PHOENIX-HD – A MINIATURE GPS TRACKING SYSTEM FOR SCIENTIFIC AND COMMERCIAL ROCKET LAUNCHES

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Abstract – Recent experience has demonstrated that tracking of sounding rockets and launch vehicles based on GPS offers a cost effective and reliable alternative to traditional radar systems. However, due to the high dynamics and adverse environmental conditions encountered during a rocket launch, a GPS tracking system for such applications has to differ in several ways from terrestrial mass-market GPS receiver. This paper presents a GPS tracking sensor developed specifically for high dynamic space applications by DLR/GSOC. Besides the GPS receiver itself, the proposed tracking system comprises a choice of tailor-made antenna sub-systems for different flight vehicles and a dedicated low noise amplifier. Following a brief description of the key components and some exemplary flight configurations, this paper addresses the qualification tests performed with the individual devices. Finally, it presents the results of the successful maiden-flight onboard the German-Brazilian VSB30 rocket launched in late 2004 from the Brazilian launch center in Alcantara.

1 – Introduction

Since the first civilian GPS navigation receivers were flown in space, onboard the Landsat 4&5 spacecrafts in 1982-4 [1,2], GPS technology has received constantly increasing attention from the space community. Considerable effort has been made to develop dedicated space-capable systems and, as a consequence, GPS receivers can nowadays be considered as widely accepted tracking sensor for space vehicles. This technology has become an integral part in the majority of LEO satellite missions. This development has greatly contributed to a significant improvement of the achievable navigation accuracy as well as an increased level of onboard autonomy.

Other than for satellites, however, only little attention has been paid to the sounding rocket and launcher segment, which is characterized by much higher dynamics. This is surprising, as in the year 2000 already, the Aeronautics and Space Engineering Board of the US National Research Council concluded that the use of GPS based tracking systems in rocket applications could help to significantly reduce project costs without sacrificing safety [3]. On sounding rockets and launch vehicles, GPS can serve multiple purposes for reasonable cost and effort. Besides providing essential information for flight safety operations during the propelled flight phase, GPS may deliver valuable information for a post-mission trajectory determination and performance assessment as well as highly accurate timing information for event triggering or time tagging of measurements. Thus, GPS may not only be considered as a cost-effective alternative to traditionally used tracking systems such as radar system. It also offers promising prospects for improved services, such as higher injection accuracy and increased onboard autonomy or even opens up new services.

Within this framework, DLR/GSOC started to develop and implement GPS tracking systems for high dynamic space applications, several years ago. A primary goal of the project was to find the best compromise between system costs, reliability and performance. The outcome was to use commercial-off-the-shelf (COTS) technology, wherever possible. Over the past years, extensive experience was gained on this field during numerous sounding rocket campaigns conducted all over the world. The employed tracking systems have been continuously improved. Recently, the latest member of the product family was introduced: the Phoenix tracking system for sounding rockets, launcher and LEO satellites.

2 – System Overview

2.1 Phoenix GPS Receiver

The Phoenix receiver represents a single-board GPS receiver for tracking of L1 C/A code and carrier signals on 12 parallel correlator channels. It may be considered as the successor of DLR's flight proven Orion [4,5] receivers for space and high-dynamics applications. Like its predecessor, the Phoenix-HD combines commercial-off-the-shelf (COTS) technology with a receiver software specifically designed for the use onboard high-dynamic platforms, such as on sounding rockets or launch vehicles. In contrast to the Orion, however, the Phoenix employs a commercially available hardware platform, the MG5001 receiver board, manufactured by Sigtec Navigation Pty., Australia [6].

GPS Hardware

The core component of the receiver is the GP4020 chip of Zarlink [7], which combines the 12 parallel correlator channels, a microcontroller core with 32 bit ARM7TDMI microprocessor, 32 kByte of internal RAM and several peripheral functions (real-time clock, watchdog, 2 UARTS etc.) in a single package. The original design features a backup battery for buffering the internal RAM, which serves as a non-volatile memory for critical receiver parameters. The battery also drives a 32.768 kHz clock crystal and a real-time clock (RTC) inside the GP4020 to maintain the current time during deactivation of the main power supply. However, as the originally used battery is unsuitable for space use, it needs to be replaced by a space capable version for flight models. Alternatively, the battery can be removed completely from the receiver board since the keep-alive power can also be supplied externally.

