites where as 3 satellites are placed in the Geostationary Orbit (GEO) at 32.5^0 E, 83^0 E and 131.5^0 E latitude and other 4 satellites inclined at Geosynchronous Orbit (GSO), two at 55^0 E and two at 111.75^0 E [8][9][10].

The unique feature of GEO stationary satellites is a larger signal coverage footprint is achieved with a minimum number of satellites [7]. The Standard Positioning Service (SPS) have BPSK modulation and is available for the civilian users. IRNSS is intended to provide all-weather absolute position accuracy provides a 20m accuracy over the Indian Ocean region and 10 m accuracy over Indian landmass and within a region extending approximately 1,500 km around it. [2][5][6].

II. ANTENNA REQUIREMENTS

Antenna has been an essential component of Space born remote sensors including Active/Passive Microwave Sensors. It operates by using EM spectrum properties of light and sound. Among various antenna models used, multiple single frequency antennas, is comparatively more complex and expensive. At present GNSS system is in dire need of antenna with increased number of bandwidth at comparatively low cost and complexity. A care full observation reveals that, antenna used for GNSS system should have the following essential features: i) It must be light weight, ii) easily producible iii) must be comparatively more efficient with independent signal reception and transmission ability and iv) it must be designed with circularly-polarized radiation system. Very often the operating frequencies of remote sensors are different. Hence it may be more appropriate to design a single antenna to operate at multi-band frequencies [25][26]. It is also observed that the microstrip antenna with RHCP system ensures more efficient and effective signal reception, independent of the basic attitude of transmitting and receiving antennas. Figure 2 shows the simple micro strip patch antenna [11] [12] [13][14].

While considering the requirement of Antenna and its model for GNSS system, a brief observation of features of micro strip antenna development in 1970's is made and its significant features are: i) consists of four parts namely, patch, ground plane, substrate, and the feeding part. ii) it is small in size and hence light weight. Owing to size reduction it is commonly used in handsets, GPS receivers and other mass-produced wireless products [18][19][20][21]. iii) By using modern printed circuit technology [17] it can be produced at comparatively. iv) Microstrip antenna can be mounted both on planar/ flat surface [15] v) it operates with a frequency range of 1 to 6 GHz and is more useful in communication systems [16]. vi) On the other hand, Spiral antennas with multiple bandwidth will produce circularly-polarized radiation. vii), **Balun** and feed structure can be integrated in A plane radiating structure of micro strip spiral antenna [22].viii) The traveling Radiation energy, formed on spiral arms, allows for broadband performance (due to mutual coupling phenomenon occurring between arms of spiral and during propagation allow the Radiation energy to travel through the spiral arms[23] [24].

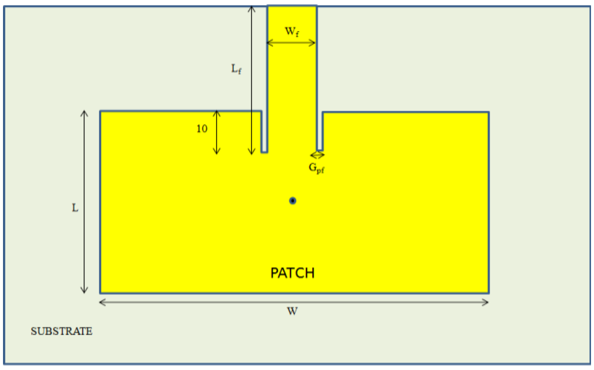


Figure.2 Simple Microstrip Patch Antenna

III. MOTIVATION

Owing to the need for speed communication and/transmission of accurate real-time information about military/civic like communication, traffic controlling, observation of earth surface during natural disaster period, weather and/or climate observation, GPS system has been established. But due to the need for constant regional observation, in particular during natural disaster period independent Satellite navigation system, is encouraged by nations like France, Japan, china and India is also inching towards establishing its own regional period independent Satellite navigation system. In this regard it has launched IRNSS satellite system, consisting of a constellation of 7 satellites serving in 24x7 positioning. Since the IRNSS satellite system, is used for positioning purpose by civilians, more concentration is given to receiving antenna model with an intention to fulfill the requirement of end user of IRNSS satellite system. Figure 3 shows the practical IRNSS user receiver antenna mounted in real time.

