A Simple And Low Cost Two-Antennas Concept For The Tracking Of A Sounding Rocket Trajectory Using GPS

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BIOGRAPHY

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Christian Arbinger received his M.Sc. degree in aerospace engineering from the Technical University of Munich in 1998. Currently he is working on his Ph.D. at DLR's German Space Operations Center (GSOC) in the space flight technology section. His field of work comprises GPS based attitude determination and spaceborne GPS applications. He is dealing with the combination of GPS and star sensors for spacecraft attitude determination, which is tested by an established ground experiment

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ABSTRACT

This paper presents results from theoretical investigations and experiments concerning the development of GPS antennas concepts in the context of the application of GPS on sounding rockets. The results are based on research activities, which has been undertaken at the German Aerospace Center (DLR), the National Institute of Space Research of Brazil (INPE) and the Aerospace Technical Center of Brazil (CTA/IAE). The objective of the research activities from INPE and CTA/IAE were to obtain detailed performance characteristics and design aspects for various possible antennas concepts directly linked to applications on Brazilian sounding rockets. The Germans DLR antenna experiment were performed in order to test a simple and low cost antenna concept, which was proposed by the Brazilian partners for a German GPS flight experiment on-board a Brazilian sounding rocket. This flight experiment was planned for the end of the year 2000 with the objective to track the trajectory of the sounding rocket based on GPS. Originally it was also planned to conduct this experiment on the Brazilian sounding rocket SV-40, but now the launcher is a VS30/Orion and the launch in spring 2001. The results of the DLR antennas experiment are based on the SV-40 as the launcher. A simple and low cost GPS antennas concept, based on only two off the shelf GPS antennas will be presented. Results for this GPS antennas concept and the related performance characteristics like satellite visibility will be discussed in detail. Further on, the observed problems will also be covered by the discussion.

INTRODUCTION

The usage of GPS measurements for tracking of sounding rocket trajectories seems to be a very interesting and attractive alternative for the substitution of the recently used C-band radars (AN/MPS-36,RIR-774C). The currently used C-band radar equipment is portable, but heavy and bulky. Consequently, cost intensive ground operations are the result. The application of low cost GPS tracking systems on sounding rockets will help to reduce the costs significantly for ground operations and therefore making sounding rockets more attractive for research activities in the areas of astronomy, migrogravity and magnetospher. Beside this, a further advantage will be that the information of position and velocity will be available on-board in real time for the payload. The Germans DLR GPS antennas experiment was performed in the context of a DLR project (c.f. [5]) with the objective of the development of a GPS based tracking system for the German Space Operations Center's Mobile Rocket Base (MORABA), which planes, prepares, implements and conducts scientific sounding rockets campaigns. Research activities regarding the application of GPS on sounding rockets were also undertaken by the Aerospace Technical Center and the National Institute of Space Research of Brazil.

A major problem in the area of GPS applications on sounding rockets is to find an adequate solution for a GPS antennas concept under given dynamic conditions like spin stabilization, visibility requirements for GPS satellites and sounding rocket characteristics.

THEORETICAL CONSIDERATIONS

Prior to arriving at the GPS receiver tracking loops, the direct and multipath signals enter through the antenna. The direct GPS signal incident on the antenna is right-hand circularly polarized. In most cases, the single reflection from a planar surface will be left-hand elliptically polarized if the angle of incidence is less than the Brewster angle [1]. An ideal GPS antenna would completely reject all signal that are left-hand circular polarized, actually, the total rejection is not obtained, but some attenuation near 10 dB is typical.

Practical antennas do not receive signals equally from all directions as in the case of theoretical isotropic radiators. Normally the most common approach for GPS antennas is the use of a single microstrip antenna patch. This printed antennas originated from the use of planar microwave technologies was suggested as early as 1950s and the first practical printed antennas appeared in the mid –1970s and have been widely developed since then.

Printed antennas have found use in most classical microwave applications, including for example radar, telecommunications, satellites for television broadcast, mobile communications, aeronautical applications and among others, GPS.

Printed antennas have numerous advantages, including:

- Light weight and small dimensions;
- Easy manufacturing using printed circuit technology;
- Flush planar technology, aerodynamic characteristics suitable for aeronautical applications;
- Easily integrated with electronic components;
- Possibility of printing on curved surfaces to make conformal antennas;
- Easily integrated into arrays.

