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Performance analysis of IRNSS using compact microstrip patch antenna for S band application

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Abstract
The Indian Regional Navigation Satellite System (IRNSS) is a newly functional regional satellite navigation system around Indian subcontinent. It is also known as its functioning name of NaVIC, Navigation with Indian Constellation, working on L5 and S band. In this paper a compact and low cost circularly polarized microstrip patch antenna is proposed for IRNSS S band application, to provide single frequency navigation solution. Fabrication of proposed antenna is performed using substrate of RT Duroid 5880 with the dimensions of $0.66\lambda \times 0.5\lambda$. The performance of IRNSS is investigated by prototype antenna and Accord made triband antenna with IRNSS/GPS/SBAS receiver which is enable to receive L1, L5 and S band data. The comparison of proposed S band antenna, triband accord system antenna and GPS antenna is presented in terms of carrier to noise ratio and positioning error. Results show that proposed antenna is suitable for S band application of IRNSS receiver.

Keywords Indian Regional Navigation Satellite System · Microstrip patch antenna · Duroid · PVT-position, velocity, timing · IRNSS receiver · GPS

Introduction

Indian Regional Navigation Satellite System (IRNSS) is established and controlled by the Indian Space Research Organization (ISRO) under Government of India. This independent navigation system was required for India since long back, because other global positioning and navigation systems are not reliable in inimical conditions. The main objective of the IRNSS is to provide positioning and navigation services to users in the Indian region. IRNSS is designed to provide navigation solutions to land, air and marine transport users (Ganeshan et al. 2005) in place of GPS. IRNSS provides approximately 10-m accuracy for positioning in the Indian region and 20 m accuracy for positioning in 1500 km around the Indian region. There are seven satellites to make the IRNSS fully operational since May 2016. IRNSS transmits signals in dual band namely L5 with centre frequency of 1176.45 MHz and S band with centre frequency of 2492.028 MHz. So dual bands as well as any of the band can be used for the navigation purpose (ISRO 2019). Since S band is less prone to ionosphere effect, we focus on the S band antenna design. We also compare it with Accord made triband antenna and GPS antenna in terms of signal strength, carrier to noise ratio with positioning accuracy of IRNSS/GPS/SBAS receiver.

Nowadays, very portable handheld wireless communication devices are in high demand for internet and mobile communication. Antenna size and its gain is the major consideration for these devices. Compact microstrip patch antenna is a better choice with portable communication devices. Navigation is one of the important application of satellite communication. For radio navigation, highly accurate receiver unit is required with its high gain antenna performance due to the longer distance between satellite and ground receiver (Wu et al. 2010; Bilotti and Vegni 2010). Circular polarization is preferred in satellite communication to overcome the limitation of transmit and receive antenna orientation.(Sahal and Tiwari 2016) The axial ratio for circular polarization must be within the 3 dB to achieve circular polarization. Microstrip patch antenna is a thin flat structured antenna in which some simple techniques can be applied to get circular polarization, so it is preferable for satellite receivers.

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In this paper a low cost compact design of microstrip patch antenna is proposed for S band IRNSS application with circular polarization. A prototype of proposed antenna is fabricated and tested. Real time navigation signal, received with proposed antenna is closed confirmation with signal received by Accord made triband antenna. The positioning information and its error are found and discussed with proposed antenna, Accord made triband antenna and GPS antenna. Here, second section includes proposed "S band antenna design", third section contains "Experimental setup", fourth section comprises "Results and discussion", and fifth section concludes the findings.