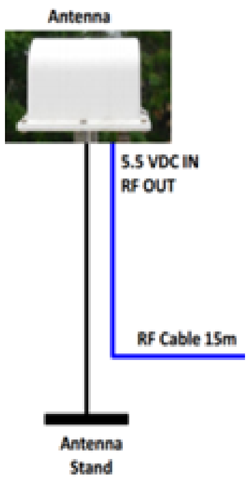


Figure. 3 Practical IRNSS user receiver antenna mounted in real time

The main objectives of this paper are as follows:

I. Explore the available antennas for L5 and S band of the IRNSS

II. Characterize the antenna parameters for IRNSS

III. Compare the results of different antennas and antenna arrays

IV. IRNSS ANTENNAS

Microstrip patch antennas, spiral antenna and/array of spiral antenna with features like: i) Rectangular Slott / triangular Slott / Spiral Slott/ different slots on the same substrate ii) /circularly-polarized radiation / RHCP radiation (Right Hand Circularly Polarized radiation) iii) Tri-band or Multi-band resonant frequencies iv) Horizontal and Vertical Stacking, multi-stacking and/or staking with QIFA. v) Fractal attributes of an antenna [antenna using a fracta*l or* self-similar design to increase the perimeter within a given total surface area or volume] vi) operation with Single layer or two layer or multilayer substrate, vii) Reduction in size viii) dielectric loss tangent, thermal expansion and conductivity properties of Microstrip patch antennas has been proposed by various scientist for application of GNSS and IRNSS Satellite navigation system.

A brief critical survey of its technical specifications is made here under: Pingping Zhang et al. proposed investigations of compact tri-band antenna for GNSS application. A tri-band antenna is designed with two Microstrip patch antennas and a quadruple inverted-F antenna inserted in two layers of substrates. The insertion of inverted-F antenna in two layers will reduce the height and achieve low profile [27]. Two patch elements (patch L and patch S), which work at 1.615 GHz and 2.492 GHz, are etched on a microwave substrate. L antenna is doubly-fed microstrip patch antenna, which achieves the LHCP radiation. S antenna is a single feed patch with U-shaped slot which is designed to broaden the bandwidth. The corner of the patch is cut to achieve the RHCP. QIFA which works at 1.268GHz is inserted in two layers of substrate, where it is arranged around L, S band antennas. RHCP radiation is obtained by feeding four inverted-F elements in equal magnitude and successive 90 phase delay. T. Vasanthan et al. proposed a Right Hand Circularly Polarized, corner truncated, Micro strip Patch antenna for multi-constellation Global Navigation Satellite System [28]. The antenna is etched on a FR4 material with dielectric substrate of 4.6. The RHCP Corner truncated MC Patch antenna shows a gain of 6.25dBi and a directivity of 7.28dBi .The self similar property of RHCP Corner truncated MC Patch antenna exhibits multi-band resonant frequencies.

Mustapha Djebari et al. proposed a Compact Multi-band Rectangular Slotted Antenna for Global Navigation Satellite Systems. A multiband rectangular microstrip antenna with two different slots designed to work for multiple GNSSs. One slot is U-shaped and other is inverted H-shaped. The size of designed antenna is 75 mm x 80 mm x 1.6 mm. This antenna works well for four different frequencies [29][30]. M. Karthick et al. proposed the design of Cantor fractal antenna that effectively supports multiband operation. The Cantor fractal antenna is designed up to four iterations [31][32][33][34][35]. The experimental results clearly depict that the antenna's multiband operation with Single layer substrate. Dushyant H. Raval designed Rectangular Microstrip patch antenna with operating frequency of 2.49GHz (IRNSS operating frequency) and a return loss of around -41 dB. Bandwidth measured at -10 dB return loss is 67 MHz and is characterized by a VSWR around 1.01 [36].

B.Sada Siva Rao et al. proposed a new planar, wideband feed for a slot spiral antenna is designed using HFSS software simulations. A spiral antenna on RT DUROID substrate for the operating frequency range of 1.2 to 1.6 GHz has been described. These specifications should be satisfied at the frequency L5 band (1.175 GHz). B.Sada Siva Rao et al. suggested using HFSS software simulations to design planar, wideband feed for slot spiral antenna at the frequency L5 band (1.175 GHz) [37]. Spiral antenna with operating frequency of 1.2 to 1.6 GHz and RT DUROID substrate has been described. These specifications should be satisfied at the frequency L5 band (1.175 GHz).Array of spiral antennas can be used to increase the gain. Spiral windings will reduce the size antennas and it is extremely small in structure. Spiral antennas with four spirals will provide broadband satellite coverage and can be used in conjunction with a space-time adaptive processor for interference suppression.