However they also have some drawbacks which limit their use:

- Relatively narrow bandwidth;
- Dielectric losses lead to low efficiency;
- Difficulties to obtain high polarization purity.

The problem with polarization purity and low efficiency, can be enhanced with use of appropriated techniques that can improve this two factors [1], [2].

The GPS ranging signal is broadcast at two frequencies: 1575,42 MHz (L1) and 1227,6 MHz (L2). The civilian users can receive only the signal L1(C/A code), and the military user can receive both (L1/L2 –C/A and P code). For GPS applications, bandwidth is not a problem, because we have good solutions for using microstrip antennas in both frequencies as piggy-back or as a single element that show excellent performance.

THE BRAZILIAN EXPERIMENT SETUP

We have at least two possibilities to use a microstrip antenna, as a single element or as an array. Depending on the application one could be better than the other and this choice need to be done with some criterion. This criterion considers the application and in this GPS problem we need to take into account the antenna arrangement.

For this work, initially, a commercial microstrip passive patch antenna was characterized and measurements were made with the antenna mounted in a circular ground plane with 0.8m diameter. The transmitting antenna used for the test was a spinning linear antenna and the test range used was a semi-open anechoic chamber at INPE with the transmitter antenna 80m distant from the tested antenna.

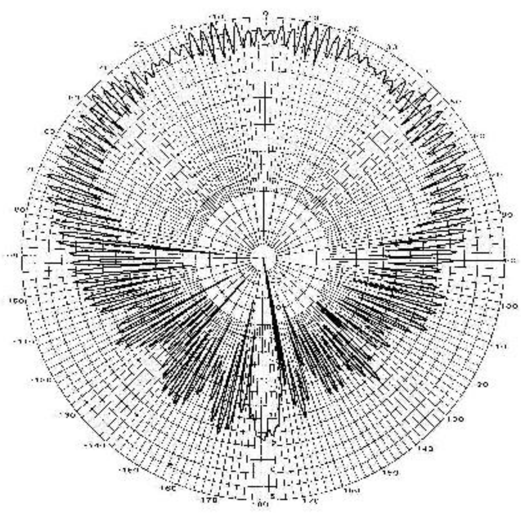

Fig 1: Radiation pattern for the cut angle ϕ =0°

The results of the radiation pattern for the cut angle ϕ =0° and θ = 0° can be seen at figures 1 and 2. Since this is a passive antenna, the measured gain is approximately 4dBi and axial rate at θ = 0° is 1.9dBi.

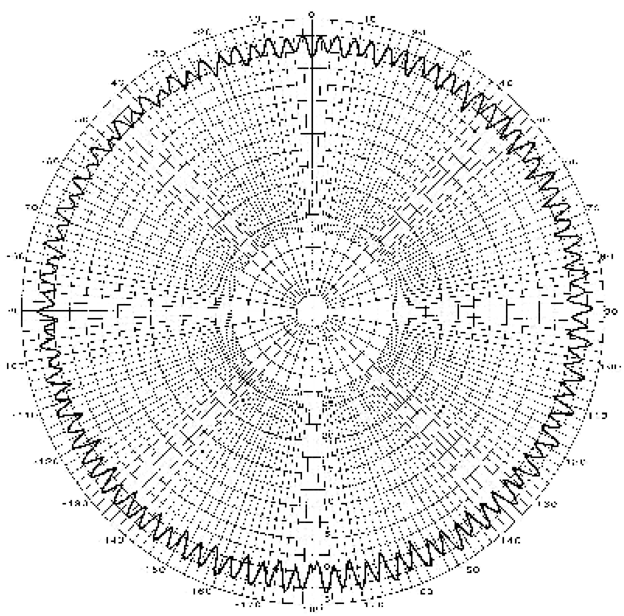

Fig.2: Radiation pattern for the cut angle θ = 0°

To use these tested antennas in an array configuration , the simplest way is combine them in an arrangement of pairs of antennas. In this case the designer can combine elements depending of the place, and the diameter of sounding rockets that they will be fixed to.

In the literature [4] is presented the effects analysis when the antenna is fixed in the surface of a cylinder with different diameters. It is observed that when we have an increase of the diameter the directivity is increased too. In these studies were showed that have a optimum number of elements related with the cylinder diameter and small variation of directivity. In this situation, we have a quasi-isotropic antenna pattern.

