Ground simulation techniques for performance evaluation of high dynamics GPS receiver for launch vehicle applications

Sandhya K S, Harikumar Ganesan, K Karthikeyan, S Syamala,
S.Hemachandran, A Abdul Shukkoor, P P.Mohanlal
Indian Space Research Organization - Inertial Systems Unit
Thiruvananthapuram, INDIA
ks_sandhya@vssc.gov.in

Abstract—**Comprehensive testing of dynamic capabilities are essential for GPS receivers used in high dynamic applications such as launch vehicles. Typical RF simulation scenarios that are used for qualification of such receivers are presented in this paper. The methods used to incorporate complex maneuvers and 3D antenna patterns are also discussed. Further, the GPS satellite visibility during flight has a direct bearing on the mounting of antenna elements on the rocket body. A novel technique - antenna bore sight elevation analysis is used to optimally fix antenna locations prior to the flight which ensures maximum GPS satellite visibility. The typical results of this method and concurrence with RF simulation results are also presented. The simulation platform also serves as a valuable resource in evaluating the achieved performance of the GPS receiver post flight. Typical cases involving evaluation of DOP performance during flight and data loss due to low visibility are also presented in the paper.**

Keywords—GPS RF simulation- Antenna bore sight analysis

I. INTRODUCTION

GPS receivers designed for launch vehicle applications must operate under high dynamic conditions: velocities up to 10km/s, accelerations up to 15g and jerks up to 20g/s. The launch vehicle dynamics dictate signal dynamics seen by the receiver; such extreme signal dynamics call for specific considerations on critical aspects of receiver design such as acquisition with wide search bands, low signal re-acquisition time and tracking with minimum error. In order to evaluate and qualify such a receiver for flight, these aspects need to be tested thoroughly. It is physically impossible to test the high dynamic capabilities of the receiver with the conventional test set up using real-time GPS sky signal; instead radio frequency (RF) simulation techniques are employed. This paper briefs the typical simulation scenarios used for evaluation of such high dynamics GPS receivers for launch vehicle applications. The techniques used for incorporating complex vehicle maneuvers, effect of 3D antenna pattern etc are also described.

The geometric mounting of antennae elements on the launch vehicle body has a direct bearing on the GPS satellite visibility from the receiver's view point. A novel antenna bore sight elevation analysis has been successfully applied in several missions for optimally fixing antenna locations prior to the flight, thereby ensuring maximum GPS satellite visibility. Typical results and their concurrence with RF simulation results are also presented.

The simulation platform also serves as a valuable resource in evaluating the achieved performance of the GPS receiver post flight. For this purpose, a flight matched trajectory input is used and the GPS satellites tracked by the flight GPS receiver alone are simulated; the others are forcibly masked. Typical cases involving evaluation of DOP performance, and data loss due to low visibility are also presented in the paper.

II. GPS RF SIMULATION METHODOLOGY

The simulation set up consists of a GPS RF simulator hardware controlled through GPIB interface from a PC running the simulator software. The RF signal from the simulator hardware is fed using RF cables through a low noise amplifier (LNA) to the GPS receiver under test. The receiver RS232 and MIL1553 data are acquired using a laptop checkout system. The GPS receiver and LNA are powered by a bench power supply. The complete test set up is shown in Fig 1 [1].

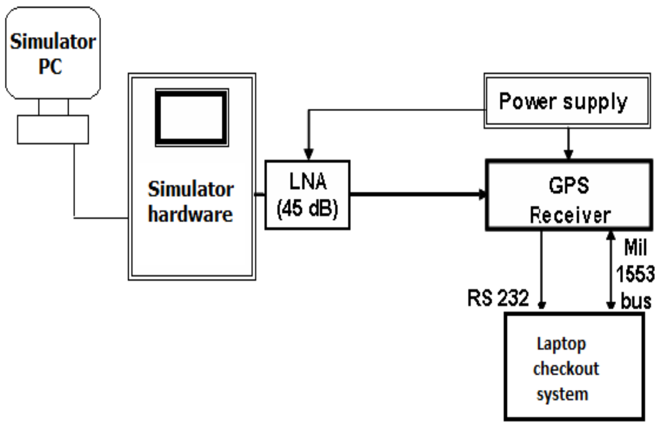

Figure 1. GPS RF simulation test set up

The launch vehicle trajectory as well as the GPS constellation is simulated using the simulator software. The scenario time, GPS almanac, atmospheric modeling etc are tuned to the requirements of the mission under study.