Nirav J. Patel et al. proposed a review of multi band microstrip antenna [38]. First paper is based on different slots on the same substrate. The second paper is based on the fractal concept [39][40][41][42]. The third is based on multi-stacking and the fourth one is based on staking with QIFA. Each one has its own merit and demerits. Depending upon the application and requirement choice can be made among multi band microstrip antenna with different Slot same substrate and/or fractal property and/or stacking property.

Dr. S. Arivazhagan et al. designed triangular fractal patch antenna with slit for IRNSS and GAGAN applications. A triangular antenna is designed with fractal model. It is designed to work at 3 frequencies: L5 (1176.45 MHz) and S (2492.08 MHz) of IRNSS and L1 (1575.42 MHz) of GAGAN [43]. The Gain achieved is 5.052 dB and directivity is 6.29723 dB which is quite impressive as this is not an array antenna [44]. Ashish N. Patel et al. presented a design of microstrip rectangular patch antenna with center frequency at 1.176GHz for IRNSS application. He designed and simulated array of four by one (1x4) microstrip rectangular antennas with microstrip line feeding based on quarter wave impedance matching technique [45].

Wen Liao et al. proposed a Tri-band Circularly Polarized Stacked Microstrip Antenna for

GPS and CNSS Applications. The proposed presented single-feed stacked microstrip patch antenna is designed with two properly squared patches made especially for tri-band circularly polarized application. Two pairs of narrow slots parallel to the edges of the top square patch are inserted with two protruding slots perpendicular to the edge [46][47][48]. The top patch can perform CNSS dual frequency (1.61 GHz and 2.49 GHz) and CP radiations using a single probe feed. By cutting a slit in the bottom patch accompanied by adjustment of Slit length the GPS frequency of (1.57GHC) can be achieved in microstrip square patch antenna [49].

Rajan H Kapadia et al., proposed the design of compact microstrip patch antenna array with Teflon substrate for L5 band and showed that by using patch array with Teflon substrate different parameters can be enhanced. [50][51]. L5 single band, 1x2, 2x2, 2x4 and 2x8 patch array antenna with Teflon substrate will show a gain of 7.3, 8.9, 11, 12.4 and 17.3dB. Similarly L5 single band, 1x2, 2x2, 2x4 and 2x8 microstrip patch antenna with FR4 material will show a gain of 3.1, 5.4, 7.7, 9.33 and 10.1 dB. [52][53]. The choice of dielectric substrate will play an important role in the performance of the antennas. Depending upon permittivity, dielectric loss tangent, thermal expansion and conductivity, cost and manufacturability substrate material can be selected.. In the present situation, Teflon/FR4/ RT-DUROID substrate material is been used. The FR4 materials are low dielectric constant having low loss tangent and can be manufactured at comparatively low cost.

V. ANTENNA STRUCTURE & DESIGN SPEICIFICATIONS

A. *Popular software tools for antenna designing & simulation*:-

ZELAND's IE3D software is popularly used by antenna manufacturers/designing industry The unique features of IF3D software are: i) Support designing components, filters used for high frequency propagations; ii) Easily resolves electromagnetic problems in using Antenna, filters and time/frequency calculation tools; iii) also helps other antenna synthesis tools to design accurate antenna systems; iv) Antenna Magus tool offers a huge database for different antenna models. ZELAND's Ansoft HFSS is commonly used as an acronym for high frequency simulator for antenna and also used for design of antenna and/or complex RF electronic circuits.

B. Antenna Designs:

Agilent Advanced Design System (ADS) is electronic design automation software designed for RF, microwave, and high speed digital applications. ADS innovative and commercially successful technologies are used by wireless communication & networking and aerospace & defense industries. While designing a microstrip antenna, numerous substrates are used to achieve good response and with dielectric constants preferable in the range of 2.2 to 12. The feed-line will be fed to the patch through a quarter-wave transformer matching network. A single microstrip patch antenna consists of patch, quarter wave transformer and feed line [54]. For good response substrates used to designing a microstrip antenna, must have dielectric constants preferable in the range of 2.2 to 12. The feed line will be fed to the patch through a quarter-wave transformer matching network. [54] , Further To optimize the performance in a patch array antenna configuration it will be necessary to vary the patch width, length and other parameter such as length of microstrip line of 100 Ω [55].

