

# Virtual Ground Based Augmentation System

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## Abstract

Since 1993, the civil aviation community through RTCA (Radio Technical Commission for Aeronautics) and the ICAO (International Civil Air Navigation Organization) have been working on the definition of GNSS augmentation systems that will provide improved levels of accuracy and integrity. These augmentation systems have been classified into three distinct groups: Aircraft Based Augmentation Systems (ABAS), Space Based Augmentation Systems (SBAS) and Ground Based Augmentation Systems (GBAS).

The last one is an implemented system to support Air Navigation in CAT-I approaching operation. It consists of three primary subsystems: the GNSS Satellite subsystem that produces the ranging signals and navigation messages; the GBAS ground subsystem, which uses two or more GNSS receivers. It collects pseudo ranges for all GNSS satellites in view and computes and broadcasts differential corrections and integrity-related information; the Aircraft subsystem. Within the area of coverage of the ground station, aircraft subsystems may use the broadcast corrections to compute their own measurements in line with the differential principle. After selection of the desired FAS for the landing runway, the differentially corrected position is used to generate navigation guidance signals. Those are lateral and vertical deviations as well as distance to the threshold crossing point of the selected FAS and integrity flags.

The Department of Applied Science in Naples has create for its study a virtual GBAS Ground station. Starting from three GPS double frequency receivers, we collect data of 24h measures session and in post processing we generate the GC (GBAS Correction). For this goal we use the software Pegasus V4.1 developed from EUROCONTROL. Generating the GC we have the possibility to study and monitor GBAS performance and integrity starting from a virtual functional architecture. The latter allows us to collect data without the necessity to found us authorization for the access to restricted area in airport where there is one GBAS installation.

**Keywords:** GNSS, GBAS, Satellite Navigation, Parthenope.

## 1. Introduction

The GNSS (Global Navigation Satellite Systems) are not sufficient to support Air Navigation in specific applications; so it is necessary to introduce Augmentation Systems. In the last years the European Scientific Community are focusing on Augmentation Systems based on Satellite infrastructure (SBAS - Satellite Based Augmentation System) and on Ground based ones (GBAS - Ground Based Augmentation System) [1],[2]. The Ground-Based Augmentation System (GBAS) is a safety-critical system that augments the GPS Standard Positioning Service and provides enhanced levels of service supporting all phases of approach, landing, departure and surface operations within its area of coverage. GBAS will be initially applied to the approach phase of flight as an alternative to ILS CAT I.

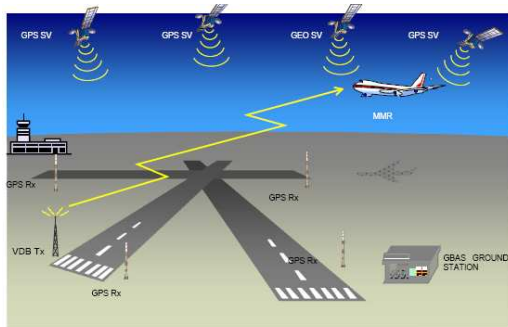


Figure 1. GBAS overview [1]

The GBAS system consists of three primary subsystems, as showed in the figure 1:

- GNSS Satellite subsystem. It produces the ranging signals and navigation messages. The satellite signals received by the GNSS receivers are subject to various error sources. Some of these error sources may be compensated through the use of differential techniques in the GBAS system.
- GBAS ground subsystem, which uses two or more GNSS receivers. It collects pseudoranges for all GNSS satellites in view, computes and broadcasts differential corrections and integrity-related information based on its own surveyed position. These high integrity computed corrections are transmitted from the ground system via a Very High Frequency (VHF) Data Broadcast (VDB) in the band 108 to 117,975 MHz. The lowest selectable frequency is 108.025 MHz and the highest one 117.950, with a separation between frequencies (channel spacing) of 25 kHz. The transmitter broadcasts pseudorange corrections, integrity parameters and various locally relevant data such as Final Approach Segment (FAS) data, referenced to the World Geodetic System (WGS-84). When it uses an antenna with an omni directional pattern, the ground station has the capability to support multiple runways and approaches. Consequently, the broadcast includes various approach segments (FAS) which consist of Path Points describing approaches for each related runway, the FAS Vertical Alert Limit/Approach Status and the FAS Lateral Alert Limit/Approach Status.
- Aircraft subsystem. Within the area of coverage of the ground station aircraft subsystems may use the broadcast