The UARTs integrated into the GP4020 chip offer two serial ports for communication, but supplementary line drivers are required to achieve RS232 or RS422 compatible signal levels. A small boot routine, residing in the GP4020's internal boot EPROM, allows for an upload of a new receiver software version via the primary serial port without the need to dismantle the integrated system.

The shielded RF front-end employs a GP2015 [8] chip to down-convert and filter the L1 signal and perform a 2-bit digitization. Narrow band filtering of the intermediate frequency is provided by a Murata saw filter. The Phoenix (MG5001) receiver also provides an onboard low noise amplifier, which notably reduce the required antenna gain.

In addition to the above core components, the MG5001 board provides a 512 kByte flash EPROM for storing the receiver software and a 256 kByte RAM memory for run-time code and data. A 10 MHz Temperature-Compensated Crystal Oscillator (TCXO) is furthermore employed to generate the reference frequency required by the front-end chip, as well as the clock for the GP4020.

By default, the receiver is operated at a +5V DC supply voltage, which is internally converted to 3.3V required by the correlator and microprocessor. The receiver features a power consumption of approximately 0.8 W and a form factor of 70 x 47 x 11 mm at a weight of about 25 g. In general, the receiver can be integrated into a rocket's service system in two different ways. In the first, it is mechanically mounted on an already existing PCB and electrically interfaced directly with this system. Alternatively, it is accommodated in a separate housing along with a dedicated interface board, forming a self-contained unit. Both variants have pros and cons, and have been successfully applied in past missions. The suitability of the different implementations depends on the specific requirements of the envisaged application.

Receiver Software

As aforementioned, the receiver software has been specifically designed to cope with the specific signal conditions usually encountered onboard a sounding rocket or a satellite launcher. The software is based on sample source code for simple terrestrial GPS applications which was earlier available as part of a development system for the Orion receiver. However, the standard software received extensive revision and has been enhanced by numerous additional features to meet the requirements of a high dynamic space flight

FIG. 1 Phoenix (MG5001) receiver board. For use onboard sounding rockets and satellite launchers, the battery and the connectors are usually removed, as these components are unsuitable for space use

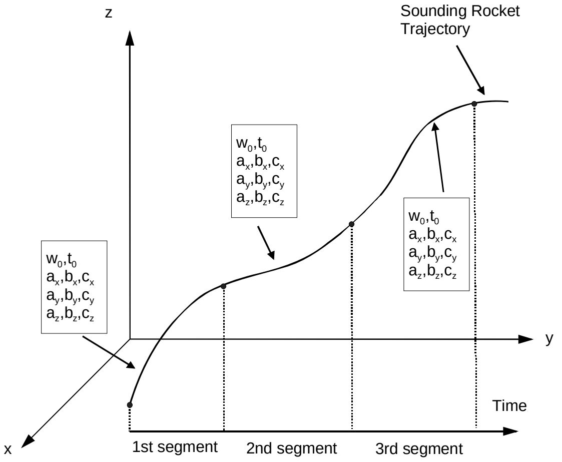


FIG. 2 Piecewise polynomial approximation of the reference trajectory of a rocket. Each time interval is represented by its start epoch (GPS week and seconds) and three coefficients per axis.

mission. The reliability and stability of the developed software has been successfully confirmed in various European and Brazilian sounding rocket flights carried out with the Orion receiver. Due to a high level of communality between the Orion and the Phoenix receiver, the software could be ported to the new platform with reasonable effort and minor changes in the source code.

One of the most important changes applied to the standard receiver software relates to the employed tracking loops. The original loops were replaced by a wide-band 3rd order phase-locked loop with FLL assist for carrier tracking and a narrow-band carrier aided delay-lock loop for code tracking. This modification ensures robust tracking and avoids systematic steady-state errors even under high signal dynamics. While tests in a GPS signal simulator environment have revealed that the receiver is generally able to track GPS signals up to accelerations of more than 15g, it cannot properly reacquire the tracking signals in case of a temporary signal loss.