III. TYPICAL SIMULATION SCENARIOS

The critical performance parameters to be evaluated in high dynamic GPS receivers are velocity, acceleration, jerk capabilities and re-acquisition time. Accordingly, two simulation scenarios are discussed here:

A. High dynamics scenario

The high dynamics simulation scenario captures the trajectory dynamics typically seen during controlled thrusting phase in high dynamics vehicles. The velocity, acceleration and jerk versus time for the scenario are shown in Fig 2, Fig 3 and Fig 4 respectively. The RMS position and velocity error of a qualified receiver under this simulation scenario are shown in Fig 5.

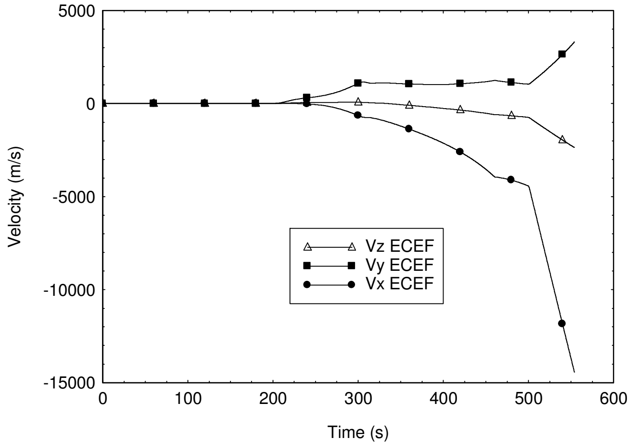

Figure 2. Altitude versus velocity magnitude

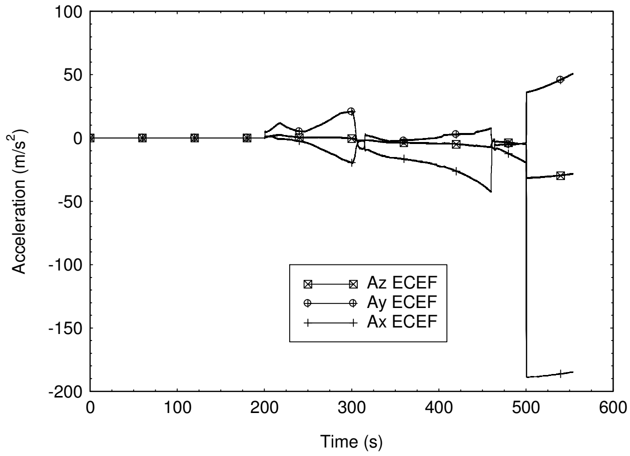

Figure 3. Altitude versus acceleration magnitude

B. Re-acquisition scenario

Re-acquisition time is the time measured from the point of RF disruption to reacquisition provided the receiver was in a stable 3D position fix for at least 5 minutes prior to the outage [1]. In order to assess this capability, 'GPS Space Vehicle (SV) signal on-off times' feature of the simulator software is used. At predetermined times into flight, simulated GPS SVs are switched off for a short period of time, typically 5 seconds. The receiver under test must re-acquire the lost signal within 6 seconds of it becoming available again.