S band antenna design

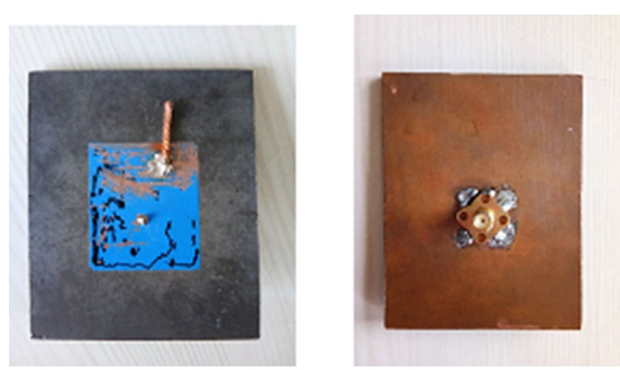
The proposed design consists of conducting patch and ground plane, made up of copper with substrate of duroid with dielectric constant of 2.2. It contains loss tangent of 0.0009 which exhibits very low dielectric loss. The antenna is fed with coaxial cable. The dimensions of the patch are 38 mm × 29 mm, tuned to achieve 2.49 GHz in S band. Dimensions of the substrate are 80 mm × 60 mm with thickness of 3.2 mm to get desired return loss and bandwidth. There are several methods to achieve circular polarization in microstrip patch antennas, like cross slits, truncated corners, and dual feed excited by two orthogonal modes technique etc. (Kumar and Ray 2003). The truncated-corners microstrip patch antenna is the best choice for small axial ratio with narrow axial ratio bandwidth (Sharma and Gupta 1983; Sahal and Tiwari 2016). Cross shaped slits gives circular polarization with good axial ratio bandwidth (Nasimuddin and Qing 2012). Feed location and feeding technique decides the impedance bandwidth and axial ratio which is ratio of minor and major axis of polarization circle or ellipse and it must be less than 3 dB, decides the polarization (Sahal and Tiwari 2016). As the circular polarization is preferred for satellite communication, half circular cuts are created at both diagonal corners to set the RHCP axial ratio is around 3 dB.

The proposed design of circularly polarized Microstrip patch antenna is focused for S band of IRNSS receiver with the resonant frequency of 2.4900 GHz. This design are prepared and simulated in Ansoft HFSS 17. The prototype of proposed design is also prepared and initially tested on Keysight Field fox Microwave Analyzer N9916A.

Return loss is the loss of power which is returned back to the antenna. As much as the value of return loss is small, the antenna can radiate more in forward direction. So the smaller (negative) value of return loss is preferred. Generally, the return loss must be less than -10 dB is considered for practical application. For proposed antenna, the return loss found to be of − 27.85 dB with the bandwidth of 60 MHz. Impedance bandwidth for simulated antenna is 2% and prototype antenna is 2.41%. The fabricated antenna received the resonant frequency of 2.5422 GHz which was higher than the desired frequency. The simulation results of the design are not matched with prototype results when tested on microwave analyzer and slight frequency deviation is found. So, the tuning stub is used on the edge of patch, to reduce the resonant frequency.

This stub will increase the effective length of patch and shift the axis of field electrically, also the position of feed point will be changed electrically. The effective length will determine the resonant frequency and effective position of feed point will decide the input impedance (Reddy et al. 2015), resulting the desired frequency is achieved with very good value of return loss. When the length of the stub is very small, less than $\lambda/4$, then by changing its length and width, the resonant frequency of the microstrip patch antenna is tuned (Ray and Kumar 2000). Generally, the 10% tuning range of frequency is achieved by changing the length of stub from 0 to 1 cm (Roy and Jha 2019). The copper stub (as shown in Fig. 1a) of 19 mm × 2 mm is attached along the length of the patch which helped to set the desired resonant frequency. This antenna radiates on the center frequency of 2.4845 GHz with the bandwidth of 60 MHz which covers S band operating bandwidth of IRNSS. The gain is 7.43 dBi and standing wave ratio of 1.24 dB. All these operating parameters make our antenna fully compatible to IRNSS application.