corrections to compute their own measurements in line with the differential principle. After selection of the desired FAS for the landing runway, the differentially corrected position is used to generate navigation guidance signals. Those are lateral and vertical deviations as well as distance to the threshold crossing point of the selected FAS and an integrity flags. Concerning the frequency selection, it tunes to the correct frequency using a channel number consisting of five numeric characters. The channel number enables the airborne subsystem also to select the Final Approach Segment (FAS) data block that defines the correct approach. The correct FAS data block is selected by the Reference Path Data Selector (RPDS) which is included as part of the FAS definition data in one of the broadcast message. In order to minimize impact upon current aircraft design and operational procedures, guidance information output is intended to be consistent with ILS requirements ("ILS look-alike"). This will reduce the certification effort of these Multi-Mode Receivers (MMR), of which the GBAS aircraft subsystem forms a part.

## 2. Background

Our research group started to study GBAS performance just 3 years ago. We have a very important mutual intellectual exchange with EUROCONTROL, the European Leader Research Group about Augmentation System, and THALES ATM, that manages the only national experimental GBAS installation at Milano – Linate, Italy (see Figure 2 – GMS, Ground monitoring Station).



Figure 2. Ground Monitoring Station

We worked on the over said installation in order to unify the national research with the European one. Thanks to our support we was able to process the measures of Linate installation with the software developed by Eurocontrol. After this goal we focus our attention on the so called *Virtual GBAS*. Due to solve economic problems that make unable the installation of a Reference GBAS Station and a Monitoring Station, we ideate a Virtual System able to generate the GGC *Generated Ground Correction* using the Eurocontrol software PEGASUS Plus.

## 3. Algorithms

As part of the operational validation of GBAS, EUROCONTROL is developing a set of Hardware and Software tools, called GBAS Modular Analysis and Research System (MARS). The high level objectives of MARS are to support the end-to-end validation of the GBAS for Cat I operations and to assess the feasibility of extending its use to support precision approach and landing operations in Cat II/III conditions [3], [4]. MARS shall be a modular set of tools, specifically developed to support the deployment of GBAS systems in the following aspects:

- Operational Approval of GBAS CAT-I.
- Site Selection and Approval of GBAS CAT-I.
- Provide inputs to the Safety Assessment of GBAS CAT-I.
- Provide inputs for the specification of GBAS CAT-II/III requirements.
- Familiarize their users with the particularities of the GBAS system.

In summary, MARS is intended to support site and operational approval of a GBAS installation.

MARS3 consists of five different modules, integrated in the PEGASUS frame, so that they can interact with each other and with other PEGASUS modules in complex processing chains.

However, each module is designed to perform a different task so that all of them can be called in stand-alone mode. The following table shows the modules of MARS3:

Module	Acronym	Functionality
External Data Converter	EDC	Convert non-SIS GBAS data
Convertor Update	Pegasus Plug-ins	Convert SIS-GBAS related data from the MMR receiver and the DPS Ground Station
Generate GBAS Corrections	GDC	Generate simulated GBAS messages
Process GBAS Messages	PGM	Analyse and manipulate GBAS messages
Compute Accuracy Prediction	CAP	Compute parameters related to the expected accuracy of a GBAS GS
GBAS Status Availability	GSA	Analyse the availability of ground and space segments of GBAS

Table 1 – Pegasus Modules

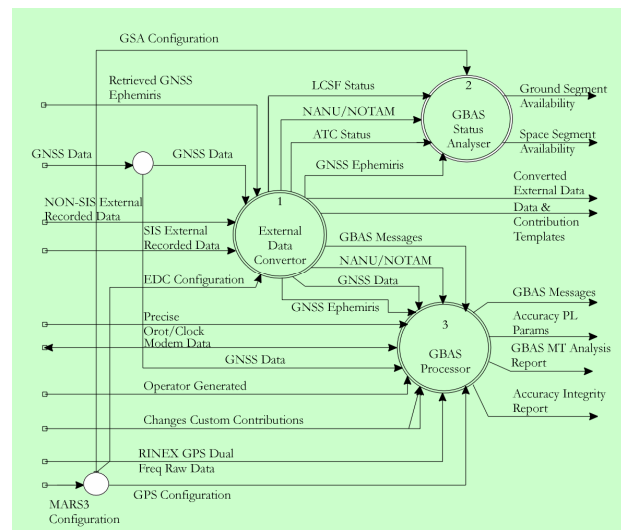


Figure 3. Data Flow Diagram [4]

Figure 3 shows the first Level decomposition of MARS3. Note that the modules GDC, PGM and CAP have been grouped under "GBAS Processor".