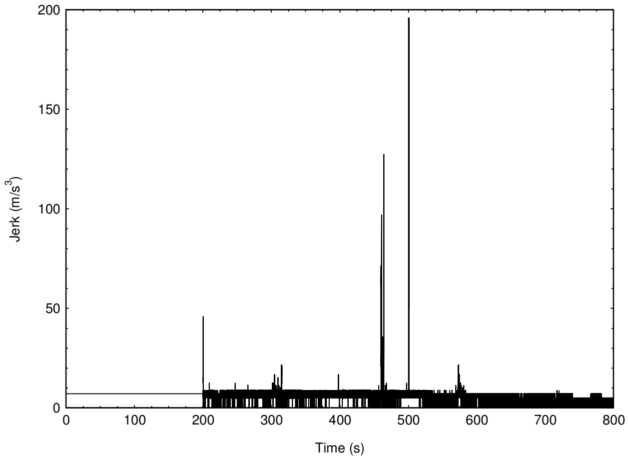

Figure 4. RMS Jerk versus time

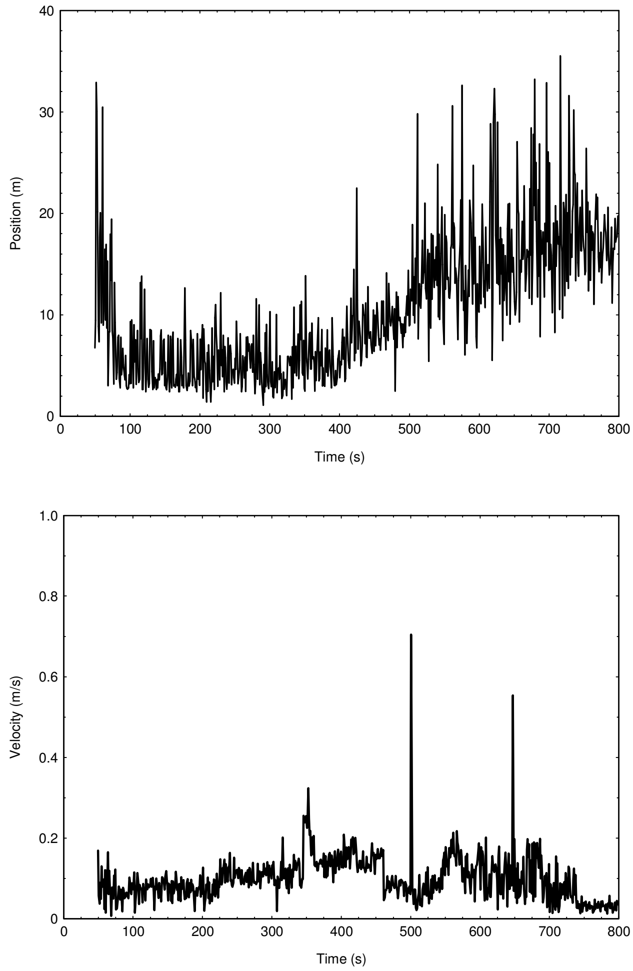

Figure 5. RMS position and velocity error

IV. SCENARIO GENERATION TECHNIQUES

The simulator software accepts trajectory inputs at 20/40/100 ms intervals from a stored user motion file. The file must contain user position, velocity, acceleration and jerk components in Earth Centered Earth Fixed (ECEF) frame, and attitudes in aircraft convention, angular body rates, angular acceleration and jerks in vehicle body frame. These are generated using an RF simulation input generation software that uses the mission profile in ECI frame for generating the above said parameters. The software gets the user position, velocity in ECI frame, body rates and quaternions in the required time interval for the entire mission duration. It then converts the parameters from ECI to ECEF frame and also derives the rest of the parameters required for RF simulation input file generation.

Receiver antenna patterns are also incorporated in the simulation to assess realistic GPS satellite visibility. This is achieved through an antenna pattern file input to the simulation software. The file contains the actual measured 3D antenna pattern expressed in attenuation decibel (dB) units in a grid of 5 degrees over an azimuth of -180 to +180 degrees and an elevation of -90 to +90 degrees.

V. ANTENNA BORE SIGHT ELEVATION ANALYSIS

In non-spinning rockets, typically two GPS patch antennae mounted at 180 degrees to each other are used to obtain a near omni-directional coverage. However, if during the flight, one of the antennae happens to face the earth for an extended period of time, then the overall GPS satellite visibility will be poor. Using antenna bore sight elevation analysis, the possibility of such a scenario can easily be identified and avoided. A case where the bore sight elevation is high is shown in Fig 6a. The corresponding number of GPS satellites visible in the RF simulation is shown in Fig 6b.