A planar microstrip patch antenna is having dielectric substrate between conducting ground plane and patch, due to which fringing effect is generated. It makes the effective dielectric constant always less than relative dielectric constant of substrate. So effective width and effective length of patch is considered for further calculations. The effect of stub increases the overall resonant length of microstrip patch antenna from L_e to $L_e + \Delta l_1$, the value of Δl_1 can be found by following equation (Kumar and Ray 2003)



(a) (b)

Fig. 1 **a** Top view of fabricated antenna, **b** bottom view of fabricated antenna

$$\Delta l_1 = \frac{(w_e)(l_e)}{W_e} \quad (1)$$

where $(w_e)(l_e)$ is effective area of stub and W_e is effective width of patch.

Now the new resonant frequency f_0 will be (Kumar and Ray 2003)

$$f_0 = \frac{c}{2(L_e + \Delta l_1)}\sqrt{E_{eff}} \quad (2)$$

where c is velocity of light in meter per second, L_e is effective length for patch and E_{eff} is effective dielectric constant of substrate.

As the new desired frequency is known to us, we can find out the approximated length and width of stub by putting the value of f_0 in Eq. (2) (Kumar and Ray 2003) (Table 1).

Here, Fig. 1a shows photograph of front side of fabricated antenna with corner truncated patch on the duroid substrate and a piece of copper wire is soldered on the surface of the patch for stub matching. Figure 1b shows the photograph of back side of the fabricated antenna, over which the SMA connector is soldered to feed the antenna. Figure 2 shows the simulated and measured values of return loss (reflection coefficient), S11 in dB of proposed antenna. The red curve shows the simulated data and blue curve shows the experimental data of return loss. Table 2 shows the comparison of antenna dimensions, patch type and size, bandwidth and gain of prototype antenna with other antennas present in the literature, and found that the size of proposed antenna is smaller with its gain value, comparing with other antennas.

Table 1 Comparison of simulated and measured results of prototype antenna

Parameters	Simulated	Measured
Resonant frequency	2.4900 GHz	2.4845 GHz
Return loss	− 22.9331 dB	− 27.85 dB
Gain	7.89 dB	7.43dBi
Bandwidth	52 MHz	60 MHz
Impedance bandwidth in %	2%	2.41%

Experimental setup

Ansys HFSS 17.2 is used to design and simulate the circularly polarized microstrip patch antenna for the resonant frequency of 2.49 GHz with RHCP axial ratio around 3 dB. The proposed design is fabricated using duroid substrate. Prototype of the antenna is initially tested with Keysight Field fox Microwave Analyzer N9916A and found that the results deviate from desired band. By properly designing and placing the stub, along the length of the patch, the resonant frequency of 2.4845 GHz is achieved with the return loss of − 27.85 dB for S band operation. Afterward this prototype antenna is connected with the IRNSS/GPS/SBAS receiver to receive the S band navigation signal by setting the receiver into S band mode only. There are two sets of IRNSS/GPS/SBAS receivers (A314 and A315) are installed at IITRAM provided by SAC ISRO, Ahmedabad for the field trial of the IRNSS. Figure 3 shows antenna set up at terrace of IITRAM with Accord made triband antenna and proposed S Band antenna. Proposed S band antenna is connected to A315,