Generally microstrip patch antenna will have FR4 substrate material. Dielectric constant of the FR4 is taken as 4.4. The feed line of is designed on the center of the patch width. Inset feed technique is used to obtain expected output on desired frequency. In microstrip patch antenna the resonant length (L) opposite corner truncated square microstrip antenna is determined by transmission line model equations. The frequency range/ feed parameter of rectangular microstrip patch antenna is 2.49GHz. Rectangular Substratum will have a dimension of 56.0mm x 73.32mm x 2.4mm. It is suggested that the width (W) of the square patch radiator must best large enough to give high efficiency but small enough for generation of higher order Modes. The advantages of Low profile Microstrip antenna are: its lightweight, low cost, it's easy integration, Easy mass production, minimum substrata loss, simple performance analysis property [56][57].

The unique features of spiral array of antennas are dual band radiation, Small aperture, small volume, light weight and good interference suppression property. A small four element Antenna measuring 4"x4"c0.02 with an optimum feed parameter of L1 L2 and L5 band can be comfortable used for any hand device. In Spiral antennas, unidirectional pattern antennas with loss cavities placed at the back to eliminate back lobes. The spiral element of Spiral antenna consists of four square Archimedean spirals with center short arms and is arranged 2x2; Table 1 shows the antenna design parameters of various IRNSS antennas.

VI. RESULTS AND DISCUSSION

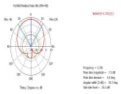
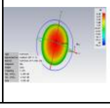
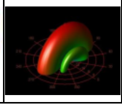
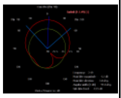
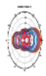
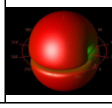
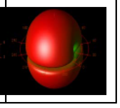
Miniature microstrip slot antenna system has been found suitable for applications like mobile handsets, PC cards, and wireless Personal Digital Assistants. Excess band width causes field distortion and hence narrow band width suitable for each application will be designed. Before designing microstrip slot antenna system we must know the exact band width need for the required application and then the effective dielectric constant, ε_r eff is to be calculated. Thus for built-in models, Length is a critical parameter to obtain an accurate value of the line length L. The apparent increase in the slot length caused due to current flowing is represented as 2L. The performance of the antenna system designed and simulated to work in varied frequency will be tested with multiple parameters like: Directivity, Gain, Return Loss, Radiation Pattern and Efficiency [58].

TABLE.1 ANTENNA DESIGN PARAMETERS

Parameters	MSP Model 1	MSP Model 2	Microstrip Rectangular Patch Antenna'14	Rectangular Microstrip Patch Antenna'15	Corner Truncated Microstrip Square Patch Antenna	Spiral Antenna	Tri-band microstrip antenna	Multiband Fractal Antenna	Triangular Fractal Patch Antenna
Frequency Band (GHz)	1.176	1.176	1.176	2.49	1.256	1.175	1.176	1.176	1.176
Substrate Type	Teflon/ FR-4	FR-4	FR-4	FR4	FR4	RT-DURIOD	NS	FR-4	FR-4/RT-DURIOD
Dielectric Constant	2.1	4.1	4.6	4.4	4.6	NS	4.3	4.8	4.8
Length of Patch (L)	86.2 mm	60.64 mm	NS	28.0 mm	NS	NS	75 mm	48 mm	57.78 mm
Width of Patch (W)	102.42 mm	77.2 mm	NS	36.66 mm	NS	NS	80 mm	57 mm	NS
Substrate Height (h)	2.4 mm	0.035 mm	1.6 mm	0.035 mm	NS	NS	1.6 mm	1.6 mm	3.05 mm

The Miniature microstrip slot antenna system usually of four parts namely copper microstrip patch, TEFLON substrate, ground plane, feeding port. The microstrip feed line is used as a feeding technique to be inserted in the patch. The return loss is expressed as logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that is fed into the antenna from the transmission line. Antenna can be fabricated in FR4 in case of shortage or non availability of TEFLON material. Table 2 and Figure 4 show the output parameters of the various antennas especially with respect to gain and directivity.

TABLE.2 OUTPUT PARAMETERS OF THE ANTENNA

Parameters	1	2	3	4	5	6	7	8	9
	MSP Model 1	MSP Model 2	Microstrip Rectangular Patch Antenna'14	Rectangular Microstrip Patch Antenna'15	Corner Truncated Microstrip Square Patch Antenna	Spiral Antenna	Tri-band microstrip antenna	Multiband Fractal Antenna	Triangular Fractal Patch Antenna
Directivity	7.1 dBi	6.84 dBi	10.9557 dBi	6.9 dB	7.28 dBi	NS	6.297 dB	NS	6.297 dB
Gain	3.1 dB	3.83 dB	8.2805 dBi	4.6 dB	6.25 dBi	9 dB	5.05 dB	2.299 dBi	5.052 dB
Return Loss (dB)	-21.521	-17.5	-24.560	-41	-22	NS	-32.65	-5	-14
Efficiency (%)	89.02	NS	54.01	67	81.2	NS	NS	NS	NS
k=G/D	0.43	0.55	0.75	0.66	0.85	NS	0.80	NS	0.8
Radiation pattern							NS		