### 3. GBAS Processor

The objective of this MARS3 functionality is to compute the pseudorange correction, as a GBAS station should do for broadcasting messages [4].

It is based on several assumptions:

- Very precise knowledge of Reference Receivers position. This allows computing more precise ranges using the GNSS Ephemeris information.
- Reference Receiver Clock cancellation using an estimation computed with measurements from several receivers.
- Very precise knowledge of the GBAS System environment (bounded Ground Segment error contribution, bounded ephemeris error contribution for each satellite, well calibrated tropospheric parameters, and bounded ionosphere error contribution).
- Redundancy information from several Reference Receivers provides a way of computing integrity parameters

With these assumptions the GBAS Ground Station computes an estimation of the error contributions for each satellite. This estimation is broadcast to the Airborne Receiver (that in this case is substitute from the Monitoring Station) through the VDB (VHF Data Broadcast) providing the user with a precise correction for the pseudorange measurement of each satellite. The PRC - Pseudo-range Correction computation based on GNSS data is done as indicated in the following figure:

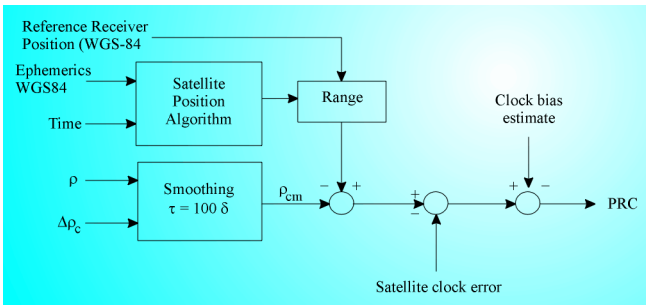


Figure 4. PRC Computation

It is important to point out that the satellite visibility is determined using ephemeris data (manipulated if desired), as well as NANU/NOTAM data in Pegasus format and masking profile data. This forced visibility (using NANU/NOTAM data and masking angle data) is combined with the reference receivers' real visibility profile.

The following steps should be followed for the computation of the Pseudorange Correction for GPS satellites at every instant:

- Computation of Range (R):  
Computation of the geometric range between the satellite antenna phase centre and the corresponding reference receiver antenna phase centre.
- Computation of Satellite Clock Error Estimate  $\Delta t_{SV}$ :  
The satellite clock errors (satellite clock error, relativistic correction term and differential satellite group delay) for L1 shall be determined based on with the following equation:

$$\Delta t_{SV} = a_{f0} + a_{f1}(t - t_{oc}) + a_{f2}(t - t_{oc})^2 + \Delta t_r - T_{GD} \quad (1)$$

Where:

- $\Delta t_{sv}$  = the satellite PRN code phase time offset (seconds),
- $a_{f0}$ ,  $a_{f1}$  and  $a_{f2}$  are the polynomial coefficients contained in GPS sub-frame 1;
- $t_{oc}$ , is the clock data reference time, in seconds, contained in GPS sub-frame 1;
- $\Delta t_r$ , is the relativistic correction term, in seconds, given by

$$\Delta t_r = Fe\sqrt{A} \sin(EK)$$

- $t_{sv}$  = the effective satellite PRN code phase time at message transmission time (seconds),
- $t$  = the GPS system time (seconds).
- TGD is the Group Delay provided in the GPS sub-frame 1.

and  $(e, A)$  are contained in sub-frames 2 and 3, while  $F$  is a constant whose value is:

$$F = \frac{-2\sqrt{\mu}}{c^2} = -4.442807633 \times 10^{-10} \text{ sec}/(\text{metre})^{1/2} \quad (2)$$

- Removal of Dual-Frequency Ionospheric Delays:  
If dual-frequency data is available, the input pseudoranges are corrected with the ionospheric delays provided by the GILION model. Moreover, it will reduce the smoothing divergence induced by the ionospheric delay.
- Computation of  $P_{CSCn}$ :  
The pseudoranges from each reference receiver ( $j$ ) and each measurement ( $i$ ) is smoothed using the following filter:

$$P_{CSCn}(i, j) = \alpha P + (1 - \alpha)(P_{CSCn-1} + \frac{\lambda}{2\pi}(\phi_n - \phi_{n-1})) \quad (3)$$

Where

- $P_{CSCn}$  is the smoothed pseudo-range,
- $P_{CSCn-1}$  is the previous smoothed pseudo-range,
- $P$  is the raw pseudo-range measurement,
- $\lambda$  is the L1 wavelength,
- $\phi_n$  is the carrier phase,
- $\phi_{n-1}$  is the previous carrier phase,
- $\alpha$  is the filter weighting function equal to the sample interval ( $T$ ), divided by the time constant ( $S$ ), of 100 seconds.