A position-velocity aiding concept has therefore been developed, which makes use of a piece-wise polynomial approximation of the nominal flight path (Fig. 2, [9]). Up to 15 second order polynomials in position can be configured and stored on-board the receiver. Based on this information, the reference position and velocity of the rocket are computed once per second. The result is then used to obtain the line-of-sight velocity and Doppler frequency shift for each visible satellite, which in turn serve as initial values for the steering of the tracking locked loops. Using this aiding concept, the receiver is able to quickly re-acquire tracking after temporary signal losses.

Further on, the software has been supplemented by an instantaneous impact point (IIP) task that computes a real-time prediction for the touch-down point of the rocket based on the latest valid navigation fix [10]. During a sounding rocket mission, the IIP describes the expected touchdown point of the vehicle under the assumption of an immediate termination of the propelled flight. The online IIP prediction provides a rapid indication of an off-nominal performance of the system during the thrust phase. If the vehicle is equipped with a flight termination system, the information provided by the IIP prediction enables the flight operator to abort the mission in case of an arising safety hazard for surrounding buildings and individuals. To the knowledge of the authors, this is the first receiver which can provide this kind of information in real-time and onboard the rocket. Finally, all measurements and data outputs are synchronized to integer GPS seconds and a 1 pulse-per-second hardware signal for timing purposes is generated at the same instant.

2.2 Antenna System

Besides the GPS receiver itself, a GPS tracking system for high dynamic platforms involves some additional components. For the reception of the GPS signal suitable antennas and low noise amplifiers (LNA) are required. Due to the adverse environmental conditions typically encountered during a rocket flight, most commercial products are not appropriate for this specific purpose.

Wrap-around antennas represent one potential solution to this problem. This type of antenna consists of properly coupled individual patches, mounted like a belt around the circumference of the rocket, providing a near omni-directional antenna characteristic. However, wrap-around antennas exhibit various drawbacks. They are difficult to design and manufacture for large diameters and are typically available for tubes with a maximum diameter of 40 inches only. In addition to the high cost of the stand-alone wrap-around antennas which can be well on the order of 10k-40k US$, specialized tubes with enhanced wall thickness and a milled groove are required to hold the antenna ring. Furthermore, wrap around antennas are subject to US export restrictions which further limit or complicate their use for non-US space projects.

Triggered by the above limitations and drawbacks, various alternative antenna systems that support tailored mission requirements at reduced system engineering cost have been developed in a joint effort of DLR and German industry and qualified on various sounding rockets [11].

One potential alternative is the use of a so-called "tip antenna", a helical antenna mounted under a radome in the rocket's nose cone (Fig. 3). This type of antenna provides almost full sky coverage during the ascent of a sounding rocket. Because of their specific radiation pattern these antennas are insensitive against rotation about the longitudinal axis and are thus well suited for the GPS tracking of a spinning rocket. A tip antenna provides an ideal choice for GPS based range safety systems that require reliable tracking during the boost phase of a rocket flight. On the other hand, its use may conflict with sensor experiments requiring a tip position or an early tip separation during the mission. Tip antennas have been successfully flown since 1998 within numerous sounding rocket missions.

FIG. 3. GPS antenna mounted in the tip of a rocket

FIG. 4 Blade antenna for GPS applications

Another option is using blade (or hook) antennas. This type of antenna (Fig. 4) is widely employed in aeronautic and aerospace applications for telemetry and telecommand data transmission. They are known for their resistivity against high temperatures and mechanical stress. For use in GPS applications, however, the antenna design had to be modified to match the GPS L1 frequency. To achieve a near full sky visibility, a minimum of two antennas is required, attached to the walls of the rocket opposite each other and connected to the receiver via a power combiner. Compared to wrap-around antennas, a blade antenna system can be manufactured at less than 10% of the overall system cost. Furthermore, this approach does not require special treatment of the rocket structure for mounting. The reception pattern of such an antenna combination resembles that of a wrap around antenna but suffers from pronounced gain drops at certain viewing angles due to a destructive interference of signals received from both antennas. While tests have demonstrated that these gaps may not significantly degrade the overall system performance in quasi static situations, they cause sever tracking problems in spinning or tumbling applications. This confines the applicability to rockets and flight phases with no or only moderate (<1 Hz) spin rates. Another potential draw back of blade antennas is they exhibit a linear polarization, which implies a 3dB gain loss when used with right-hand circularly polarized GPS signals as well as a lack in multipath suppression.

