Impact of Radiation Pattern of GNSS Receiver Patch Antenna in positioning during high rotation rate & Mitigation Techniques

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Abstract

Global Navigation Satellite System (GNSS) receivers are used in launch vehicles for aiding inertial navigation systems for improving the navigation accuracy. In satellites, they are used for finding the precise location of the spacecraft as well as for time based commanding. In a GNSS receiver system, configuration of antenna system along with antenna pattern and RF front-end configuration has a direct impact on visibility of GNSS satellites during different phases of the mission, especially under rotation dynamics. Internationally, the high dynamics capability of a GNSS receiver is specified in terms of linear dynamics. In this paper, an analysis on impact of antenna radiation pattern of a GNSS receiver under high rotation rate is studied. Different body rotation rates are simulated using a GNSS RF Signal Simulator and the performance of GNSS receiver antenna pattern in the two antenna configuration is studied in detail. Analysis of the flight performance of GNSS receiver system in orbital platform experiment under rotation rates is also highlighted in this paper. Limitation w.r.t two antenna configuration with single RF front-end is also discussed and a novel mitigation technique for the above problem using dual RF front-end configuration is also proposed.

1. Introduction

Global Navigation Satellite Systems (GNSS) Technology has seen a giant leap especially in the last two decades with the addition of more constellations globally and regionally. The main intended application of GNSS system is for navigation, be it terrestrial, aircraft, launch vehicle or spacecraft. Other than navigation applications, usage of GNSS receivers have increased to wide range of other applications such as. surveying, precise time keeping and environmental monitoring. Increasing demand and wide usage of GNSS receivers for variety of applications has put stringent conditions on their performance and environmental specifications.

Presently, usage of integrated navigation systems (Inertial navigation aided with GNSS navigation) has become a de-facto standard in launch vehicle (LV) applications. Most challenging requirement of an LV GNSS receiver is its capability to function under high dynamics. Commercially available GNSS receivers are meant for terrestrial use and are bound by ITAR restrictions and are limited to the platforms where velocity and altitude do not exceed 515 m/s and 18 km respectively. Also, such receivers are invariably designed for low dynamics typically accelerations less than 3 g and jerks less than 2 g/s. In order to cater to high dynamic LV applications, specially designed high dynamic receivers are essential.

A high dynamic GNSS receiver meeting the LV dynamics and environmental specifications is designed for India's LV applications. System is capable of receiving GPS and NavIC signals and can be used to aid the INS system. In conventional LVs, GNSS aided navigation system is used for real time trajectory monitoring of the vehicle and preliminary orbit determination (POD) of the injected satellite. Further, GNSS aided INS system is used as the core navigation system for newly developed low cost launch vehicles. A modified version of the LV GNSS receiver is used in Orbital platform Experimental for positioning as well as time keeping application.

One thing to note here is that the high dynamics capability of a GNSS receiver is intended for ensuring the performance at high velocity, acceleration and jerk (i.e. linear dynamics). Performance of the receiver under rotation rate is solely depending on continuous visibility of satellites under body rates, which depends on the antenna pattern only. A study on the impact of antenna radiation pattern in positioning application during high rotation rate is detailed in this paper.

2. Layout

This paper is organized into different sections as follows. GNSS receiver basic configuration including antenna system details, antenna mounting configuration and effective radiation pattern is discussed in Sections 3 & 4. Theoretical study on radiation pattern under body rotation is given in Section 6. Details on different simulation tests carried out using GNSS RF signal simulator and their results for the present LV antenna configuration is briefed in Section 7 and the analysis of the simulation results is given in Section 8. Real flight performance of GNSS receiver in orbital platform experiment under body rate condition is highlighted in section 9. Techniques to mitigate intermittency in solution availability under high rate condition is proposed in Section 10 which is followed by conclusion, acknowledgments and references.

3. GNSS Receiver Configuration

In general, a GNSS receiver system will have following components: Antennae, LNA, Power combiner and GNSS receiver. Configuration and interconnections of the sub-systems are as shown in Figure-1.