Generally slot length is directly proportional to the resonant frequency and hence the resonant frequency will be increased by altering the coupling length of slot. Four element patch array antenna in ADS tool at 1.176 GHz frequency for IRNSS application shows all the results of single element, 1x2 array antenna, 1x4 array antenna of gain, return loss and directivity. The 3D/2D view of the radiation pattern of the various antennas are shown in Table 2 Accordingly the return loss for four element patch array antenna is -24.560 at frequency 1.176 GHz at L band. Gain is 8.2805 dBi and Directivity is 10.9557 dBi at frequency 1.176 GHz. Antenna efficiency is 54.010 % [59]. The Proposed Microstrip antenna is designed and simulated using electromagnetic full wave solver for IRNSS S1 band frequency 2.49 GHz. The return loss of proposed antenna at 2.49 GHz is -41 dB. The bandwidth of the patch antenna is 67 MHz; Gain of the antenna at 2.49 GHz is 4.6 dB. Directivity of the Rectangular patch antenna at 2.49 GHz is 6.9 dB and 94.8^0 angular width at 3dB. The antenna efficiency is around 67%. Table 3 and Figure 5 show the performance of different antenna arrays in terms of gain and directivity.

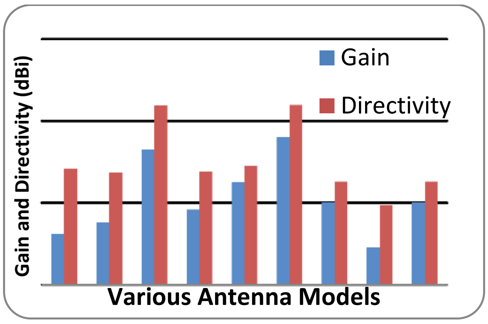


Figure.4 Performance metrics of various antennas

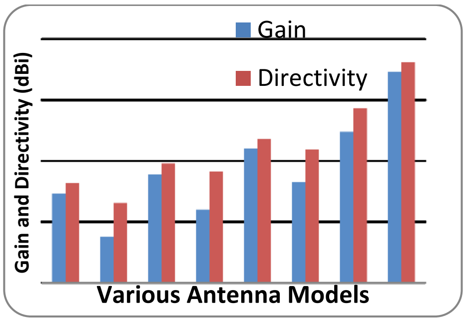


Figure.5 Performance Metrics of Antenna Array

TABLE.3 PERFORMANCE OF ANTENNA ARRAYS

Parameters	Microstrip Patch Antenna					Microstrip Rectangular Patch Antenna		
	1	2	3	4	5	6	7	8
	L5 single patch	1x2 Array	2x2 Array	2x4 Array	2x8 Array	Single Element	1x2 Array	1x4 Array
Frequency Band (GHz)	1.176					1.176		
Gain (dBi)	7.3	8.9	11	12.4	17.3	3.76	6.02	8.28
Directivity (dBi)	8.2	9.8	11.8	14.3	18.1	6.57	9.13	10.96
k = G/D	0.89	0.90	0.93	0.86	0.95	0.57	0.65	0.75

VII. CONCLUSION

The designs of antennas for IRNSS have been reviewed here. Each one has its own merit and demerits one can select the suitable approach based on the application and requirement. From review of different antenna designs, we can conclude that by using different types of slots, we can achieve multi-band performance which is useful in the application of navigation. From the comparison results, it is clear that the designed antennas are suitable for IRNSS bands. Few antennas providing a lower gain and directivity in single antenna but if we make an array for same dimension element which obtained better results like higher gain, directivity and radiation pattern. The detailed discussion of Rectangular Microstrip Patch antenna with special reference to design parameters and e selection of the substrate is also made here. These antennas are showing remarkable performance over the frequency of L5 and S bands with high gain and directivity. The array has multiple elements allowing for spatial nulling of interfering signals necessary for IRNSS applications. Spiral antennas are also useful for microwave direction finding applications. In the future better antenna can be designed and fabricated in terms of compact in size, better gain and directivity, minimum loss and better efficiency.