To overcome the latter disadvantages of blade antennas, specific flush mounted patch antenna devices have been designed and implemented by Kayser-Threde. These can be fitted into specific recesses in the walls of the rocket and are used to replace the blade antennas in the above described dual-antenna combination. Despite slightly higher production costs and the increase in integration effort, compared to blade antennas, the total cost of such a system is still notably below that of a wrap-around antenna. As expected, ground tests and flight experience have shown that the patch antenna configuration slightly outperforms the blade antenna combination in terms of obtained carrier-to-noise ratios and multipath mitigation.

2.3 Low Noise Amplifier

A low noise amplifier (LNA) is generally required in the antenna branch to amplify the GPS signals to a level suitable for the GPS receiver's R/F input and to compensate the losses in the R/F cables between the antenna and receiver. While most GPS antennas for terrestrial applications have an LNA already build in, the aforementioned solutions for rocket applications are all passive antennas and thus require an external amplification. Since the required amplifiers are not as exposed to the outside environment as the antennas onboard a rocket, the electrical and mechanical requirements are less stringent for theses devices. Theoretically, this allows the use of commercial products, widely available on the market in many forms and qualities. However, in view of an envisaged use of the Phoenix system onboard micro- and nano-satellites a dedicated miniaturized, light-weight and ruggedized LNA has been designed and implemented and thoroughly tested with regard to the intended use in space applications.

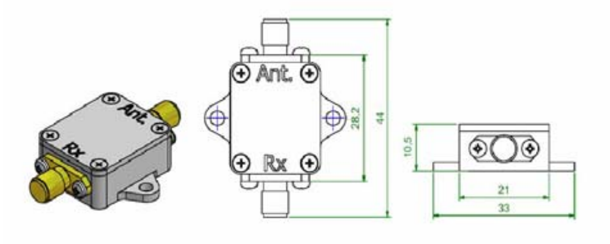


FIG. 5 Technical drawing of the developed LNA for use with the Phoenix tracking system in rocket and space applications

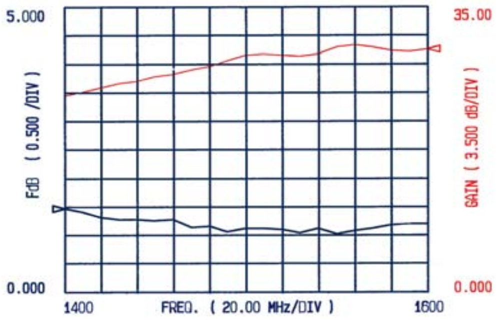


FIG. 6 Overall gain and noise figure for the miniaturized LNA measured over a frequency range from 1.4 GHz to 1.6 GHz

Fig. 5 provides a technical drawing of the developed LNA, whereas Fig. 6 presents the measured amplification gain and noise figure as a function of frequency near the GPS L1 frequency (1.575 Ghz).

2.4 Typical Flight Configuration

Fig. 7 and 8 depict two slightly different flight system concepts. Both been successfully validated in the framework of numerous sounding rocket missions, which have been supported in the past. Configuration (a) employs a tip antenna for the signal reception during the propelled flight phase up to tip separation. This makes the system ideally suited for spinning vehicles. After de-spin and tip ejection, the receiver is switched to the dual-blade antenna sub-system, providing the receiver with GPS signals up to touch-down. Switching between the individual antennas is usually accomplished by an R/F relay controlled either by timers, a break-wire or a barometric switch.

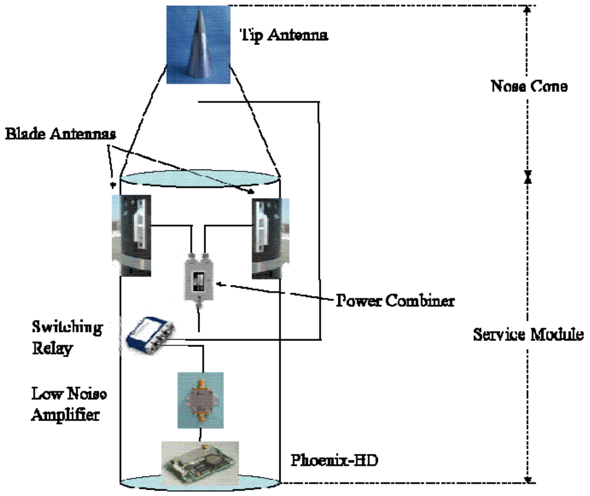


FIG. 7 Flight configuration (a) employs a tip antenna for the propelled part of the flight, and is therefore well suited for tracking of spinning vehicles. After tip separation, a blade antenna combination is used for signal reception.

