Pre-flight Assessment of a Dual Blade Antenna System for GPS Tracking of Sounding Rockets

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Abstract

The present report describes the preliminary on-ground evaluation of a dual blade antenna system for sounding rockets. Despite pronounced interference patterns of the combined antennas, the system allows continuous tracking of 7-9 out of 10 visible satellites at any time with a 12 channel GPS receiver. Aside from quasi-static orientation changes, the proper system performance has also been verified for rotation rates of up to 0.5Hz. Further testing is, however, required to derive a more detailed, global antenna diagram and to analyze the tracking performance at higher spin rates.

1 Introduction

As part of the TestMaxus-4 campaign [1] a novel antenna system for GPS tracking of sounding rockets will be flown in late February 2001. It comprises two blade antennas for the L1 frequency, which are connected to the GPS receiver via a combiner and mounted back to back on opposite sides of the service module.

Fig. 1 Blade antenna for GPS L1 frequency attached to 14" service module of the Test Maxus-4 flight

Fig. 2 Turn table with Test Maxus-4 service module and Orion GPS receiver for assessment of the dual blade antenna system

Blade antennas (Fig. 1) have previously been used for S-band telemetry data transmission and can easily cope with much higher temperatures than common GPS patch antennas. Compared to wrap-around antennas that are otherwise used for GPS tracking of launchers [2], a blade antenna system can be manufactured at less than 10% of the overall system cost and does not require special milling of the sounding rocket structure for mounting. On the other hand, a blade antenna exhibits linear polarization, which implies a 3dB gain loss when used with right-hand circularly polarized GPS signals and a lacking multipath suppression. This is not a fundamental detriment, however, since the total gain of the antenna system can be adjusted by suitable amplifiers and since no reflecting surfaces other than the rocket body are present during the flight. Another potential draw back of the envisaged dual antenna system is the fact that destructive interference may result in pronounced gaps in the overall antenna diagram. The latter effect should be most evident, if the diameter of the supporting structure and the resulting separation of the antennas is of similar order as the wavelength of the R/F signals. For the envisaged test flight, the 14” diameter of the Orion rocket and the overall size of the antennas imply a separation of roughly two wavelengths between the phase centers at the L1 frequency (λ=19.0 cm). It has therefore been decided to evaluate the antenna characteristics in a simple ground test prior to the launch.

2 Test Setup

In accord with the envisaged flight configuration, two blade antennas designed and manufactured by DLR where attached to a 14” (35.6 cm) cylinder segment of 60 cm height. The signals from both antennas were combined by an Anaren power divider using cables of equal length to preserve the phase relation of the incoming signals. Following an amplification of 28.5 dB the signals were processed by a Mitel Orion GPS receiver [3].

The system was then put on a turntable (Fig. 2), which allowed a motor driven rotation of the mockup about the vertical axis, which coincides with the symmetry axis of the cylinder. At a rate of about 0.5 °/s, a full turn takes roughly 12 minutes, which implies a quasi-static change of the antennas’ orientation with respect to the incoming signals and the related receiving condition. Nevertheless, the total measurement time is still short enough to avoid major variations of the apparent GPS constellation. Accordingly, the elevation of a given satellite in the local reference system of the rocket module remains essentially constant throughout a revolution (Fig. 3).

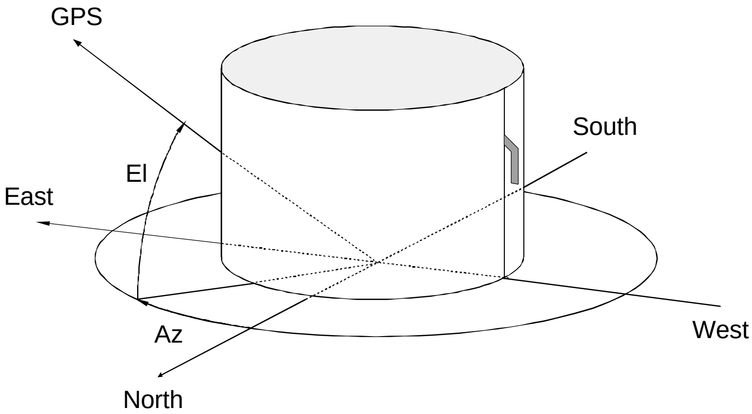

Fig. 3 Test setup for measuring the blade antenna diagram using real GPS signals

Starting from a known initial azimuth of each antenna, the system was rotated trough roughly two complete revolutions during which status data from the Orion GPS receiver were recorded at an interval of 2 secs. The data used for the subsequent analysis comprise the total number of tracked satellites, the PRN and the computed azimuth and elevation for each of the received satellites as well as the lock status and signal to noise ration (SNR) of each channel.