POSSIBLE ANTENNAS CONCEPTS

Once the Sonda III rocket is spin stabilized it is necessary to have an antenna (or an array) that can provide coverage of the local part of the GPS constellation under that dynamic condition. It has been considered a number of alternatives that were available due to the particular physical characteristics of the Sonda III.

The first alternative was to use a conventional GPS antenna that would point upwards, i.e., along the longitudinal axis of the launching vehicle. The nose cone is fabricated from fiberglass (mostly) and it is transparent to RF. Tests indicated that about a 1 dB attenuation occurred due to the fact that the cone was not a perfect radome and that was considered acceptable. Since the irradiation diagram of a single antenna is symmetrical in this condition, it would be possible to use it provided the rocket would not change its initial attitude (pointing upwards).

The second alternative considered was an array of microstrip antennas that would be wrapped around the outer structure of the rocket so that the resulting irradiation diagram would be the closest to an spheroid or an ellipsoid of revolution. In practice this diagram looks more like a toroid in 3D space and the only direction that looses some gain is the longitudinal axis of the vehicle (or the revolution axis of the toroid). The design of such an array of microstrip antennas could not be carried out due to the need of adequate software to design this special arrangement of irradiating elements.

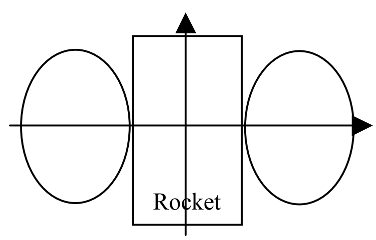

Fig. 3: Cross-sectional view of rocket cylinder and irradiation pattern

Normally this set of antennas are printed on a strip of printed circuit board (PCB) which is then fixed in a circular depression on the outer skin of the cylindrical structure of the rocket. This kind of fixation provides the necessary protection to the friction with the atmosphere during the ascent and the descent phase.

The same software problem as with the microstrip array occurred with the case of attaching a number of discrete antennas at the external surface of the cylindrical structure of the rocket. The only difference in this case is the protection for the friction with the atmosphere is constructed around the antenna.

An alternative tested before in other wavelengths was tried because it showed great simplicity and effectiveness. The approach was to use only two antennas fixed at opposite positions on the outer surface of the structure cylinder.

In the case of the Sonda III rocket the solution adopted was to hide the antennas under the protection of the nose cone that proved to enable contact with the GPS satellites. Due to physical limitations of the inner diameter of the cone the two antennas were fixed at a distance of 150mm of each other, each facing outward (180^0) relative to the other. The picture bellow shows the arrangement of the antennas for the case of four antennas used for two receivers. Each pair of antennas is used with a different receiver. It can be seen that the passive antennas shown are the commercial models of a known company.

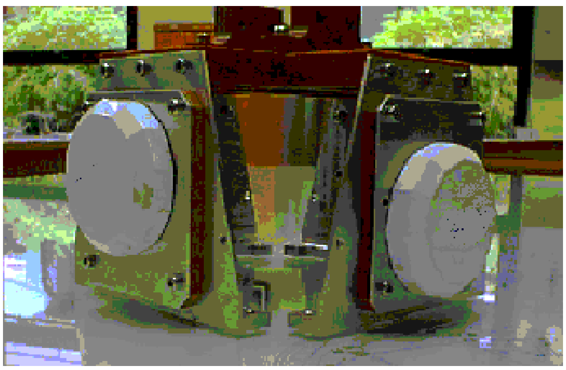

Fig. 4: Two antennas from the set of four in their support

The presented array of two antennas has been tested in laboratory and in the field, with a GPS receiver in a static condition. It will soon be tested in flight in a trajectory that will reach up to 500Km in the apogee.

For the experiment, it was chosen an array with two elements connected through a two-way power combiner to the GPS receiver. The setup can be seen in figure 5, where it can be observed the relative positions of the antennas as they will be mounted in the rocket.

The test setup has two antennas spaced 15 cm one from the other and mounted back to back.. The size of the mock-up is 310mm long and 300mm in diameter. Our experiment do not have the antennas fixed at the surface of the cylinder, but they are fixed at the frontal part of the rocket (nose cone) and covered by a radome with conic structure.