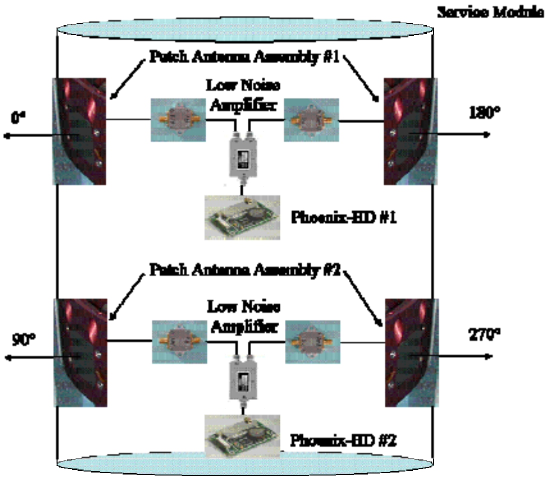


FIG. 8 Flight configuration (b), has been developed for tracking of non-spinning sounding rockets and satellite launch vehicles. A full redundancy concept is applied to increase the operational reliability.

The second configuration (b) has mainly been developed for use in the European Maxus program, where GPS has evolved to one of the key tracking sensors for flight safety purposes over the recent years. An increased level of operational reliability therefore was required which could be achieved by applying a redundancy concept. Two identical, but completely independent GPS tracking sub-systems (except for the common power supply) are employed, comprising two dual-patch antenna combinations, four LNAs and two Phoenix GPS receivers. Since the Maxus rocket represents a guided, non-spinning vehicle, the patch antenna system can be used for signal reception from lift-off to landing. This configuration may also be well suited for an application on satellite launch vehicles in both versions, either with blade or with flush mounted patch antennas.

3 – Environmental Testing

Since the Phoenix receiver is entirely built with COTS components, and only minor modifications have been applied to the receiver hardware before its utilization in space applications, like e.g. the exchange of the R/F connector or the removal of the battery, a thorough validation of the hardware was required. The platform has undergone numerous environmental tests, including thermal and thermal-vacuum tests, single event effect radiation tests and vibration tests. These are aimed at the demonstration of the survivability under representative conditions during a rocket launch. The performed test and the obtained results are discussed in more detail in the following paragraphs.

3.1 Thermal Vacuum Testing

To assess the impact of extreme temperatures and vacuum conditions onto functionality and performance of the Phoenix receiver, numerous thermal and thermal-vacuum tests have been conducted in close accord with established ECSS test procedures [12]. Except for the keep-alive battery, which was removed from the test devices, the receiver hardware has been assessed as obtained from Sigtec Navigation. Overall, these tests have demonstrated a proper performance within a temperature range of -30° to +70°, which covers both the manufacturer's specification and the ECSS recommended limits for AOCS space electronics. In a non-powered mode, the receiver survived extreme temperatures of -40° and +80° with no subsequent malfunction. An observation of a linear variation of the receiver power consumption was made, of approximately +8%/100K. Even though this is within the nominal operation limits, this increase has to be taken into account for the dimensioning of the power system and electronic fuses.

To assess the potential impact of temperature and/or vacuum onto the tracking and navigation performance, the above tests have been conducted in a zero-baseline configuration. This means that a second receiver (reference receiver) has been operated in parallel to the test device outside the test chamber, which were both connected to the same antenna. Such a configuration provides an easy way to identify small changes in the performance of the receiver under testing, by simply comparing the data obtained from both receivers. During the tests, no temperature or vacuum level dependence of the navigation quality could be identified. An increased frequency of cycle slips and outages in various tracking channels was only observed during accelerated heating and cooling phases, with temperature gradients above 5°C/min. These tracking problems may best be attributed to thermal stress of the employed 10 MHz TCXO reference oscillator. This can most likely be circumvented by a wider setting of the PLL carrier tracking loop.