REFERENCES

[1] Dana.J.Johnson Ph.D , “The Global Positioning Systems”, Analysis center papers, Northrop Grumman Analysis center, 2006.
[2] http://en.wikipedia.org
[3] Presentation by S. Anandan, “Launch of first satellite for Indian Regional Navigation Satellite system next year”, 2010.
[4] IRNSS presentation by Mr K.N.Suryanarayana Rao (Project Director, ISRO)
[5] http://www.aai.aero
[6] http://www.isro.org/satellites/irnss.aspx
[7] Vyasaraj Guru Rao. Gerard Lachapelle and Vijay kumar S B, “Analysis of IRNSS over Indian Subcontinent”, Proc. of ITM, The Institute of Navigation, Session B5, San Diego, CA, pp. 1-13, 2011.
[8] A.Bhaskarnarayana (ISRO), “Indian IRNSS and GAGAN”, presentation to COSPAR Meeting, Montreal, July 15, 2008.
[9] K.N.Suryanarayano Rao, “GAGAN - The Indian Satellite based Augumentation system”, Indian Journal of Radio and Space Physics, vol. 36, pp. 293 – 302, 2007.
[10] Yung-Fu Tsai and Kay-Soon Low, “Performance Assessment on Expanding SBAS Service Areas of GAGAN and MSAS to Singapore Region”, Proc of Position, Location and Navigation Symp., pp. 686-691, 2014.
[11] J.D.Kraus, “Antenna and Wave Propagation,”4th edition, Tata Mcgraw Hill Publications, 2013.
[12] Ramesh Garg, Prakash Bartia, Inder Bahl and Apisak Ittipiboon, “Microstrip Antenna. Design Handbook”, Artech House Inc, Norwood, MA, pp. 1-68, 253-316, 2001.
[13] Aaron k. shackelford, kai-fonglee and K.M. Luk, “Design of Small-Size Wide- Bandwidth Microstrip-Patch Antennas”, IEEE Antennas and Propagation Magazine, vol.45, issue-1, pp. 75-83, 2003.
[14] Waterhouse R& D Norak, “A Printed Antennas for Wireless Communication”, John Wiley and sons Ltd.2007.
[15] Randy Bancroft, “Microstrip and Printed Antenna Design”, SciTech Publishing Inc, 2nd Revised edition, 2009.

[16] Subbulakshmi, P and R. Rajkumar, "Design and characterization of corporate feed rectangular microstrip patch array antenna", Proc. of IEEE International Conference on In Emerging Trends in Computing, Communication and Nanotechnology, pp. 547-552, 2013.

[17] J Suganya and N Thangadurai, "Reconfigurable Micro strip Patch–Slot Antenna Array", International Journal for Trends in Engineering & Technology, vol. 5, issue-1, pp. 81-84, 2015.

[18] N. Padros, J.I. Ortigosa, J. Baker, M.F. Iskander and B. Thornberg, "Comparative Study of High-Performance GPS Receiving Antenna Designs," IEEE Trans. Antennas Propagation, vol. 45, no. 4, pp. 698-706, 1997.

[19] J.M. Baracco, L. Salghetti-Drioli and P. de Maagt, "AMC Low Profile Wideband Reference Antenna for GPS and GALILEO Systems," IEEE Trans. Antennas Propagation, vol. 56, no. 8, 2008.

[20] M.W. Nurnberger, T. Ozdemir and J.L. Volakis, "A Planar Slot Spiral for Multi-Function Communications Apertures", Proc. of IEEE Antenna Propagation Society Int. Symp., vol.2, pp. 774-777, 1998.

[21] Y. Zhio, C.-C. Chen, and J.L. Volakis, "Tri-band miniature GPS Array with a Single-Fed CP Antenna Element", Proc. of IEEE Antenna Propagation Society Int. Symp., pp. 3049-3052, 2007.

[22] Manoj Kr. Dahiya, Ritu Goel, Sandeep Kumar, Vikas Kaushik, "Comparison of Bow shape Microstrip Antenna and Rectangular patch Microstrip Antenna", International Journal of Soft Computing and Engineering, vol.2, issue-3, pp. 499-501, 2012.

[23] George.T. and T. sachtsiris, "Analaysis of a Multiband Sierpinski Gasket Monopole Antenna printed on dual Band Wireless devices", IEEE Transactions On Antenna and Propagation, vol. 52, no.10, pp. 2571-2579, 2004.