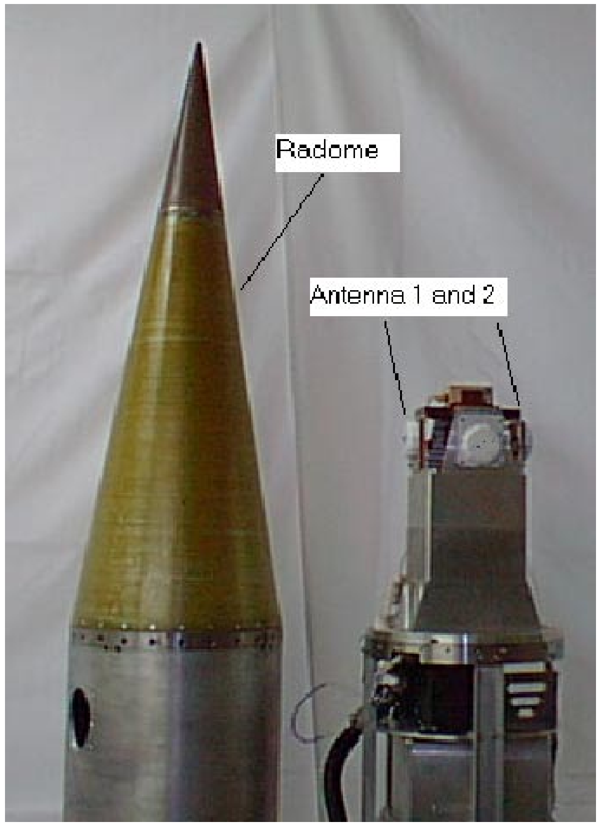

Fig. 5: Setup of the Brazilian flight experiment

Measurements done with and without radome showed a small influence of it in the results. The array configuration was measured in several cuts and in figure 6 is showed the cuts $\phi = 0°$ with θ being the roll and ϕ being the azimuth angle.

The axial rate at $\theta = 90°$ for the cut $\phi = 0°$ is near 5dB, and the gain approximately -3.56dBi. It is necessary to consider the small distance between antennas and the small ground plane where they were fixed. For the antennas test there have been problems with the mock-up fixation, that is, to position the antennas at the center of phase of the irradiating element. This fact, between others as pointing angles error, could be responsible for some interference and high axial rate.

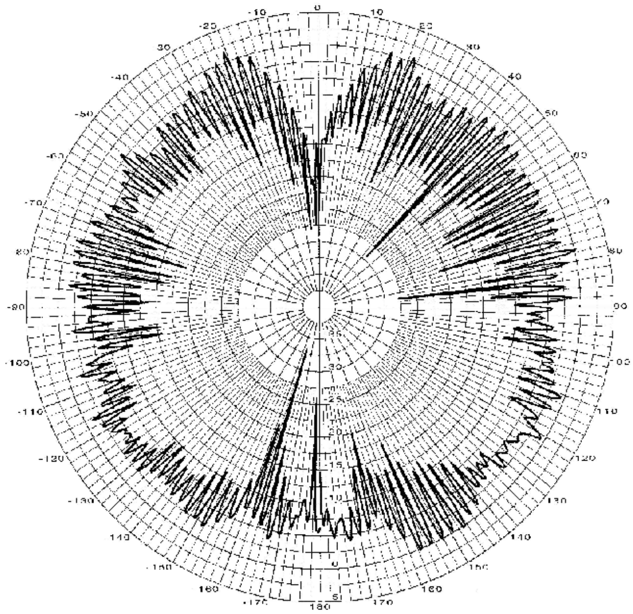

Fig 6: Radiation pattern for the cut angle ϕ =0°

DLR – GPS ANTENNA EXPERIMENT

As already mentioned in the introduction, it was planned to have a GPS flight experiment on-board the Brazilian sounding rocket VS-40. The VS-40 is spin stabilized with a spin rate of 2.7 Hz and has a diameter of 1 m. The diameter of 1 m is very large for a sounding rocket and therefore no standard antennas concepts (e.g. wrap around antenna) could be applied.

Based on the results of the Brazilian experiment, a two GPS antennas concept was chosen for the DLR flight experiment . The main objective of this GPS antennas experiment was to demonstrate the feasibility of this simple and low cost two-antennas concept under the given dynamic environment and further, to obtain the performance characteristics of this concept.

For this reason, a mockup (see Figure 7) of the sounding rocket has been build. The surface material of the mockup was aluminum. The diameter was 1 m and the height of the mockup was 1.5m. In order to evaluate the performance under the given dynamic conditions, the mockup was attached on the top of a turn table. More information about the used HW is given in Table 1.