3.2 Vibration Testing

Vibration load poses a major threat to electronic devices onboard a rocket and is thus a matter of serious concern for all components to be flown in rocket applications. During the system level environmental tests conducted with the service modules of the sounding rocket missions accomplished so far, the Phoenix tracking system has been thoroughly examined with regard to its vulnerability to vibration and shock. The tested receivers showed no indication of potential problems to withstand representative vibration loads, such as visible cracks in the PCB, loosened components or a complete hardware breakdown. Furthermore, the system has demonstrated its capability to cope with the mechanical loads imposed to a device onboard a rocket during the four successfully flight missions supported so far.

Fig. 9 provides an exemplary vibration profile applied to the three main axis of the service module through the environmental tests conducted with the SHEFEX payload module, a German sounding rocket experiment launched in late October 2005 from the Norwegian rocket range Andøya [13].

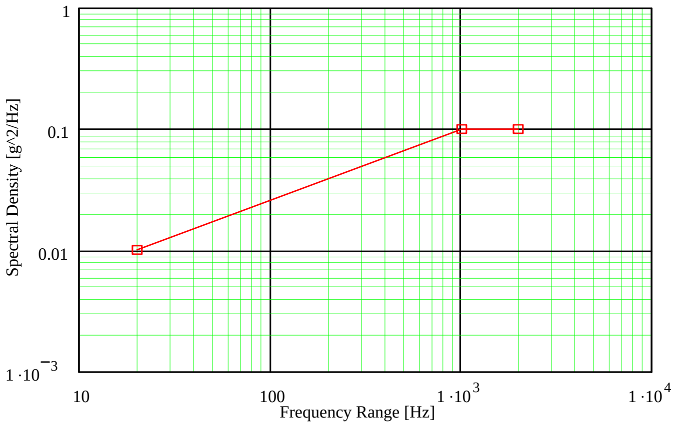


FIG. 9 Load profile used for vibration testing of the SHEFEX service module (derived from vibration spectrum of an Improved Orion motor) [14].

3.3 Radiation Testing

A further risk of damage to electronics used in space comes from the presence of high energetic particle radiation in the near-Earth space environment. To assess the susceptibility of the Phoenix hardware to so-called Single- Event Effects (SEEs) caused by the impact of single high-energy particles, an initial series of proton radiation tests has been conducted with the receiver. In contrast to traditional radiation test methods, where electronic devise are inspected on a component level, the present tests have been conducted on a system level.

Throughout the testing process, numerous receiver upsets were encountered that resulted in an immediate system freeze. These were caused by single event upsets (SEUs) occurred in the GP4020 baseband processor or the SRAM module. Further analysis showed that the probability of a single-event upset can be considered to be roughly proportional to the applied particle flux. After the occurrence of an SEU, the receiver could be brought back to normal operation by power cycling the system. This has shown that the encountered phenomenon is apparently non-destructive.

Surprisingly, no single event latch-ups were encountered during any of the three performed test runs. This indicates a good overall resistance of the system against energetic particle induced short-circuit latch-ups (SELs). In regards to the sensitivity of the receiver to highly energetic practical radiation, a total of three tests is evidently not an adequate number to draw a final conclusion. Still, it provides valuable information about the capability to survive in a near-Earth orbit. Furthermore, these results are in good agreement with test results obtained in independent tests performed by SSTL [15].

In addition to the above single event tests, the receiver and the LNA have undergone a series of total ionizing dose (TID) radiation tests, mainly in preparation of a flight onboard a satellite. Due to the extremely short time the GPS tracking system is exposed to the space radiation environment during a rocket flight, susceptibility to TID effects is, however, of no matter of concern in this context.

4 – Flight Qualification

In November 2004, the Phoenix tracking system for rocket applications performed its maiden flight in the framework of the VSB30 project. Primary goal of this jointly conducted Brazilian-German sounding rocket mission was to flight qualify the cooperatively developed new VSB30 vehicle (Fig. 10) for future use in European and . Aside from the payload module, the VSB30 rocket comprised a S31 boost motor and a S30 second stage motor. Both solid-propellant motors have been developed and manufactured in Brazil. The vehicle was flown in an unguided configuration. The main objective of flying a Phoenix receiver onboard the VSB30 vehicle was to assess the robustness and proper functioning of the hardware and software during a real high dynamics space mission. Furthermore, the GPS system provided valuable information for post mission analysis regarding flight behavior and performance of the VSB30 rocket [16].