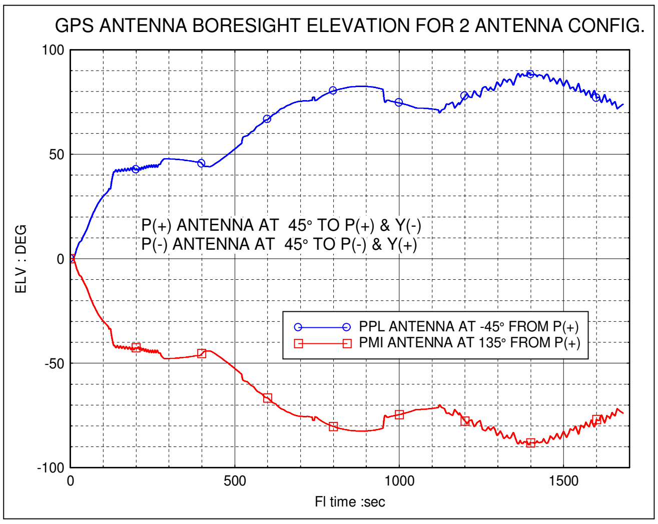

Figure 6a. A case of large antenna bore sight elevation

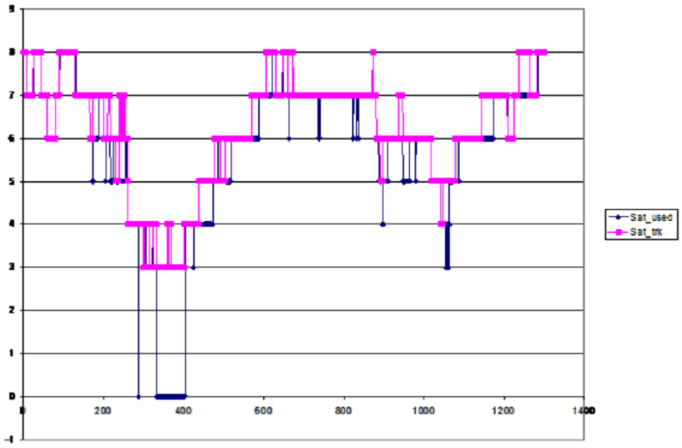

Figure 6b. No: of GPS satellites tracked & used (large bore sight case)

It can be seen that by 200sec into flight the number of satellites tracked falls to less than four. The phenomenon happening here is that, by this time, one of the antennae is nearly facing the earth due to rocket body roll, as is evident from Fig 6a. So the receiver loses track of the satellite signals that had been received through that antenna. The increase in number of satellites tracked from 400sec onwards is due to the same satellite signals reaching the receiver through the other antenna element and consequent re acquisition by the receiver. Similar signature is seen due to roll near 1000 seconds also.

Another case where the bore sight elevation is lesser is shown in Fig 7a and the corresponding number of GPS satellites visible in the RF simulation is shown in Fig 7b. The bore sight elevation being smaller, both the antenna elements retain GPS signal tracking during rocket body roll maneuvers. Hence the number of GPS satellites tracked remain more than five throughout the flight.

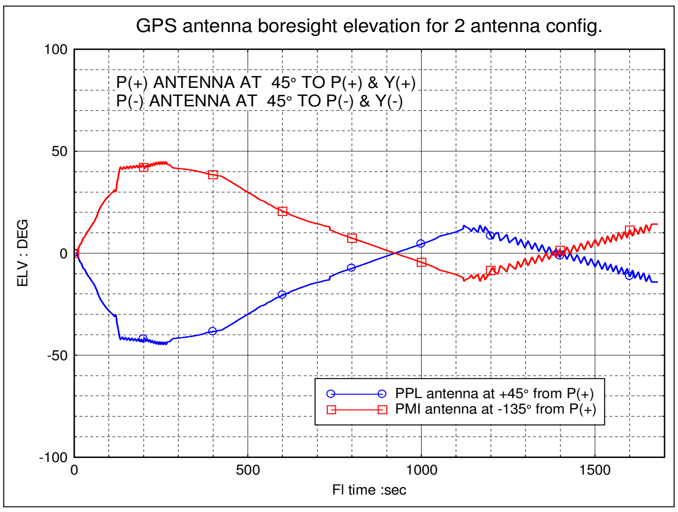

Figure 7a. A case of lower antenna bore sight elevation

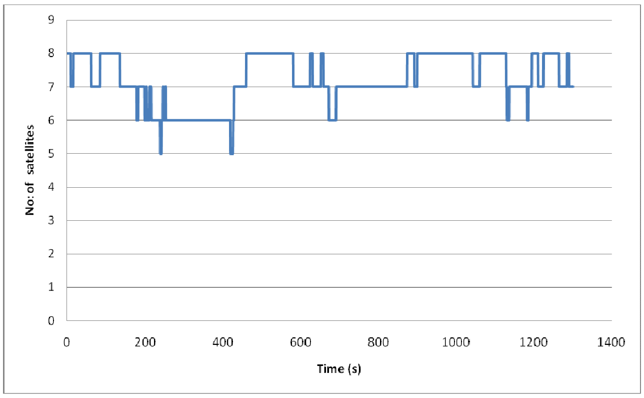

Figure 7b. No: of GPS satellites tracked (lower bore sight case)

The former case corresponds to antennae mounting at 'Pitch+ Yaw-' and 'Pitch- Yaw+' quadrants while the latter case corresponds to antennae mounting at 'Pitch+ Yaw+' and 'Pitch- Yaw-' quadrants for a particular mission. The GPS visibility is seen to be poor in the former configuration where as it is good in the latter. In practice, a mounting configuration wherein, for the flight duration of interest, the maximum bore sight elevation is less than 30 degrees, and for most of the time it is near zero, is found to ensure sufficient visibility. The value of this method is that it serves as an extremely simple and useful tool to quickly assess the GPS visibility with various mounting configurations. Once the suitable configuration is chosen, a full-fledged GPS RF simulation can be performed with the chosen configuration to confirm the results.