- Addition of Dual-Frequency Ionospheric Delays:  
If it is selected by the operator and dual-frequency data is available, after filtering the ionospheric free observables the ionospheric delay must be added again to the pseudorange in order to include in the PRC the ionospheric contribution to be used at user level.
- Computation of the Pseudorange Correction for each satellite ( $i$ ) and reference receiver ( $j$ ):  
It is computed using the computed range, the smoothed pseudorange and the satellite clock correction.

$$PRC_{CSC}(i, j) = R(i, j) - P_{CSCn}(i, j) - (c \times \Delta t_{SV}(i)) \quad (4)$$

- Compute the receiver clock adjustment for each reference receiver:

$$\Delta t_{j=i \in S_c} k_i \times PRC_{CSC}(i, j) \quad (5)$$

Where:

- $PRC_{CSC}$  is the smoothed pseudo-range correction
- $i$  is the satellite index;

- j is the reference receiver index;
- Sc is the set of valid ranging sources tracked by all reference receivers;
- Nc is the number of elements in set Sc;
- ki is the weighting factor

$$\Delta t_j = \sum_{i \in S_c} k_i \times PRC_{CSC}(i, j)$$

- h) Compute the PRCsca:  
The following term to be computed is the carrier smoothed pseudorange with the receiver clock adjustment removed (second term of right hand side of following equation)

$$PRC_{sca}(i, j) \equiv PRC_{csc}(i, j) - \sum_{i \in S_c} k_i \times PRC_{csc}(i, j) \quad (6)$$

- f) Computation of the Transmitted Pseudorange Correction:

$$PRC_{TX}(i) \equiv \frac{1}{M(i)} \sum_{j \in S_c}^{M(j)} PRC_{sca}(i, j) \quad (7)$$

Where:

- PRCsca is the carrier smoothed and receiver clock adjusted pseudo-range correction;
- PRC<sub>TX</sub> is the broadcast correction;
- M(i) is the number of valid receivers producing valid PRC for satellite i.

## 4. Results

The Department of Applied Science in Naples has create for its study a Virtual GBAS Ground station [5].

Starting from three GPS double frequency receivers (Novatel OM4, Septentrio Polarix, Trimble 4700) we collect data of 24 h measures session from 11.00 (UTC) of 27<sup>th</sup> August 2006 to 12.00 (UTC) of 28<sup>th</sup> August 2006. Based on this observation we generate in post processing the GC (GBAS Correction) as a GBAS Reference Station and compute a GBAS position solution by applying the simulated messages to the data from Novatel reference receivers.

The three known antenna position are:

	Latitude	Longitude	Altitude
Novatel	40° 50' 30".7	14° 15' 19".80	83.198 m
Septentrio	40° 50' 31"	14° 15' 19".91	83.460 m
Trimble	40° 50' 30".8	14° 15' 19".86	83.869 m

Table 2 – Reference Antenna Coordinate

Using Pegasus Plus as post process program, we have the possibility to check the kind of positioning made by receiver. The Position Type is a variable associated to this value. The coding of the parameter POS\_TYPE is provided in the following table 3:

Pos_Type	Description
0	no position solution available
1	Unsmoothed GPS standalone position solution
2	GPS standalone position solution
3	SBAS NPA position solution
4	SBAS PA position solution
5	GBAS position solution

Table 3 – Position Type

As showed by Figure 4 the type of position is 5 (GBAS Solution) only in the first half of measure session. In the second half of serial data, the Trimble receiver doesn't work so the virtual reference station was not able to generate the GC.

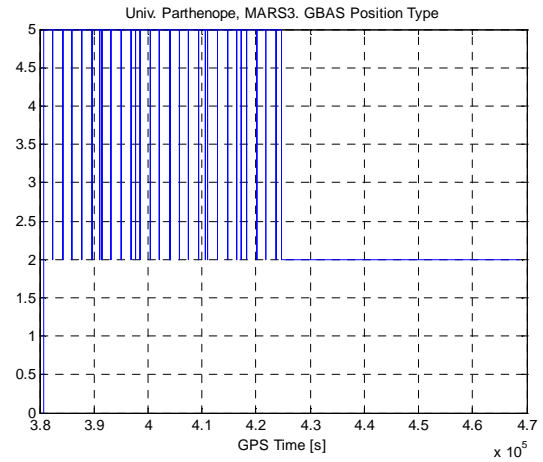


Figure 4. Position Type Diagram

Also in first half measure session the position type has not a stable course due to the loss of signal of Trimble receiver. The next figures show the horizontal and vertical errors