The rocket was launched from the north-Brazilian space center, Alcantara, near the Equator. During the 13.8 s total burn-time of the S31 boost motor the vehicle reached a peak total velocity of 498 m/s and a peak thrust acceleration of 6.8 g (relative to the Earth frame), measured at t+2.5. About 3 seconds after booster burnout and separation of the first stage, the S30 second stage motor was ignited. During the subsequent 28.5 s propelled flight, the vehicle was carried to an altitude of 40.8 km, which was reached at burn end. Shortly before burnout, the maximum up-velocity of 1925 m/s was recorded. The horizontal velocity component built up through the propelled flight phase amounted to 450 m/s. During the burn-phase of the S30 second stage motor, a peak acceleration of 11.3 g was determined. Fig. 11 illustrates the velocity and acceleration profile measured during the first 60 seconds in flight.

FIG. 10 The VSB30 rocket had an overall length of 12.7 m. It employed a VS31 boost motor and a VS30 second stage motor, which carried a 400 kg payload to an apogee of 240 km

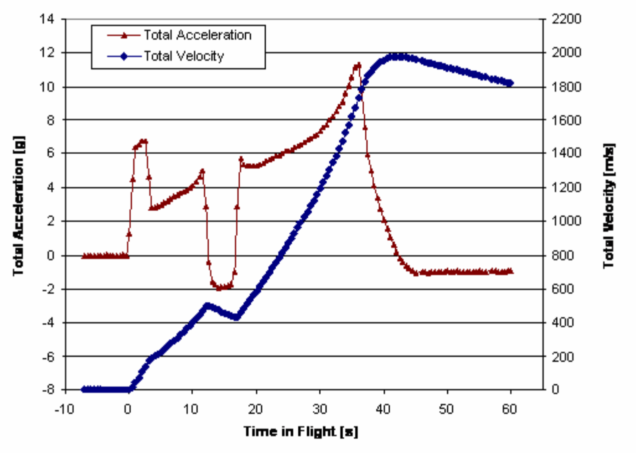


FIG. 11 Velocity and acceleration profiles recorded during the first 60 seconds of the VSB30 flight.

The payload segment with an approximate mass of 400 kg was carried to an apogee height of almost 240 km, which was reached at 252 s after leaving the launch pad. During the atmospheric reentry a peak acceleration of 12.9 g was measured. Roughly 11 minutes after start of mission the payload impacted about 190 km north-easterly from the launch site, in the ocean. An illustration of the mission profile is provided in Fig. 12.

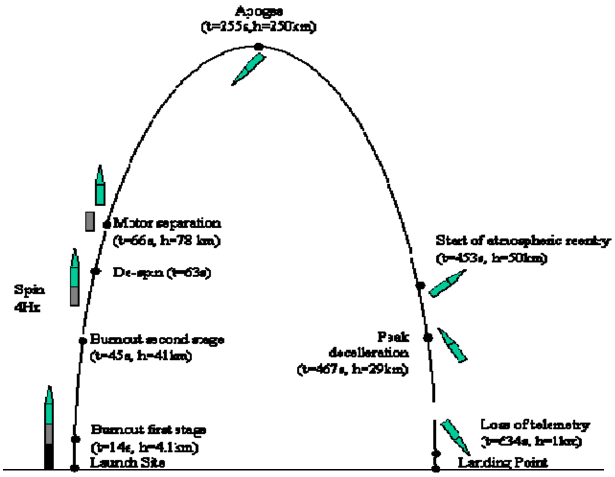
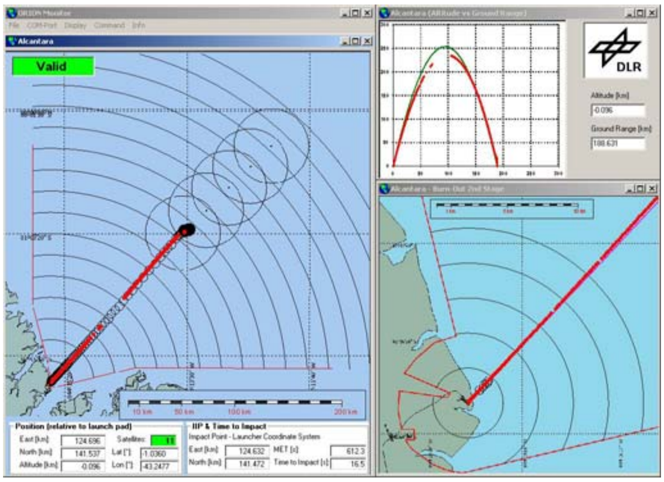