The used GPS receiver was a Mitel, GPS Architect Receiver Developer Kit. The Mitel GPS Architect Developer Kit includes the SW of the GPS receiver, which allows one to modify the SW and adapt the receiver to the individual application.

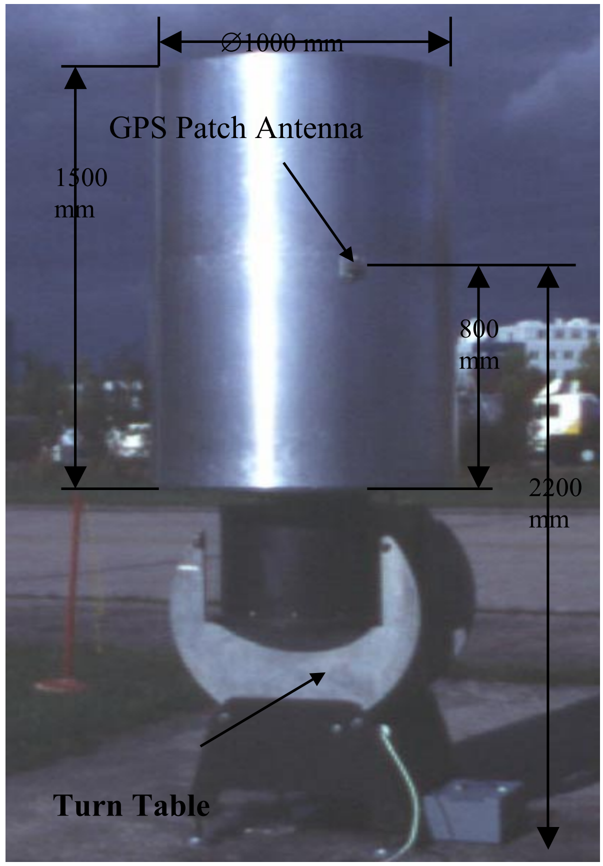

Fig 7: Turn Table

Table 1: Used Hardware

Turn Table	GENISCO, Model C-181 Spin Rate:0.01 deg/sec – 1000 deg/sec Inclination: ± 45 deg
Sounding Rocket Mock Up	Aluminium Construction with an Aluminium Surface, attached on top of the turn table
GPS Patch Antennas	2 Motorola Oncore Active GPS Patch Antennas, with hemispheric FOV Elevation masking angle was set to zero
Power Divider	Anaren Power Divider for 1.0 – 2.6 GHz
GPS Receiver	Mitel, GPS Architect Receiver, 12 Channel Parallel Receiver

The used GPS antennas were two commercial of the shelf, low cost Motorola Oncore Active GPS Patch Antennas, with hemispheric FOV, the elevation masking angle was set to zero. The two GPS antennas were connected with adequate cables to a two-in-one-out power divider and from there to the antenna input of the GPS receiver (see Figure 8 and Figure 9).

