Federal Aviation Administration

# Ground Based Augmentation System

## Performance Analysis and Activities Report

**Reporting Period: April 1 – June 30, 2016**

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## 1. Introduction

The Ground Based Augmentation System (GBAS) team under the direction of the Navigation Branch (ANG-C32) in the Engineering Development Services Division in the Advanced Concepts and Technology Development Office at the Federal Aviation Administration's (FAA) William J Hughes Technical Center (WJHTC) provides this GBAS Performance Analysis / Activities Report (GPAR).

This report identifies the major GBAS related research, testing, and validation activities for the reporting period in order to provide a brief snapshot of the program directives and related technical progress. Currently, the GBAS team is involved in the validation of the GAST-D ICAO SARPs, GBAS ILS/VDB interference testing, supporting system design approval activities for an update to the CAT-I approved Honeywell International (HI) Satellite Landing System (SLS-4000) and future CAT-III capable SLS-5000, Block II updates, and maintaining six Ground Based Performance Monitors (GBPMs) and a prototype GAST-D Honeywell Satellite Landing System at Atlantic City International Airport (ACY).

Objectives of this report are:

a) To provide status updates and performance summary plots per site using the data from our GBPM installations
b) To present all of the significant activities throughout the GBAS team
c) To summarize significant GBAS meetings that have taken place this past quarter
d) To offer background information for GBAS

## 2. GBAS Updates by Site

The GBPM was designed and built by ANG-C32 to monitor the performance of GBAS installations. There are currently six GBPMs in use. They are located in Newark New Jersey (EWR), Houston Texas (IAH), Moses Lake Washington (MWH), Rio de Janeiro Brazil (GIG), and two in Atlantic City New Jersey (ACY). The GBPM is used to monitor the integrity, accuracy, availability, and continuity of the FAA's LAAS Test Prototype (LTP) and Honeywell's SLS-4000. The plots in each of the following sections utilize a compilation of data collected at one minute intervals. For live, up-to-date data, refer to http://laas.tc.faa.gov. A more detailed description of the GBPM configuration can be found in Appendix D of this report.

### 2.1 EWR SLS

- Newark Liberty Int'l Airport has a Honeywell SLS-4000 that was granted operational approval on September 28, 2012. The ground station is currently configured in CAT I – Block I mode.
- Since the EWR SLS-4000 went live, there have been a total of 1519 GBAS approaches conducted at EWR. Airline carriers include United Airlines (Boeing 737, 787), British Airways (Boeing 787), and Lufthansa (A380 Airbus).