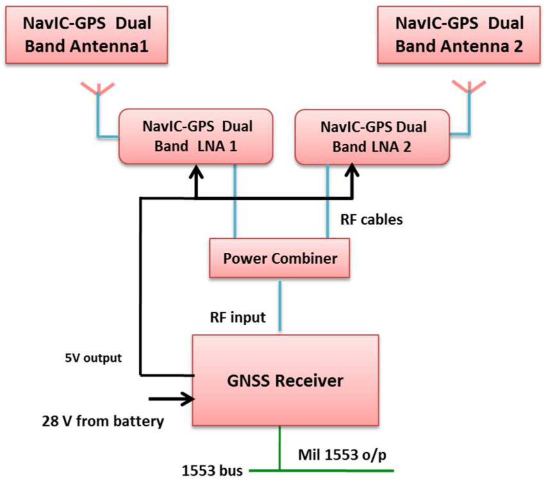

Figure 1. GNSS Receiver System Configuration.

In the GNSS receiver system considered for study which is a generic configuration followed in launch vehicle/ spacecraft applications, there are two antennae mounted diametrically opposite (180^{o}apart) in the launch vehicle/ spacecraft body in order to have better satellite visibility. The antennae, LNA and power combiner are dual band elements, i.e. able to function in GPS L1 and NavIC L5 frequency bands. Antennae and LNA are closely placed and the signals acquired by the antennae are amplified by the LNA in each chain. Signals from the two LNAs are further combined using the power combiner and the output of the power combiner is given as RF input to the GNSS receiver. The outputs of the GNSS receiver are position, velocity and time computed by the receiver. These are passed to the mission computer through MIL STD 1553B interfaces.

4. GNSS Receiver Antenna System

GNSS antenna is a stacked Circular Polarized Micro strip Patch Antenna. They operate at two frequencies - 1575.42 MHz and 1176.45 MHz for reception of GPS L1 and NavIC L5 signals. The specification of antenna is given in figure 2. [2]

The antenna is made up of two square patches stacked one above the other with one designed to resonate at L5 and the other at L1 frequency bands. Circular Polarization (RHCP) is achieved by corner truncating the square bottom patch. The combination of stub along one diagonal and corner truncation along another diagonal of upper patch is used for achieving a good axial ratio. A Single probe feed of 50Ω input impedance is connected to the upper patch through via hole in the bottom patch while the bottom patch is excited through electromagnetic coupling.

Table 1 Specifications of antenna.

S.no	Parameter	Specification
1	Frequency	1575.42 MHz - L1 band 1176.45 - L5 band
2	Antenna Type	Stacked Microstrip patch Antenna
3	Coverage Factor	90% (-15dBic)
4	Bandwidth (RL>10 dB)	± 5 MHz
5	Return Loss	≥14 dB
6	Gain	3 dBic (typical)
7	Polarization	RHCP
8	Axial Ratio	≤5 dB
9	Impedance	50 ohms
10	Antenna substrate / Radome material	RT6002/RO4003C

4.1. Antenna Radiation Pattern

As mentioned in the above sections, there are two antennae mounted diametrically opposite to have omni-directional coverage. Signals from the antennae after LNA amplification are combined together using power combiner and thus the resultant radiation pattern of the GNSS receiver will be the combined antennae pattern of the two antennae.

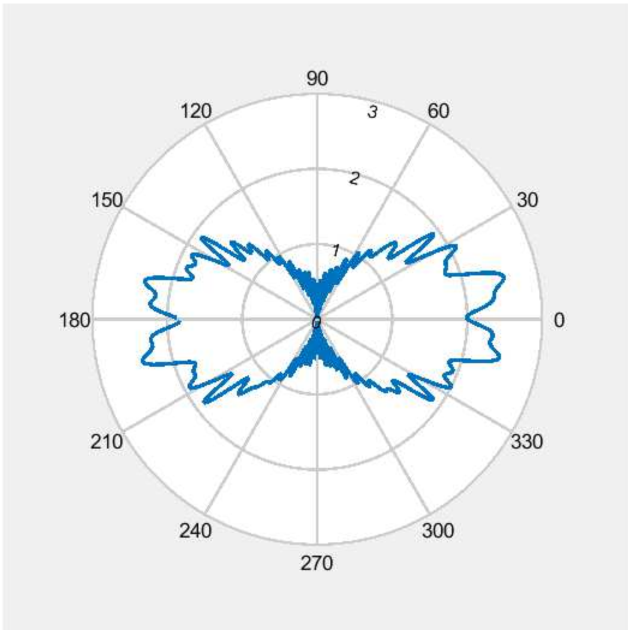

Figure 2. Antenna Radiation Pattern-Azimuth vs Gain (Polar plot) for a fixed elevation angle of 0.5º. Two antenna are mounted 180º apart, hence max gain is seen around 0º and 180º azimuth.