3 Antenna Diagram of a Single Blade Antenna

The sensitivity and antenna characteristics of a single blade antenna (model #3) were independently measured by disconnecting the second antenna (model #2) from the power devider. SNR readings collected from 12:01 to 12:28 on Jan 19, 2001 were reduced to the reference azimuth of the respective antenna and superimposed in common diagrams, each covering satellites in a similar elevation band.

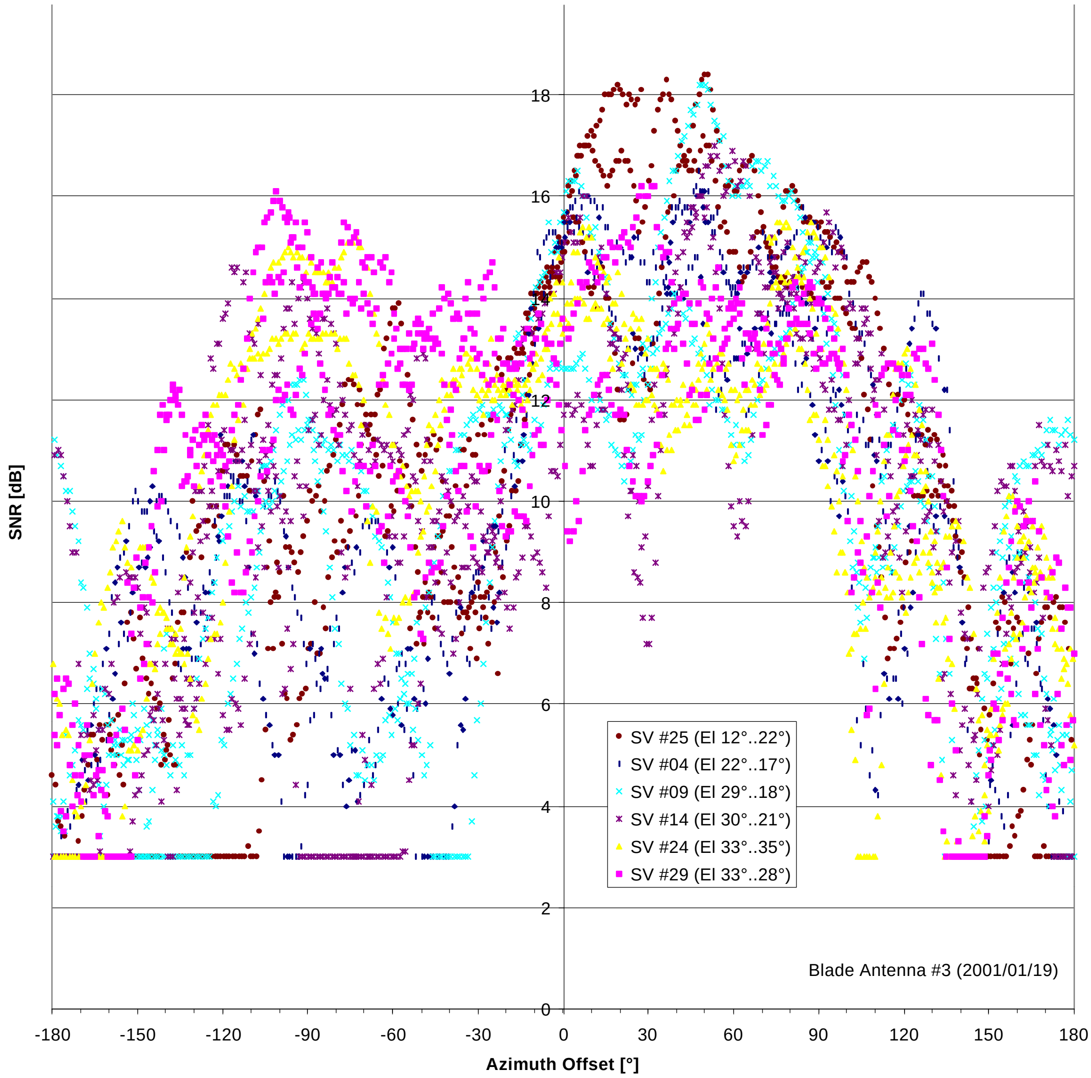

Fig. 4 Azimuth variation of a single blade antenna (model #3) for low elevation angles (12° to 35°)