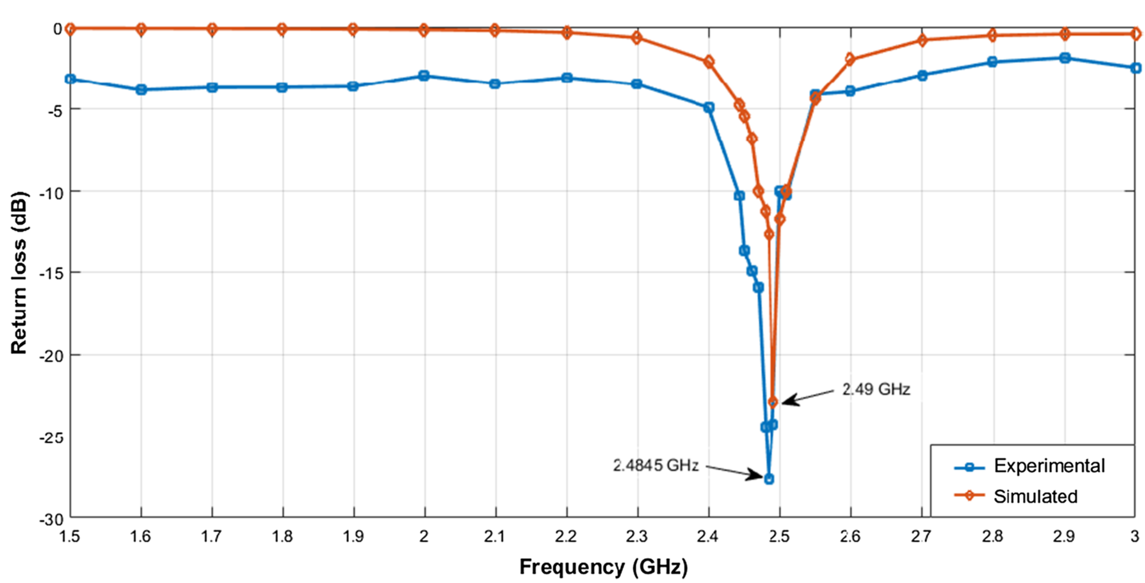


Fig. 2 Simulated and measured value of return loss (reflection coefficient) S11 in dB for proposed antenna

Table 2 Comparison of proposed antenna performance parameters with other S band antenna design from the literature

Reference remarks	Size of ant. mm^2	Patch type and size	BW %	Gain dBi
Nascetti et al. (2015) S band 2450 MHz	96 * 96	Square 57 * 57 mm^2	Not metioned	7.3
Pachigolla et al. (2018) ISM band 2.4 GHz	50 * 50	Reactangle 29 * 38 mm^2	3.75	1.75 for FR4, 4.1 for Arlon
Desai et al. (2018) Transparent Ant MIMO Band 1: 2.4 GHz WLAN Band 2: 3.7 GHz WiMAX	50 * 50	Slotted interconnected ring resonator 24 mm diameter	Single element Band 1: 18.70 Band 2: 21.28 2*1 element Band 1: 11.29 Band 2: 11.64	Single element Band 1: 1.12 Band 2: 2.28 2 * 1 element Band 1: 1.98 Band 2: 2.95
Desai and Upadhyaya (2018) Transparent Ant for smart devices Band 1: 2.4 GHz Band 2: 5.5 GHz	35 * 35	Two over lapping rings 16.2 mm diameter	Band 1: 5.61 Band 2 : 3.62	Band 1: 0.70 Band 2: 1.67
Hussein et al. (2019) S band 2 to 4 GHz	70 * 70	Gear shaped radiating patch 31 mm diameter	2.39	4.27
Proposed antenna	80 * 60	Rectangle 38 * 29 mm^2	2.41	7.43