FIG. 12 VSB30 verification flight mission profile



Position (relative to launch pad)
East [km] 124.696
North [km] 141.537
Altitude [km] -0.096
Satellites 11
Lat [°] -1.0360
Lon [°] 43.2477

IIP & Time to Impact
Impact Point - Launcher Coordinate System
East [km] 124.632
North [km] 141.472
MET [s] 612.3
Time to Impact [s] 16.5

Altitude [km] -0.096
Ground Range [km] 188.631

FIG. 13 Map displays showing ground track (red) and instantaneous impact point (open circles) of the VSB30 vehicle. The nominal (green) and actual (red) altitude profile are depicted in the upper right-hand side window.

The receiver provided continuous and reliable navigation information during the entire flight up to the loss of telemetry near landing, with the exception of two small outages due to temporary telemetry problems as well as a 60 seconds interval without 3D navigation around apogee. A post mission analysis revealed that the latter outage could be attributed to a false lock on an individual receiver tracking channel, which made it unable to compute a valid navigation solution. About one minute after the occurrence of this apparent false lock, the receiver recognized the tracking error and flagged the channel as invalid. 3D navigation could be regained immediately thereafter. The receiver software has, therefore, been upgraded to prevent use of erroneous pseudo range data in the navigation solution.

Apart from the above phenomenon, no abnormal tracking behavior or receiver performance could be discovered. Neither during the free-flight phase nor the high dynamic phases right after lift-off and during reentry the receiver exhibited any sign of tracking instability. It constantly tracked between 9 and 12 satellites, yielding typical PDOP values of 1.5 and better. Despite the lack of absolute reference data, the performed self-consistency checks confirmed the good overall accuracy of the raw data as well as navigation fixes. The retrieved results compare well with the results obtained in previously performed GPS signal simulator tests.

Despite its experimental status, the Phoenix GPS tracking system has been used as auxiliary data source for flight safety operations during this mission. The navigating fixes and IIP predictions computed by the Phoenix receiver onboard the rocket were sent in real-time to the flight control center on ground and displayed on a dedicated monitoring system (Fig. 13). As for the navigation solution, accurate and reliable impact point predictions were available from lift-off to landing, except for the navigation data outages mentioned above.

5 – Summary and Conclusion

A miniature GPS tracking system for sounding rockets and satellite launch vehicles, designed and implemented by DLR/GSOC, has been presented. The key components of the system are a Phoenix-HD GPS receiver, various tailor-made antenna solutions for different flight system configurations and a dedicated low noise amplifier for adequate signal amplification. The Phoenix receiver combines a commercial-off-the shelf hardware platform with a receiver software specifically designed for use in high dynamic applications. Likewise, all other system components are based on COTS technology which keeps the overall system costs on a reasonable level compared with specific space qualified devices. Furthermore, the paper presented results of various qualification tests performed in order to assess the capability of the system to cope with the harsh environmental conditions typically encountered during a rocket launch. The tests have successfully demonstrated, the receiver is well suited for utilization in the envisaged space applications. In late 2004, the first successful test flight of a Phoenix tracking system onboard the German-Brazilian VSB30 sounding rocket was performed. The dual stage rocket reached a maximum velocity of about 2000 m/s and a peak acceleration of approximately 12 g, measured during the thrust phase. The Phoenix GPS system was able to provide reliable and accurate navigation information from lift-off up to landing. In addition to the flight in Brazilian, Phoenix units were flown in December 2004 as part of the European Texus-41 campaign in Kiruna, Sweden as well as onboard the German SHEFEX rocket launched from the Norwegian rocket range in Andoya in October 2005. It has recently been proposed to fly the Phoenix-HD tracking system on the upper stage of a Cosmos rocket, as well as onboard the future European Vega launcher.

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