The result for five satellites in the range from 12° to 35° elevation is shown in Fig. 4. Near the maximum of the antenna sensitivity, signal-to-noise ratios (SNR) of 12 dB to 18 dB are achieved. This is roughly comparable to a commercial M/A COM patch antenna with a vertical boresight, if one accounts for the 3dB gain loss introduced by the linear antenna polarization. Depending on the particular satellite tracked and the actual elevation at the time of a measurement, SNR variations by ±2 dB to ±4 dB may be observed at a given azimuth relative to the antenna meridian. Likewise, for each individual satellite, SNR variations of similar amplitude can be observed with relative maxima separated by azimuth angles of 30° to 60°. Aside from these effects, which could e.g. be indicative of interference from signals reflected at nearby structures, a strong asymmetry of the antenna diagram with respect to the meridian plane is obvious. In particular, the maximum average sensitivity is achieved at an azimuth of the tracked satellite, which is about 50° larger than that of the antenna meridian. It may be assumed that this asymmetry is likewise related to an imperfection of the test setup, comprising e.g. an open top of the mockup, various wholes in the tube structure, an attached radio link for data logging as well as lacking shielding of the turn table itself. Presently, however, no conclusive explanation exists for either of the above observations and further measurements in a dedicated antenna test stand will be required for full analysis.

At higher elevations (50° to 90°) pronounced azimuth variations of the signal-to-noise ratio may likewise be observed, even though the local extreme values exhibit a wider separation. In total, the antenna diagram of a single blade antenna attached to a rocket body of the given diameter is considerably less uniform than that of a common patch antenna. In addition, it can receive radiation incident from the both the front side (absolute azimuth offset less than 90°) as well as the backside (absolute azimuth offset larger than 90°).

4 Antenna Diagram of a Dual Blade Antenna

When mounting two blade antennas back-to-back on opposite sides of the sounding rocket mockup and combining the received signals, the overlapping antenna diagrams may result in interference patterns that further affect the overall antenna characteristics. Irrespective of the antenna separation, the signals will always add up in phase, if the line-of-sight vector is perpendicular to the baseline connecting the two antennas. For a separation of two wavelengths (cf. Fig. 5), a phase shift of one wavelength will furthermore apply for radiation that enters at an angle of 60° or 120° with respect to the antenna baseline. Destructive interference, in contrast will be observed for entrance angles of 42°/138° (1.5λ phase shift) and 76°/104° (0.5 λ phase shift).

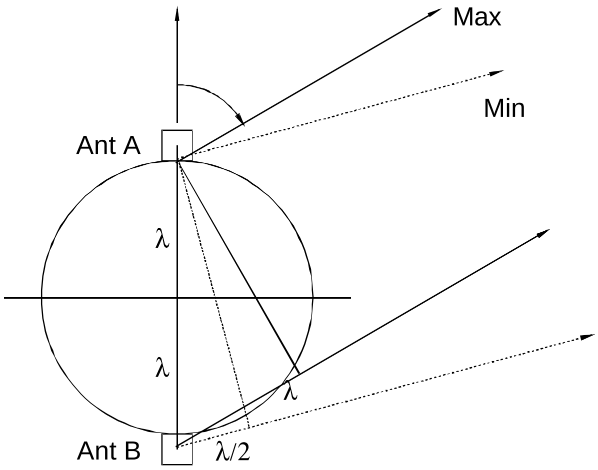

Fig. 5 Signal interference for dual antenna configuration with 2λ baseline

The actual pattern observed in the test is depicted in Fig. 6, which shows the azimuth dependence of the measured signal-to-noise ratio for three satellites with elevations between 7° and 20°. The measurements cover two complete revolutions of the turn tab le and were collected between 12:30 and 12:54 UTC on 2001/01/19. All azimuth readings are referred to the meridian of antenna model #3 for ease of comparison with the single antenna diagram shown Fig. 4.

As expected, pronounced maxima of the combined antenna diagram can be observed at azimuth offsets of 60°, 90° and 120°, while the SNR drops below the receiver threshold near 42° and 76° and 104°. At the global maximum, an SNR value of 20 dB is attained, which is 2 dB higher than the peak value of the single antenna. As with the single antenna, a notable East/West asymmetry of the antenna diagram is evident, i.e. the sensitivity is much higher for azimuth angles of 0° to +90° from the antenna meridian than for the respective negative values. So far, no conclusive explanation is available for this symmetry violation. Near the antenna meridians (azimuth offset 0°/180°) an apparent minimum of the overall sensitivity can, furthermore, be noted, which is likewise unexplained.

Irrespective of the azimuth angle of the antenna system, a total of 7-9 out of 10 visible satellites could continuously be tracked and used for the navigation solution. While the employed GPS Orion receiver lost frame lock on multiple channels in case of low SNRs, continuous tracking was always ensured. As a further test, the turn table has been spun-up to 0.5 Hz, thus completing a full revolution in two seconds. Throughout this test, the receiver continued tracking on all channels and provided a valid navigation solution.