**Figure 1 - EWR SLS-4000 Configuration**

### *2.1.1 Real Time Performance Data*

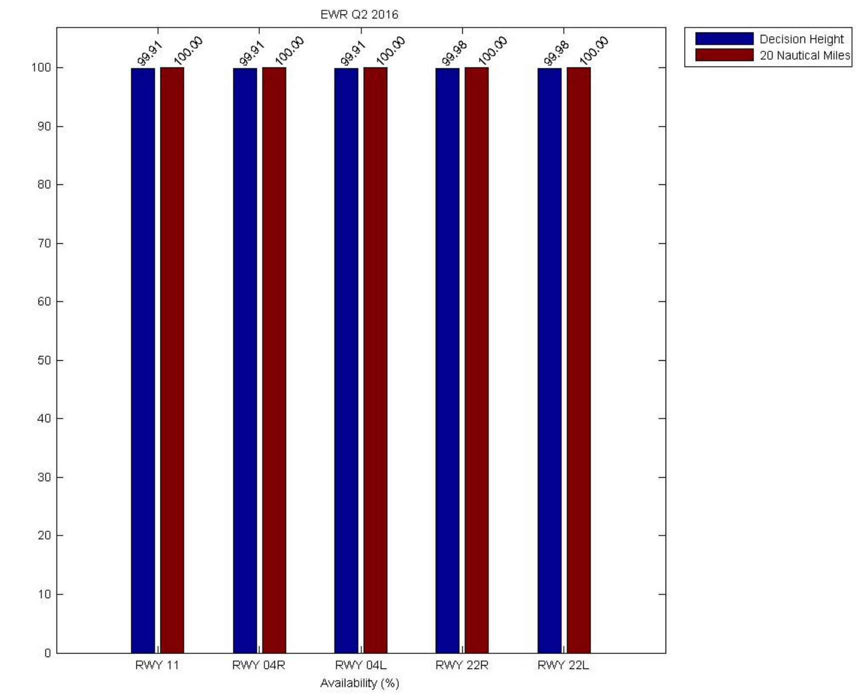


**Figure 2 - EWR Availability**

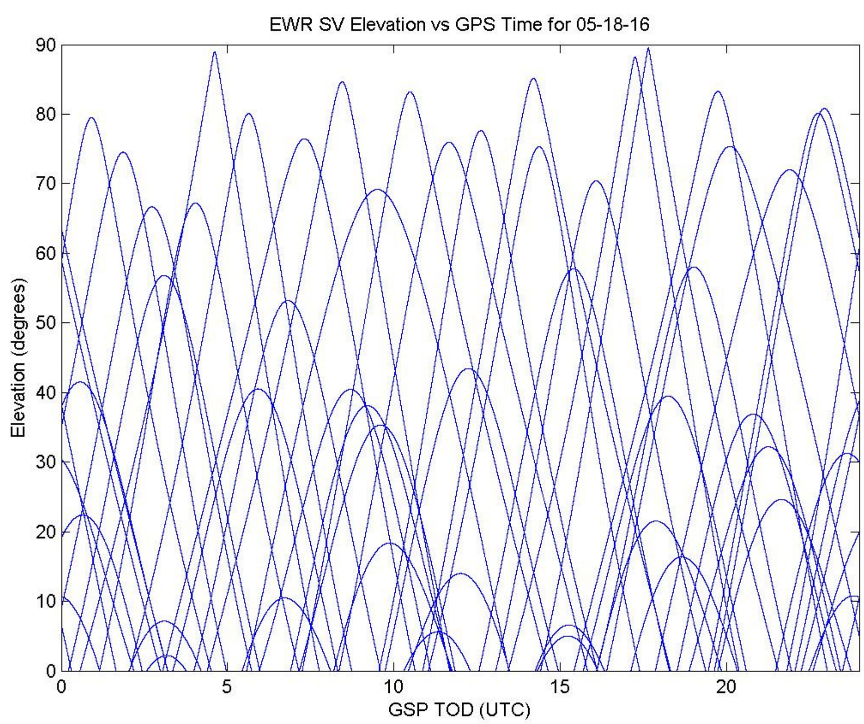


**Figure 3 - EWR SV Elevation vs GPS time 05/18/16**

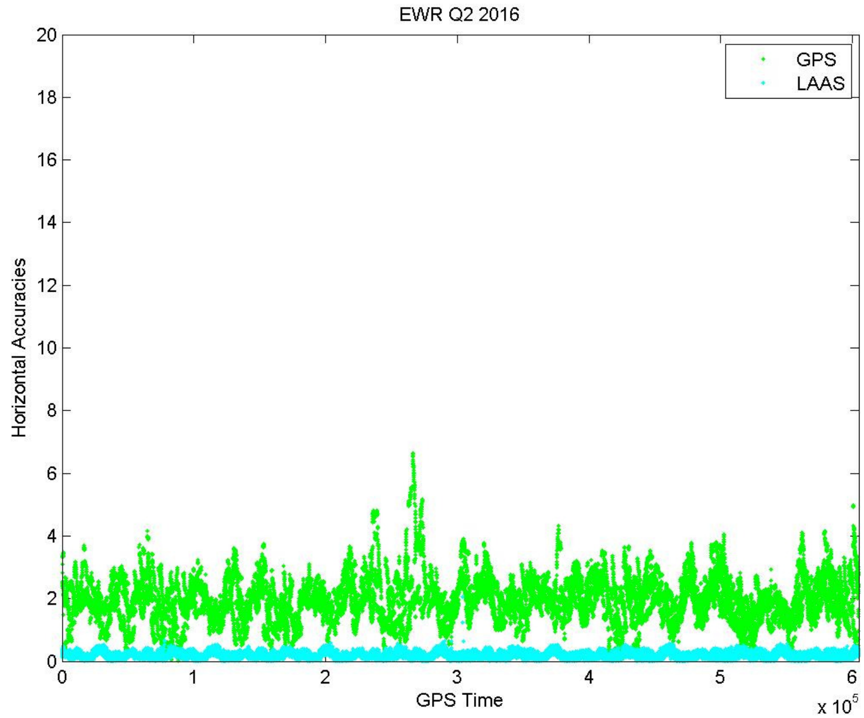


**Figure 4 - EWR Horizontal Accuracy**

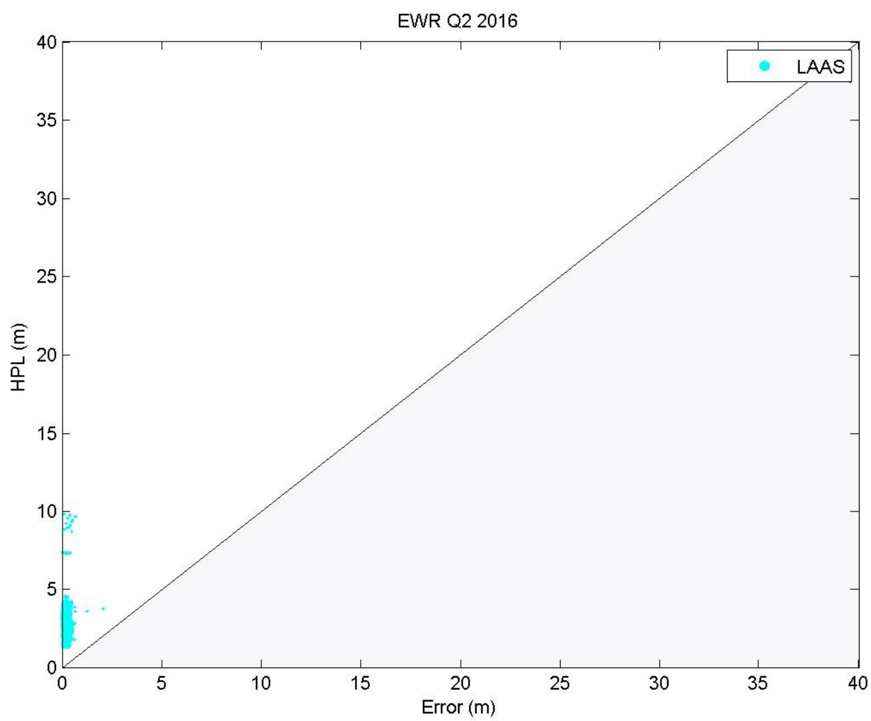