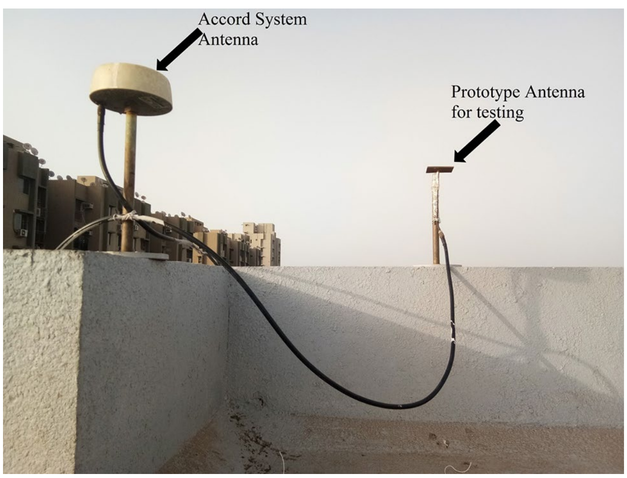


Fig. 3 Antenna set up at terrace of IITRAM

Accord made triband antenna is connected with A314 and GPS antenna is connected to its GPS receiver to collect the positioning data. The antenna is mounted at approximately 25-m height from the ground at IITRAM. The value of carrier to noise ratio (C/N_0) and positioning data have been analyzed to find the signal strength and position accuracy of IRNSS at stationary condition. Table 3 shows the specifications of our experimental setup using which the performance of IRNSS is analyzed with proposed S band antenna and Fig. 4 shows the front view of IRNSS/GPS/SBAS receiver and the computer monitor which shows the value of carrier to noise ratio. The vertical bars shown on both the screen are the amplitude of carrier to noise ratio. One bar indicates one channel received by receiver. As per Fig. 4, six channels are received, and according to atmospheric conditions its amplitude varies frequently.

Results and discussion

The performance analysis of IRNSS is carried out with three different antennas to evaluate the signal strength in terms of carrier to noise ratio and positioning error. The Accord made triband antenna is connected to A314 IRNSS/GPS/SBAS receiver, the proposed S band antenna is connected to A315 IRNSS/GPS/SBAS receiver to

Table 3 Specification of experimental setup

System	Indian Regional Navigation Satellite System
Antenna type	Proposed antenna, accord made triband antenna, GPS antenna
Receiver type	A314, A315 accord IRNSS/GPS/SBAS receiver, GPS receiver
Data type	L1, L5, S band
Location	Institute of Infrastructure Technology Research and Management, Ahmedabad, Gujarat, India
Time period	25–31 March 2019

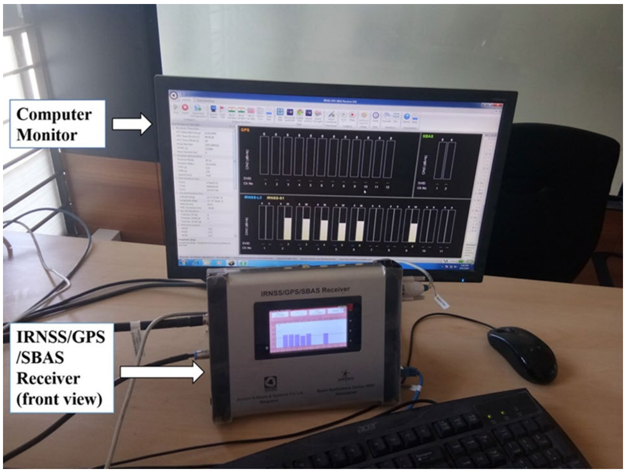


Fig. 4 Experimental setup at lab of IITRAM

Table 4 Carrier to noise ratio for IRNSS channels received by Prototype antenna

Channel no.	PRN	IRNSS+GPS mode (L1+L5+S) (Accord system antenna)		IRNSS S band mode (Prototype antenna)	
		C/N_0^a (dB-Hz)	Iono type	C/N_0^a (dB-Hz)	Iono type
1	1	38.5	Dual	40.3	Grid
2	2	43.6	Dual	38.9	Grid
3	3	43.0	Dual	37.9	Grid
4	4	42.2	Dual	38.8	Grid
5	5	41.6	Dual	39.6	Grid
6	6	40.3	Dual	41.2	Grid
7	7	39.4	Dual	39.3	Grid

[a]These data are changed continuously with minor variations according to the time