[24] Haneishi,M,Yoshida Sand Oka.N, " Back Feed Type Circular Polarized Microstrip Disk Antenna By One Point Feed", Transactions on Institution of Electronics and communication Engineering Japan part B, vol.163, pp. 559-565,1980.

[25] Shinya Tada ,Ridho Chayono, Yuichi Kimura And Misao Haneishi, "A Consideration on Radiation Properties of Multiband Sierpinski Gasket Microstrip Antenna(SG-MSA)", Proc. of International Symposium of Antennas and Propagation, Japan, pp. 697-700, 2004.

[26] Jaume Anguera, Enrique Martinez and Carles Puente, "Broad Band Dual Frequency Microstrip Patch Antenna with Modified Sierpinski Fractal Geometry", IEEE Transactions On Antenna and Propagation, vol. 52, no.1, pp. 66- 73, 2004.

[27] Pingping Zhang, Hao Wang, Yan Wang, Yong Huang, Jie Wang and Xiaolong Shoa, "Investigations of Compact Tri-band Antenna for CNSS Application", IEEE Microwave Conference Proceedings (APMC), Asia-Pacific, pp.1100-1102, 2013.

[28] T.Vasanthan, V.Vignesh, MS.Rajeswari.R and M.Dinesh, "Design of Corner Truncated Microstrip Square Patch Antenna for Multi-Constellation GNSS Applications" Proc. of International Academic Conference on Electrical, Electronics and Computer Engineering, Chennai, pp.68-70, 2013.

[29] Dr. Dru A. Smith, "The Future of Global Navigation Satellite Systems: Anyone, Anywhere, Anytime, Any Accuracy by 2027", http://celebrating200years.noaa.gov/visions/gnss, 2012.

[30] Djebari, M. and Abdelhadi, A., "Compact multi-band rectangular slotted antenna for Global Navigation Satellite Systems (GNSS)", Proc. of Electronics, Communications and Photonics Conference (SIECPC), pp.1-5, 2013.

[31] D.Anagnostou, M.T.Chryssomallis and J.C.Lyke, "Improved Multiband Performance with Self Similar Fractal Antennas", Proc. of IEEE Tropical Conference on Wireless Communication Technology, pp.271- 272, 2003

[32] Jaspreet Kaur, Surjeet Singh and Ankush Kansal, "Multiband Behaviour of Sierpenski Fractal Antenna", Research Journal of Information Technology, vol. 3, pp. 35-43, 2011.

[33] G. Srivatsun and Shuba rani, "A Compact Multiband Fractal Cantor Antenna for Wireless Appplications", European Journal of Scientific Research, vol.71, no.2, pp. 273-282, 2012.

[34] Gopalakrishnan srivatsun, sundaresan subha, "A self-similar fractal cantor antenna for MICS band wireless applications", Wireless engineering and technology, vol. 2, pp. 107-111, 2011.

[35] B. Manimegalai, S.Raju, and V. Abhaikumar "A Multifractal Cantor Antenna for Multiband Wireless Applications", IEEE Antennas and Wireless Propagation Letters, vol.8, pp. 359- 362, 2009.

[36] Dushyant H. Raval, "Design of a Rectangular Microstrip Patch Antenna for Indian Regional Navigational Satellite System", International Journal for Scientific Research & Development, vol. 3, issue 02, pp. 316-317, 2015.

[37] B.Sada Siva Rao, T.Raghavendra Vishnu, Habibulllah Khan and D.Venkata Ratnam, "Spiral Antenna Array Using RT-Duroid Substrate for Indian Regional Navigational Satellite System", International Journal of Soft Computing and Engineering, vol.2, issue-2, pp.555-557, 2012.

[38] Nirav J. Patel, Prof. A. K. Sisodia, "The review on tri-band microstrip antenna for GNSS applications", Journal of Emerging Technologies and Innovative Research, vol. 2, issue 3 pp. 472-476, 2015.

[39] Raj Kumar,J.P shinde and P.Malathi, "The Design of CP Triangular Fractal Patch Antenna with Slit", Proc. of ISAP, Japan, pp. 1074 – 1077, 2007.

[40] Bamsley,M.F, "Fractals Everywhere", 2nd Ed., Academic press professional, Newyork, 1993.

[41] Carles Puente –Baliarda, "On the Behavior of the Sierpenski Multiband Fractal Antenna", IEEE Transactions on Antenna and Propagation, vol. 46, no.4, pp. 517-524, 1998.

[42] Jordi Romeo and Jordi Soler, "Generalized Sierpinski fractal Multiband antenna", IEEE Transactions on Antenna and Propagation, vol. 49, no.8, pp. 1237- 1239, 2001.