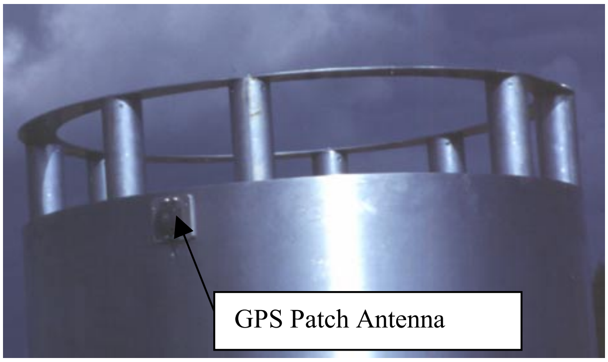

Fig 8: Mockup Construction

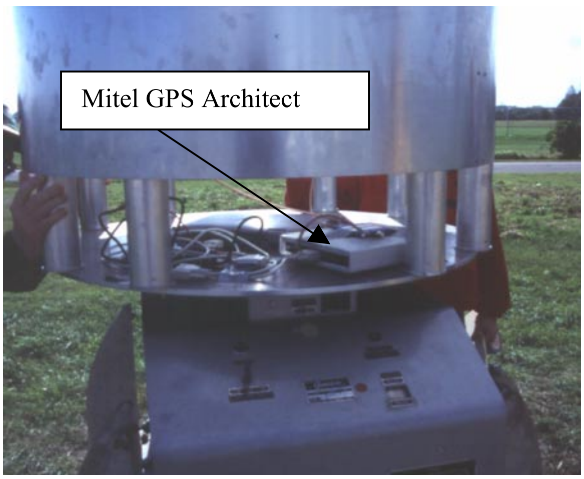

Fig 9: Mitel GPS Architect receiver

Also theoretical investigations have been performed at the DLR in order to calculate the expected antenna pattern (see Figure 10) and allows a comparison with the results from the Brazilian experiment, obtained for another diameter of the sounding rocket. But more important, this calculations were the base for the initial information, whether it is feasible to adapt this simple antennas concept also for a sounding rocket with a much larger diameter than the one, which has been used in the Brazilian experiment. Further on, these calculations were helpful for an assessment of the antennas concept performance.

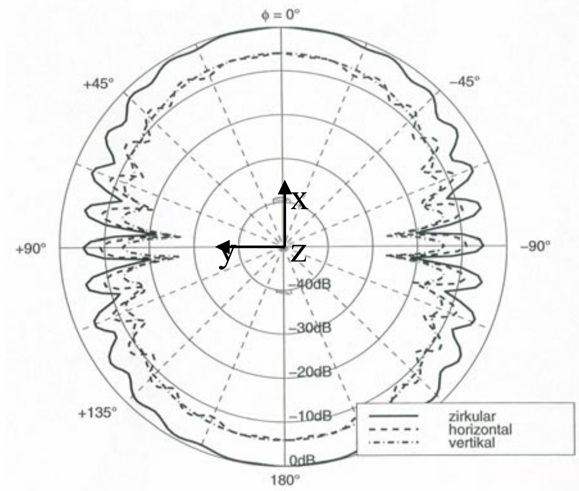

Fig 10: Calculated Horizontal Diagram (Ø = 1m, θ = 90 [deg])

RESULTS – BRAZILIAN EXPERIMENT

The array of two antennas worked well in the static tests performed in the field. It has been used mounted in the flight configuration, just on top of the battery pack, and inside the cone of the rocket. The RF cabling was assembled in house, and was a little bit over 500mm total length. There was no signal amplification of any kind and the array output (actually the power combiner output) was directly connected to the receiver. Even though there were two arrays of antennas in the same support, only one array was connected to the receiver. The second array will be used with a second receiver and was not tested this time but it was maintained once it is part of the flight arrangement. The receiver manufacturer monitor software was used to register the performance of the setup.

It has been detected a small decrease in the signal to noise ratios of the received signals from the satellites, most in the order of one or two dBs compared to the case of a single passive antenna (used in the position of maximum gain upwards). Typical gains varied in the range of 40 to 50 dB.

Still considering the array, it was not possible to detect any possible misbehavior on any specific angle of elevation of the satellites from the GPS constellation.

RESULTS – DLR GPS ANTENNAS EXPERIMENT

The results of the DLR GPS antennas experiment with respect to visibility conditions and GPS receiver tracking behavior are presented in the Figures 11 and 12.

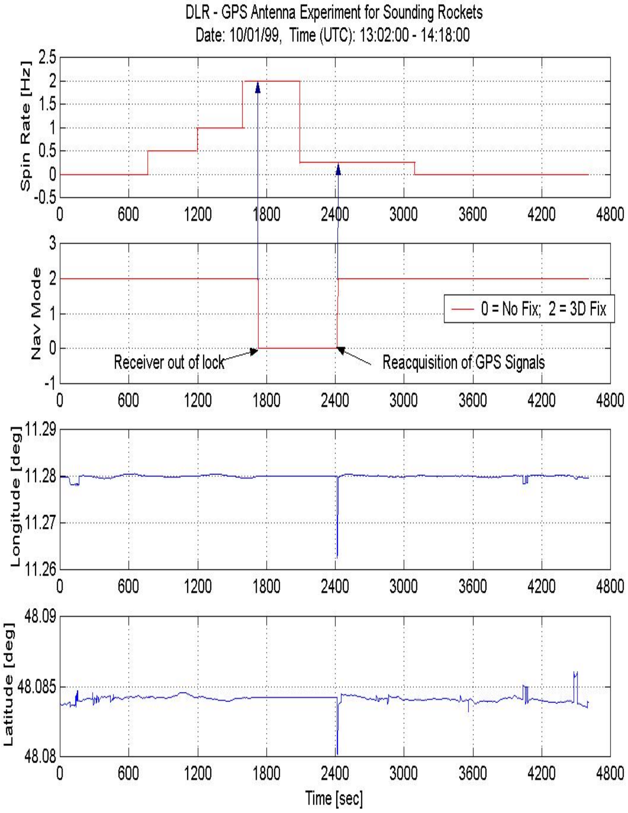

Fig 11: GPS Position Solution of the Mitel GPS Architect receiver based two-antennas concept