**Figure 5 - EWR Horizontal Protection Level vs. Error**

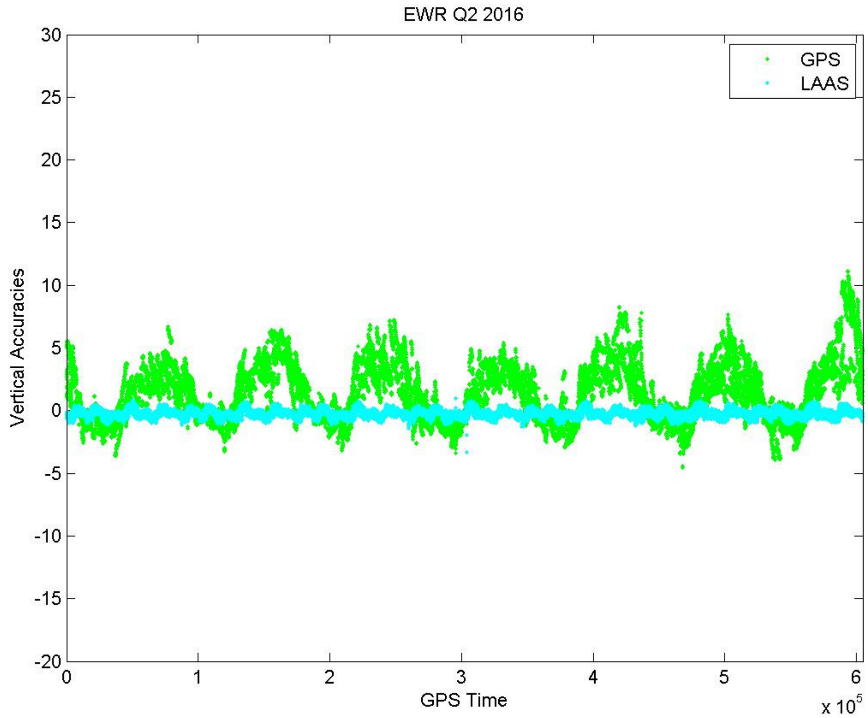


**Figure 6 - EWR Vertical Accuracy**

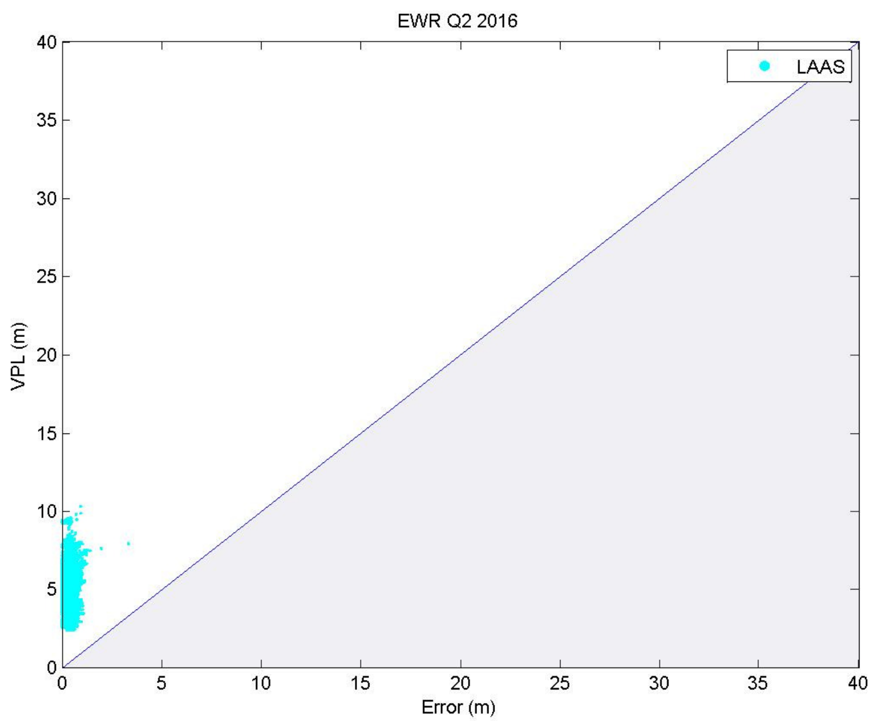


**Figure 7 - EWR Vertical Protection Level vs. Error**

## 2.2 IAH SLS

- George Bush Intercontinental Airport in Houston, TX has a Honeywell SLS-4000 that was granted operational approval on April 22, 2013. The ground station is currently configured in CAT I – Block I mode.
- Since the IAH SLS-4000 went live, there have been a total of 1632 GBAS approaches conducted at IAH. Airline carriers include United Airlines (Boeing 737, 787), British Airways (Boeing 787), Cathay Pacific (Boeing 747-8), Emirates (A380 Airbus), and Lufthansa (A380 Airbus).