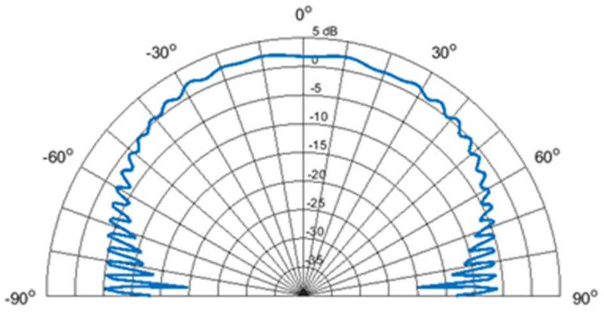

Figure 3. Simulated antenna gain pattern with 0° azimuth and elevation from -90° to +90°.

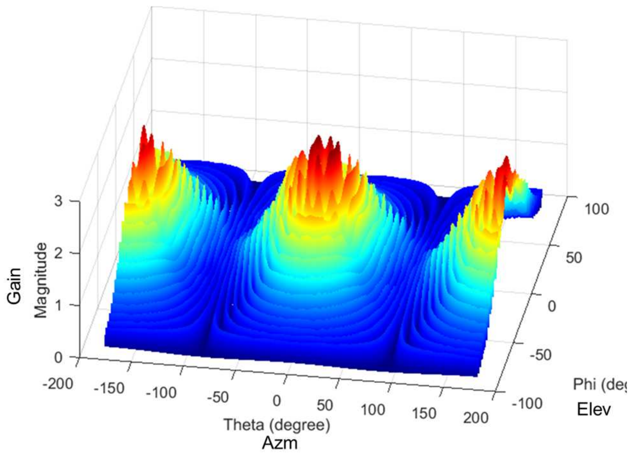

Figure 4. Antenna Radiation Pattern- 3D plot. Gain vs Azimuth vs Elevation. Two antenna are mounted 180º apart, hence max gain is seen around 0deg and 180º azimuth and at an elevation of 0º.

Figures 3 to 5 denote the simulated antenna gain pattern of the GNSS receiver system used in orbital platform experiment. The diameter of the vehicle structure is approximately taken as 3m for the antenna radiation pattern study. Based on the above figures, for maximizing the satellite visibility, the elevation angle and azimuth of the visible satellites is to be within ± 70°.

5. Pre-requisites for GNSS solution Computation

A satellite will be used for solution computation under the following conditions:

1. Satellite ephemeris is downloaded. GPS requires around 18-36 seconds of tracking of the satellite for ephemeris download. NavIC takes 24-60sec.
2. Satellite time (TOW) is decoded. GPS requires 12-18 seconds & NavIC requires 24-36 seconds of continuous tracking of a satellite. TOW is validated using two frames and hence more than one frame is required.

Under the above two conditions, continuous tracking of minimum 4 such satellites for 1 sec is required for solution computation.

6. Theoretical Limit for Single Axis Rate

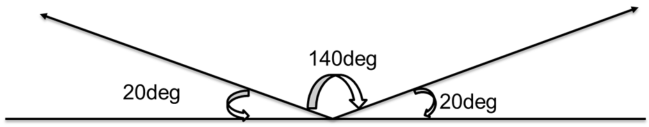

Figure 5. Angular region with sufficient gain for computation of theoretical Limit for Single Axis Rate

From the above figure, azimuth angle in either direction ($0^{\mathbf{o}}$ or $180^{\mathbf{o}}$) for which continuous tracking is possible is $140^{\mathbf{o}}$. GPS requires continuous tracking of min 12-18 seconds for solution computation. Hence, theoretical maximum rate at which solution computation is feasible can be computed as follows:

$$Max\ angular\ Rate = \frac{140}{18} = 7.78\ deg/s \quad (1).$$

Theoretical maximum rate thus computed is ~7 deg/s.