collect real time navigation signal. Table 4 shows the values of carrier to noise ratio in dB and ionospheric delay correction model for Accord made triband antenna and proposed S band antenna. The acceptable value of C/N_0 for IRNSS is greater than 32 dB (Parmar et al. 2015). We found the carrier to noise ratio is between 37 and 41 dB for each channel of satellite and is in acceptable range for proposed S band prototype antenna. The first and eighth channels are not used for tracking. Channel number two to seven must be tracked and ninth channel can be tracked by adding PRN massage comment in IRNSS (ISRO 2019). The positioning information with Accord made triband antenna is 23.0044004129077 and 72.6216892127453 and positioning information with proposed S band antenna is 23.0044471749422 and 72.6216352279293. This shows that the positioning data acquired by S band antenna is in good approximation with the triband antenna. Here, the location coordinates of IITRAM which are 23.00439687 and 72.62182262 have been considered as a golden reference to determine the error in positioning (Rawat et al. 2018). So, the positioning error for S band prototype antenna is found which is less than 10 m. Table 5 shows the latitude, longitude and altitude of IITRAM at stationary point using three different antennas with three different receivers. Table 6 shows that positioning error is 1.9 m for GPS antenna, 1.27 m for Accord made triband antenna (IRNSS dual band + GPS antenna) and 1.29 m for proposed S band antenna. The altitude of the rooftop of the IITRAM is 84.50 m at which the IRNSS antennas are mounted. The altitude error is 3.81 m for GPS antenna, 6.29 m for Accord made triband antenna (IRNSS dual band + GPS antenna) and 5.27 m for proposed S band antenna. For IITRAM, the X position is 1,754,426.3 m, Y position is 5,605,814.42 m and Z position is 2,477,176.59 m, which are considered as a golden reference or reference position stored in IRNSS/GPS/SBAS receiver to calculate the positioning error. The position error is calculated by Eq. (3) and it is verified with the receiver data also. The positioning error can be calculated by the following equation,

$$\text{Error} = \sqrt{\left(X - X_1\right)^2 + \left(Y - Y_1\right)^2 + \left(Z - Z_1\right)^2} \tag{3}$$

where X_1, Y_1 and Z_1 are the instantaneous value of real time positioning data collected from the IRNSS receiver. The positioning data from receiver is subtracted from Golden reference, X, Y, Z individually, by adding and taking square of its answer and finally finding square root of it, we get the final positioning error at the location of IITRAM for stationary point.

Table 5 Positioning information of IIT RAM with three different antennas

S. no.	Antenna type	Latitude	Longitude	Altitude (m)
1	GPS antenna	23.00440922470994	72.62166043201685	80.69
2	IRNSS dual band + GPS antenna	23.0044004129077	72.6216892127453	78.21
3	IRNSS S band antenna	23.0044471749422	72.6216352279293	79.23

Table 6 Position and altitude error at IIT RAM with three different antennas

S. no.	Antenna type	Position error (m)	Altitude error (m)
1	GPS antenna	1.9	3.81
2	IRNSS dual band + GPS antenna	1.27	6.29
3	IRNSS S band antenna	1.29	5.27

Conclusion

In this paper, a compact and low cost circularly polarized Microstrip patch antenna design is proposed for S band application of IRNSS receiver. Initially, the hardware prototype of the proposed antenna is tested using Keysight Field fox Microwave Analyzer N9916A and found to be shifted from the desired resonant frequency of IRNSS receiver. After proper single stub matching, we achieved the desired resonant frequency and bandwidth in the hardware prototype. The positioning information of IITRAM is found by connecting Accord made triband antenna, proposed S band antenna and GPS antenna to individual receivers and compared the error in positioning data. Positioning error is least with Accord triband antenna which receives L1, L5 and S band data and altitude error is least with GPS antenna. A single frequency Grid model for ionosphere correction is applied for S band operation to correct the ionosphere delay and provides precise positioning data for single frequency user. Results reveal that the positioning error of 1.29 m for the single frequency operation using proposed prototype S band antenna is achieved, which are less than 10 m and fulfill the objective of Indian Regional Navigation Satellite System. Further, the signal strength, carrier to noise ratio and positioning data are found with good accuracy with proposed single band (S band) antenna also. This compact antenna can be used to find PVT and proved a good choice in the low cost for single band navigation solutions.

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Compliance with ethical standards

Conflict of interest The authors hereby confirm that there is no conflict of interest with respect to the current manuscript.

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