**Figure 8 - IAH SLS-4000 Configuration**

### *2.2.1 Real Time Performance Data*

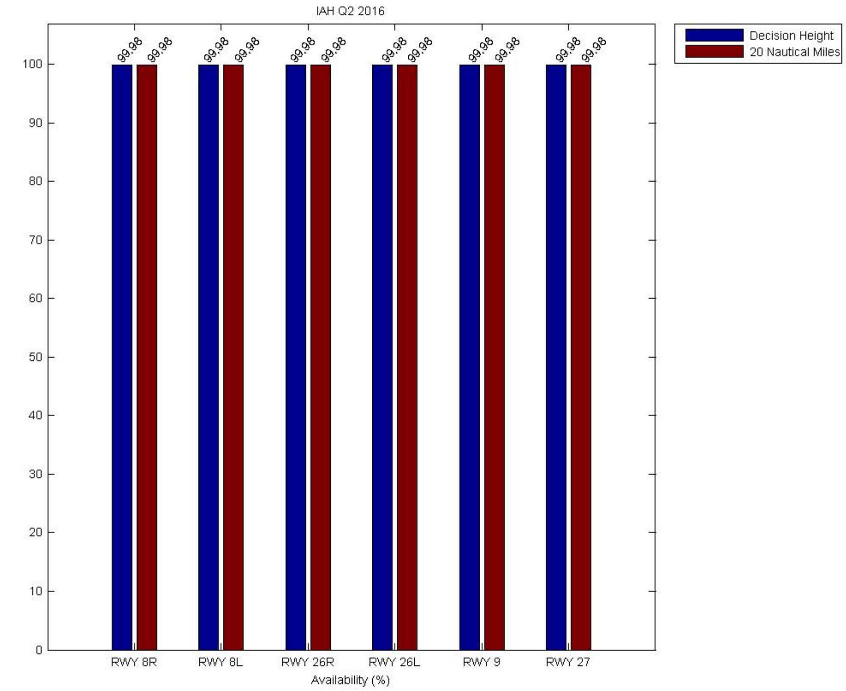


**Figure 9 - IAH Availability**

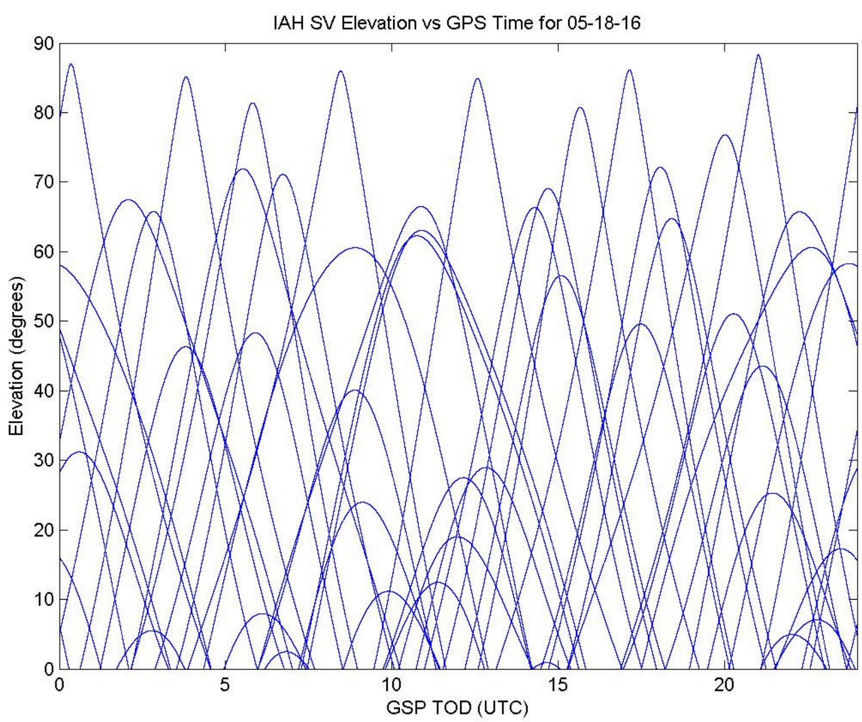


**Figure 10 - IAH SV Elevation vs GPS time 05/18/16**

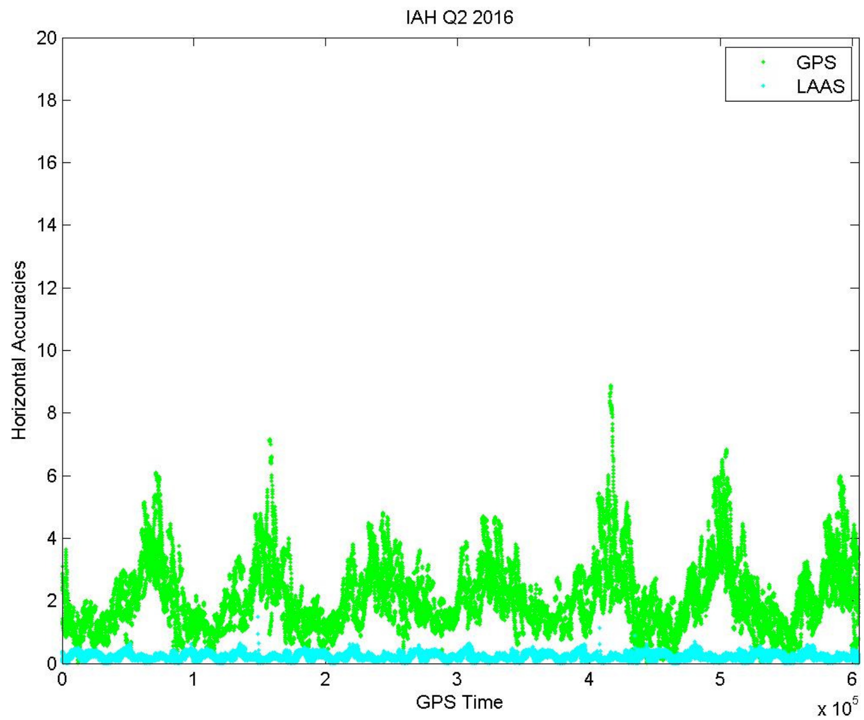


**Figure 11 - IAH Horizontal Accuracy**

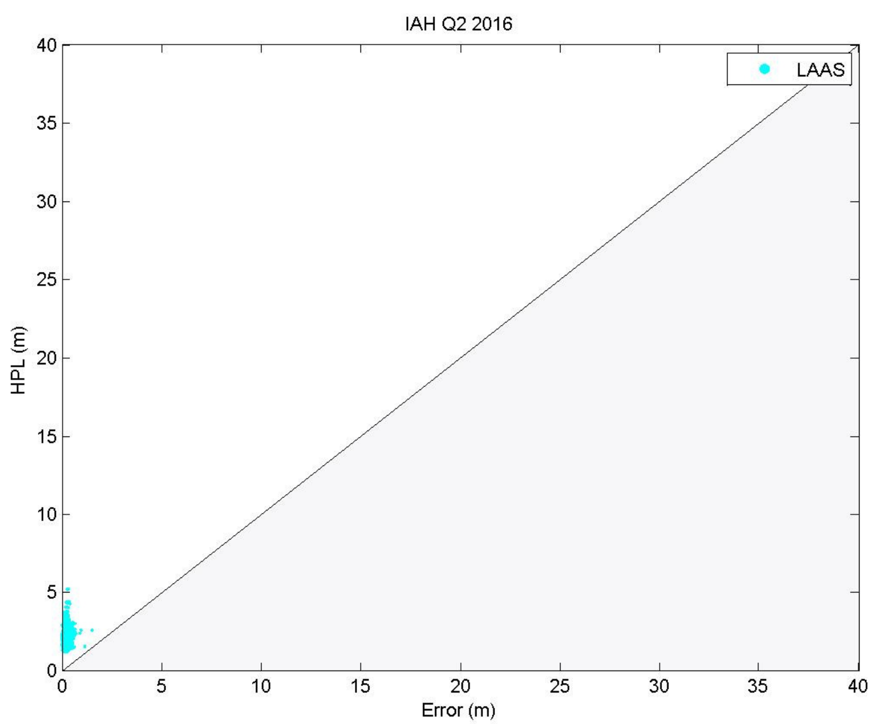


**Figure 12 - IAH Horizontal Protection Level vs. Error**

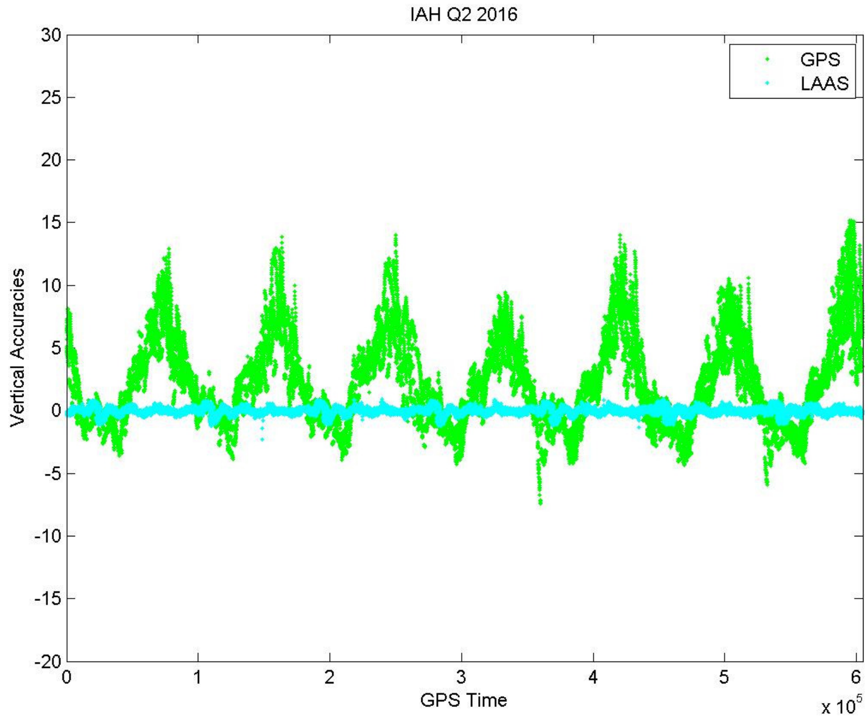