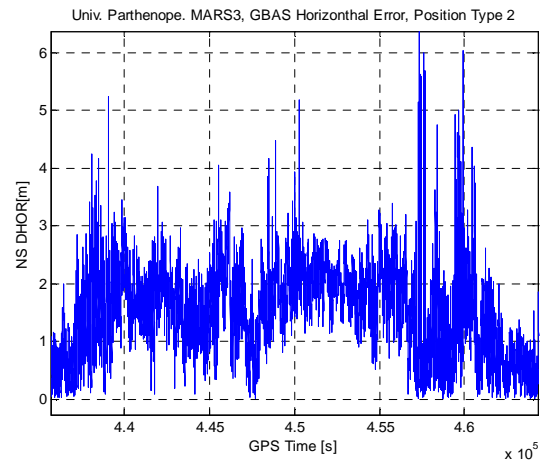


Figure 5. Horizontal Error, Position Type 2

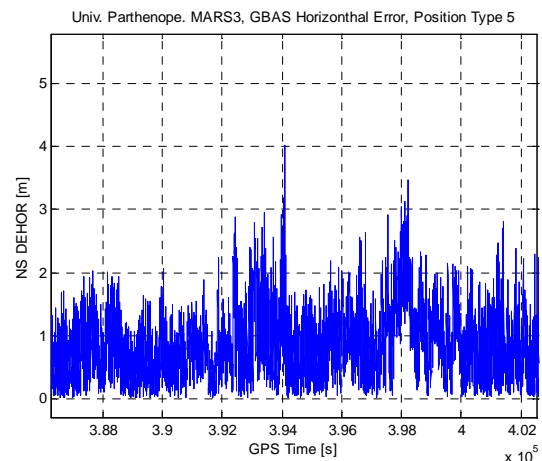


Figure 6. Horizontal Error, Position Type 5

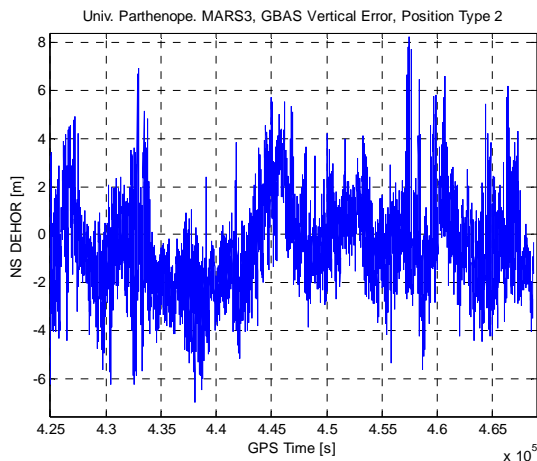


Figure 7. Vertical Error, Position Type 2

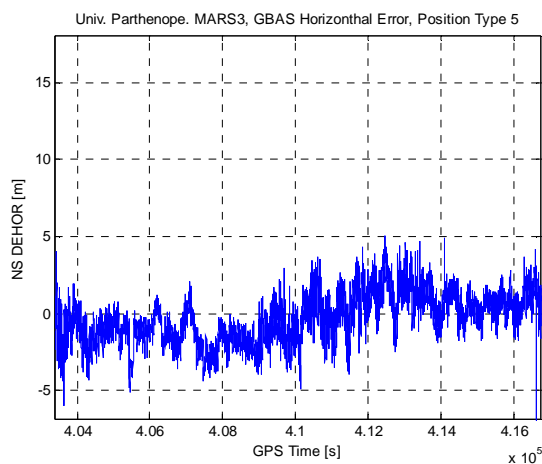


Figure 8. Horizontal Error, Position Type 5

In the small interval when the pos\_type is 5, the GBAS position solution gives results showed in previous figure 6 and 8.

It can be seen that comparing the same horizontal errors for the GBAS solution and GPS stand alone one, the accuracy is better for the augmented solution else if not enough.

For the vertical canal, instead, the accuracy improves with GBAS solution as showed in figure 7 and 8.

Future goal is to do a dynamic test of the VGBAS also studying the RAIM (Receiver Autonomous Integrity Monitoring) for the GBAS reference station.

## Reference

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