VI. POST FLIGHT SIMULATION CASES

Post flight analysis of a GPS receiver in a launch vehicle requires methods entirely different from traditional inertial navigation systems. In the latter case, since the system is self contained, almost always, the flight observations are explainable from the analysis of the telemetry parameters. However, as the GPS receiver operates on external RF signals, captured through an RF chain involving multiple components like antennae, LNAs, RF combiners and cables, there are many parameters that critically affect the system performance, but are not directly observable. RF simulation techniques can be leveraged to obtain clues on such flight observations. A few such cases are discussed here:

A. Identification of data loss due to high PDOP

Position Dilution Of Precision (PDOP) is a measure of quality of GPS receiver position fix [3]. It depends on the user receiver – visible GPS satellites constellation geometry. A low PDOP indicates better positioning. Typically PDOP figures less than 6 are considered to be good, whereas theoretically there is no upper limit. However many GPS receivers have an internal limit for PDOP beyond which the position solution is masked. In case of on-flight GPS data loss, RF simulation can be used to isolate whether the loss is due to hitting this limit. A typical case of positioning loss due to PDOP limit is shown in Fig 8 for a receiver under static simulation test.

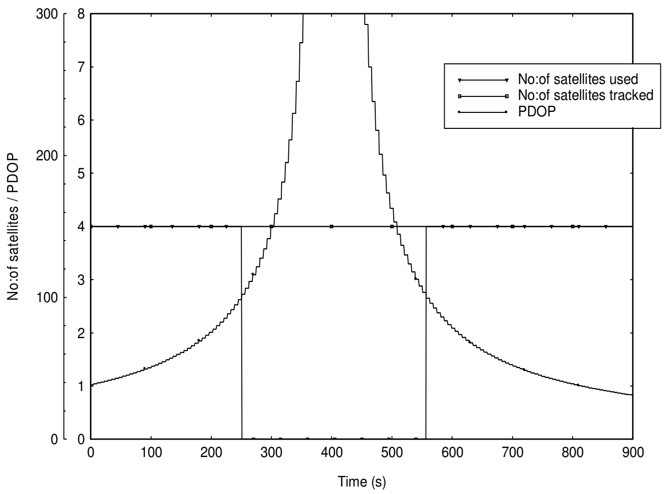

Figure 8. GPS data loss due to high PDOP

B. Identification of signal loss due to antenna null

Though the two patch antenna combination is considered to provide good omni-directional coverage, antenna nulls are unavoidable. For each antenna element having a hemispherical pattern, the attenuations from zero up to 5 degrees are considerably higher and this region can be considered as a gain null. If the line of sight between the receiver and the satellite happens to be along this null region, signal loss can be expected. A combination of antenna bore sight analysis and RF simulation methods can be used to identify such signal losses.

VII. CONCLUSION

In this paper, the RF simulation techniques for performance evaluation of high dynamic GPS receivers for launch vehicle applications were presented. The simulation test bed, typical scenarios used for evaluation, and scenario generation methods were detailed. A novel antenna bore sight elevation analysis was introduced and the usefulness of the same for pre-flight studies was highlighted. Actual on-flight observations and their post flight simulation reconstructions were also discussed. The cases and results presented emphasize the value of these simulation techniques at all stages viz. qualification, pre-flight studies as well as post flight analysis. .

REFERENCES

[1]. Hemachandran S, Harikumar G, Mahendramurali L G, Baskaran M, Abdul Shukkoor A, Mohanlal P P, "Qualification of high dynamics GPS receiver for space borne application", Poster presented at ISRO-DOS workshop on computer and information technology (WCIT-08), VSSC, Thiruvananthapuram, 2008

[2]. Sandhya K S, Abdul Shukkoor A, Mohanlal P P, "User manual for RF simulation profile generation software", IISU Technical report No. IISU-TR-238-2009

[3].Misra, Pratap and Enge, Per, "Global Positioning System: Signals, Measurements and Performance" Lincoln, MA: Ganga-Jumana Press, 2001.