[43] Jawad K.Ali,Zaid, A.Abed Al-Hussain,Ammer, A.Osman Nad Ali.J.Salim, "A New Compact Size Fractal Based Microstrip Slot Antenna for GPS Applications", Proc. of Progress In Electromagnetics Research Letters, KualaLumpur, pp. 700-703, 2012.

[44] Arivazhagan, S., Kavitha, K. and Prasanth, H.U., "Design of a triangular fractal patch antenna with slit for IRNSS and GAGAN applications", Proc. of International Conference on Information Communication and Embedded Systems (ICICES), pp.665-669, 2013.

[45] Ashish N. Patel and A. K. Sisodia, "Design and Simulation of Patch Array Antenna for Indian Regional Navigation Satellite System (IRNSS)", International Journal of Engineering Development and Research, vol. 3, issue 1, pp. 261-265, 2014.

[46] Zhenchao Yang and Karl F. Warnick, "A Planar Passive Dual Band Array Feed Antenna for Ku Band Satellite Communication Terminals", Proc. of Antennas and Propagation Society International Symposium, Chicago IL, pp. 1-2, 2012.

[47] M. T. Ali, T. A. Rahman, M. R. Kamarudin, M. N. Md Tan and R. Sauleau, "A Planar Antenna Array with Separated Feed Line for Higher Gain and Sidelobe Reduction", Progress In Electromagnetics Research C, vol. 8, pp. 69-82, 2009.

[48] Yijun Zhou, Chi-Chih Chen and John L. Volakis, "Dual Band Proximity-Fed Stacked Patch Antenna for Tri-Band GPS Applications", IEEE Transactions on Antennas and Propagation, vol. 55, issue-1, pp. 220-223, 2007.

[49] Wen Liao; Qing-Xin Chu; Shu Du, "Tri-band circularly polarized stacked microstrip antenna for GPS and CNSS applications", Proc. of International Conference on Microwave and Millimeter Wave Technology, pp.252-255, 2010.

[50] C. L. Mak, K. M. Luk, K. F. Lee and Y. L. Chow "Experimental Study of a Microstrip Patch Antenna with an L- Shaped Probe", IEEE Transactions on Antennas and Propagation, vol. 48, issue - 5, pp. 777-783, 2000.

[51] Jia-Yi Sze and Kin-Lu Wong, "Slotted Rectangular Microstrip Antenna for Bandwidth Enhancement", IEEE Transactions on Antennas and Propagation, vol. 48, issue - 8, pp. 1149 -1152, 2000.

[52] Rajan H Kapadia and Raj Hakani, "Design and implementation of a Planar Array Antenna for L5 band of Indian Regional Navigational Satellite System (IRNSS)", International Journal of Innovative Research in Technology, vol. 2, issue 1, pp.10-14, 2015.

[53] Rajan H Kapadia, Raj Hakani, "Design and Implementation of a Planar Array Antenna for Indian Regional Navigational Satellite System (IRNSS)", International Journal for Technological Research in Engineering, vol. 2, issue 7, pp. 1242-1246, 2015.

[54] Gunasekaran T, Veluthambi. N, Ganeshkumar. P and Kumar. K.R.S, "Design of edge fed microstrip patch array antenna

configurations for WiMAX", Proc. of IEEE International Conference on In Computational Intelligence and Computing Research, pp. 1-4, 2013.
[55]. Prakash Kumar Mishra, R. Raaj, P. Maddhyeshia and R.K. Vishwakarma, "Design of Dual Band Slot Loaded Rectangular Microstrip Antenna for Global Positioning System", Proc. of International Conference on Communication Systems and Network Technologies, pp. 37-40, 2013.
[56] T.R.Harris, "The Design Process of a rectangular microstrip antenna" North Carolina State University, http://www4.ncsu.edu/~trharris/files/text/Harris-740PatchProj.pdf, 2014.
[57] Girish kumar and K.P.Ray, "Broadband Microstrip Antennas", Artech house, Boston, London, 2002.
[58] Shabu and Manju James "Comparison of Single Patch and Patch antenna Array for a Microwave Life Detection System", Proc. of International Conference on Communications and Signal Processing, pp. 171-174, 2011.
[59] Fakharzadeh, Mohammad, "A Compact 4 by 1 Patch Array Antenna-in-Package for 60 GHz applications", Proc. of IEEE Antennas and Propagation Society International Symposium, pp. 1-2, 2012.