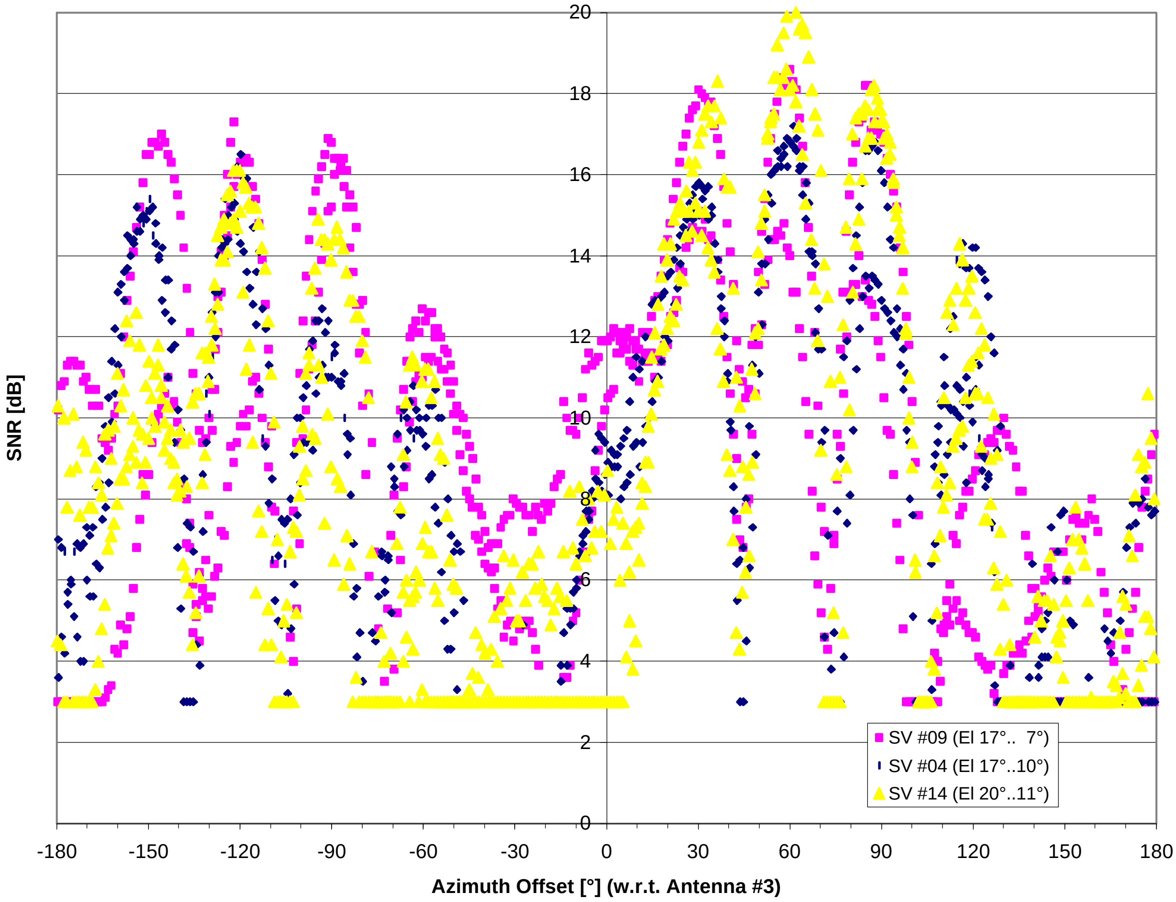

Fig. 6 Signal interference for dual antenna configuration with 2λ baseline

5 Summary and Conclusion

Preliminary test results for a dual blade antenna system mounted on a 14" sounding rocket mockup have been presented. As expected, the combined system exhibits a highly anisotropic sensitivity due to strong interference of the individual antenna patterns at the given 2λ separation. Observed asymmetries of the single antenna pattern may be attributed to the imperfection of the test setup with multiple sources of spurious interferences and tests in a dedicated antenna test lab will be required to obtain reliable results. For practical applications, the system nevertheless provides an overall global coverage and allows tracking of a sufficient number of GPS satellites irrespective of the sounding rocket orientation. Furthermore, tests with spin rate of up to 0.5 Hz indicate that the system allows tracking also during the tumbling phase that is expected on the descending path prior to reentry into the dense part of the atmosphere.

References

[1] Montenbruck O., *Test Maxus-4 GPS Experiment – Interface Control Document*; TMX4-DLR-ICD-0001; Version 1.0, 22 Dec. 2000 (2000).

[2] Bull, B.; A Real Time Differential GPS Tracking System for NASA Sounding Rockets; ION GPS 2000 Conference, Salt Lake City, 19-22 Sept. 2000 (2000).

[3] Montenbruck O., Enderle W., Schesny M., Gabosch V., Ricken S., Turner P.; *Position-Velocity Aiding of a Mitel ORION Receiver for Sounding-Rocket Tracking*; C5-5; ION GPS 2000 Conference, Salt Lake City, 19-22 Sept. 2000 (2000).