7. Simulation Tests carried out

In order to assess actual GNSS receiver performance under body rate conditions, a GNSS RF simulator along with actual flight hardware is used. Antenna radiation pattern of the actual flight antenna was given as an input to the GNSS simulator and the RF output from the simulator is given as input to the receiver.

Following tests were carried out:

1. Case-1: Single axis angular rate input was given about an axis perpendicular to azimuth-elevation plane.
2. Case-2: Angular rate input given in all 3 axes in the orbital condition.

7.1. Summary of Test Results

Table 2 Summary of Test Results of Case-1. GNSS Receiver is able to give position-velocity solution up to a rate of 7 deg/s.

Sl no.	Body Rate (Roll) – deg/s	% solution availability	Remarks
1	0.5	97.88	
2	1	97.21	
3	2	97.01	
4	5	69.40	Positioning performance is severely affected
5	7	59.28	
6	8	0	No Position Fix
7	10	0	

Table 3 Summary of test results of Case-2. In the orbital conditions, GNSS Receiver is able to give solution up to a rate of 5 deg/s in all 3 axes.

Sl no.	Body Rate (Roll) – deg/s	% solution availability	Remarks
1	2	96.38%	
2	5	74.62%	
3	6	6.78%	Solution availability severely affected

8. Analysis of Test Results

In case of single axis rate, as computed using the theoretical limit, receiver is able to give position-velocity solution up to an angular rate of 7 deg/s. In order to assess the performance of GNSS receiver used in orbital platform experiment, 3-axis rates under orbital condition also is simulated and the test results show that up to 5 deg/s angular rate about all three axes, solution computation is possible.

9. Performance of GNSS receiver in orbital platform experiment under body rate conditions

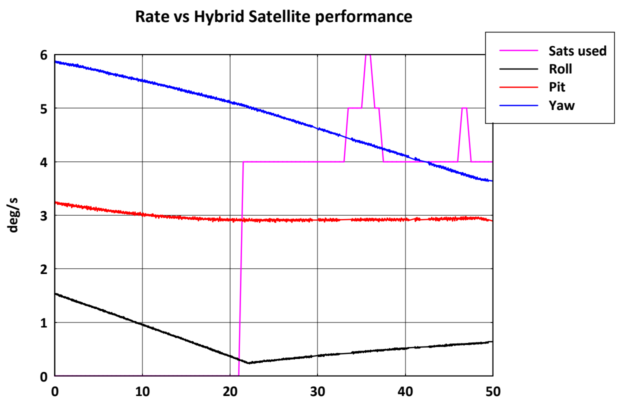

Figure 6. Angular rate vs satellites used for solution computation in orbital platform experiment

Performance of GNSS receiver aboard orbital platform experiment under 3-axis body rates is shown in figure 6. At the start of a particular orbit, orbital platform was in passive control mode and hence rates were there along 3-axes. Yaw rate of ~6deg/s, pitch rate of 3 deg/s and 1deg/s roll rate was there. Pink curve shows the no. of satellites used for solution computation. Min 4 no. of satellites are required for solution computation and if min 4 satellites are not there, it shows 0. As seen from the figure, initially when rates were high, no satellites were used and solution is not available. After 20sec, yaw rate has come down to less than 5deg/s and further solution is available.

10. Mitigation Techniques to avoid solution loss at Higher Rate

Instead of two antenna configuration, three-antenna configuration (with antennae separated by 120°) was studied. Because of the interference of gain from three antennae, antenna radiation pattern is worsened in the case. A technique that would possibly mitigate the intermittency of solution under high body rates is the usage of four antennae separated at 90°. The signals from diametrically opposite antennae are to be combined and processed using two separate RF front ends. As there are two independent RF front-ends, issue with interference of antennae pattern will be absent. However validation of this scheme is to be pursued and is in progress.

11. Conclusion

Performance of a GNSS receiver under body rate conditions is very much dependent on the antenna radiation pattern of the receiver. With existing antenna pattern (two antennae mounted 180° apart), it is not possible to ensure continuous visibility of satellites under angular rates. Availability of GNSS solution under body rates is very sensitive to receiver location and rate axis. Four antennae configuration (with two independent RF front ends) is an option for improving performance at high rate. Simulation studies with this configuration are being carried out.

12. Acknowledgements

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13. References

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