**Figure 13 - IAH Vertical Accuracy**

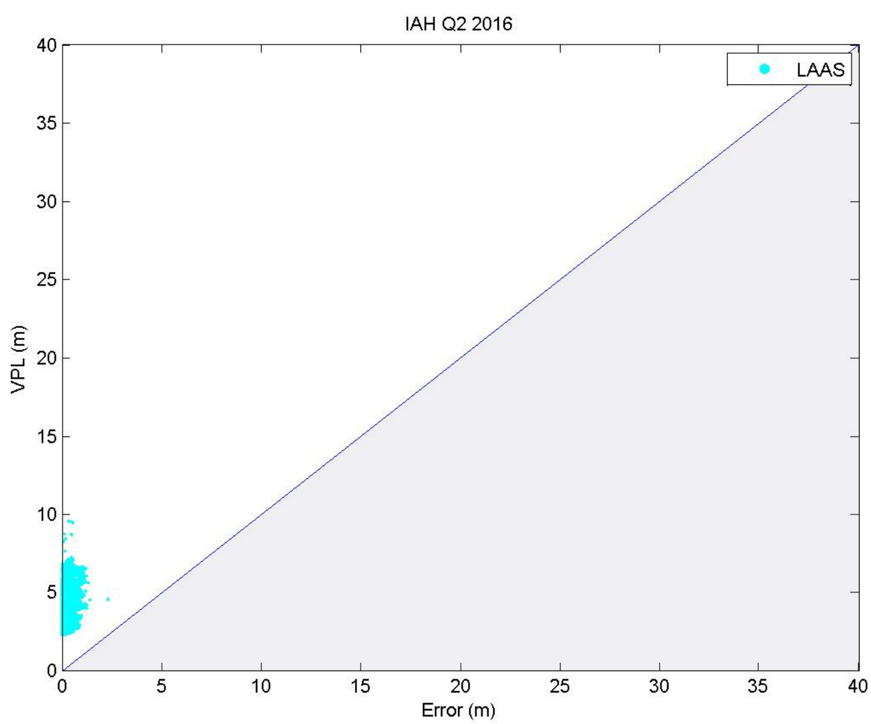


**Figure 14 - IAH Vertical Protection Level vs. Error**

## 2.3 MWH SLS

- Grant County Airport in Moses Lake, WA has a private-use Honeywell SLS-4000 owned by Boeing that was granted operational approval on January 9, 2013. The ground station is currently configured in CAT I – Block I mode.
- Boeing uses this site for aircraft acceptance flights and production activities
- Boeing has also operated this site in a prototype GAST-D mode for flight testing to support GAST-D requirements validation
- While Grant County Airport (GEG) is a public use airport, it has no commercial flights
- This system requires a significant amount of multipath masking which can affect the constellation geometry at times, causing inflated protection levels and error, and a slight decrease in system availability.