The main results of the DLR GPS antennas experiment can be summarized in the following way:

- The proposed simple, low cost two-antennas concept worked very good with respect to the visibility requirements, if the GPS receiver was able acquire and track the signals
- The acquisition, tracking and reacquisition of GPS signals could be performed under various rotational dynamics conditions
- The entire system (antennas concept and receiver) worked very well for spin rates around 1 Hz
- Problems are realized, when the spin rate was increased from 1 Hz to 2 Hz, the receiver could not track the GPS signals any more. After the spin rate has been reduced again, the GPS receiver acquired the signals within 5 min and than tracked continuously
- The loss of GPS signal seems to be driven by the behaviour of the GPS receiver oscillator. Further tests are necessary in order to proof this assumption

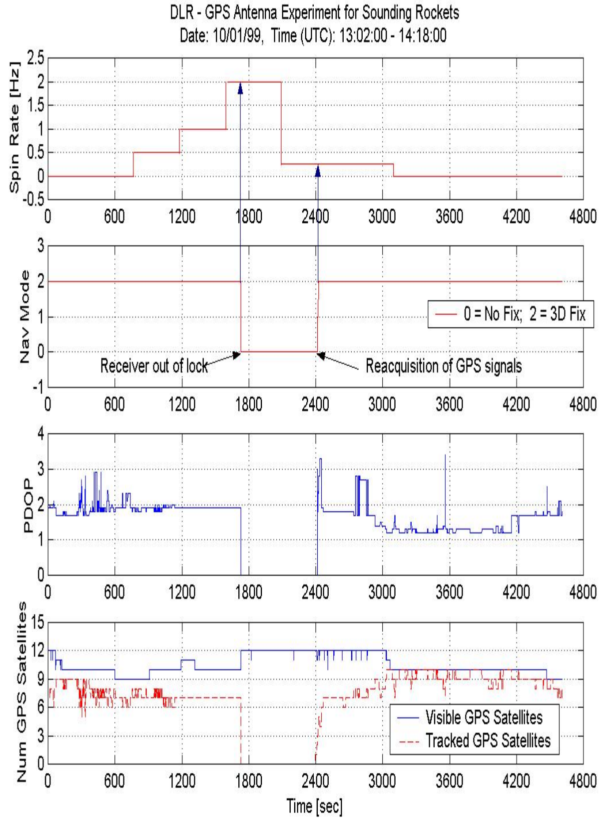

Fig 12: Tracking Performance of the Mitel GPS Architect receiver based two-antennas concept

CONCLUSIONS I – BRAZILIAN EXPERIMENT

We need to observe that two elements array antenna performance is a summitry of several factors that include no accurate measurements, small no symmetry of the mock-up and the quality of each element of the array in terms of axial rate. The fixation of the antenna at small ground plane and proximity of antennas can allow no wanted coupling that perturb the pattern.

Instead of these problems, the system performance was good and show to be enough for the utilization with GPS receivers, as the results presented at static measurements.

CONCLUSION – DLR GPS ANTENNAS EXPERIMENT

The conclusions from the DLR GPS Antennas Experiment are presented below:

- Theoretical investigations and derived results as well as previous results based on experiments could be confirmed

• It was demonstrated by an experiment that the simple and low cost two-antennas concept could be in principle applied for the acquisition, tracking and reacquisition of GPS signals on sounding rockets, even if the diameter of the sounding rocket is relatively large (e.g. 1 m)
• The fact that the receiver got out of lock at a spin rate around 2 Hz was most likely driven by the behaviour of the receiver oscillator.
• Additional investigations and test are necessary in order to improve the robustness for high spin rates

• The low cost and simple GPS two-antennas concept is a promising concept providing good and reliable results, but further research is necessary for improvements of understanding the effects on the GPS receiver side

AKONWLEDGMENT

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