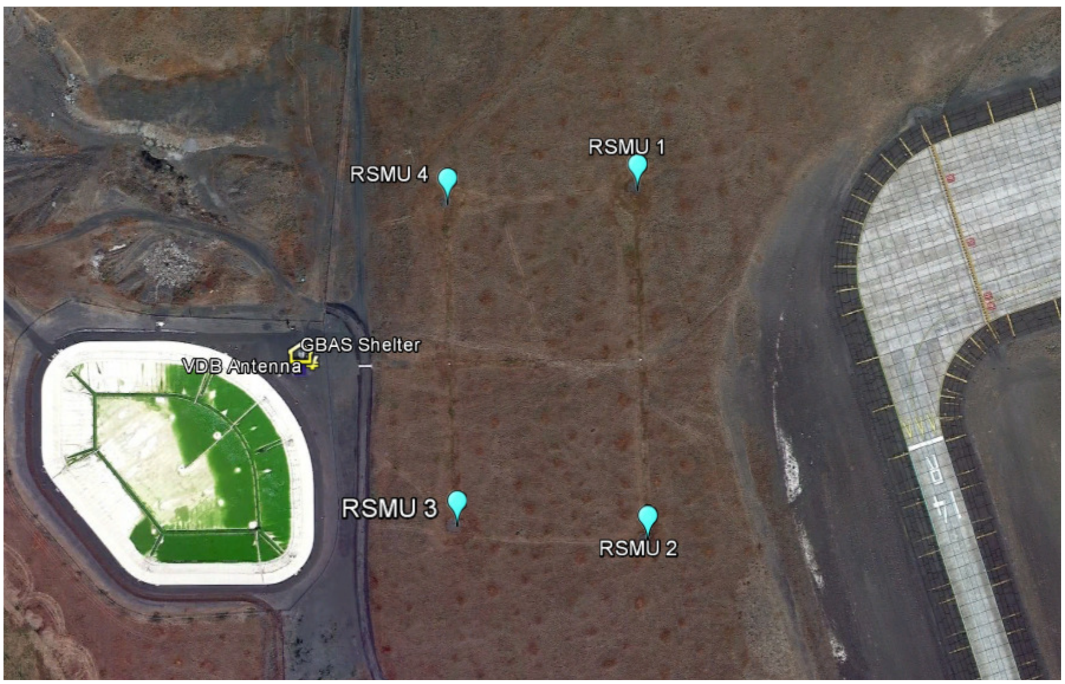


**Figure 15 - MWH SLS-4000 Configuration**

### *2.3.1 Real Time Performance Data*

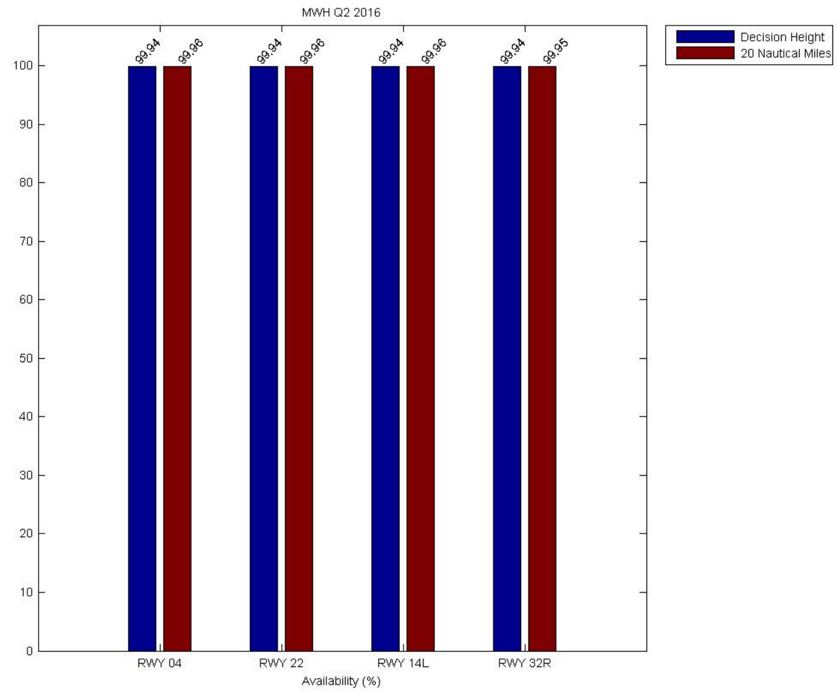


**Figure 16 - MWH Availability**

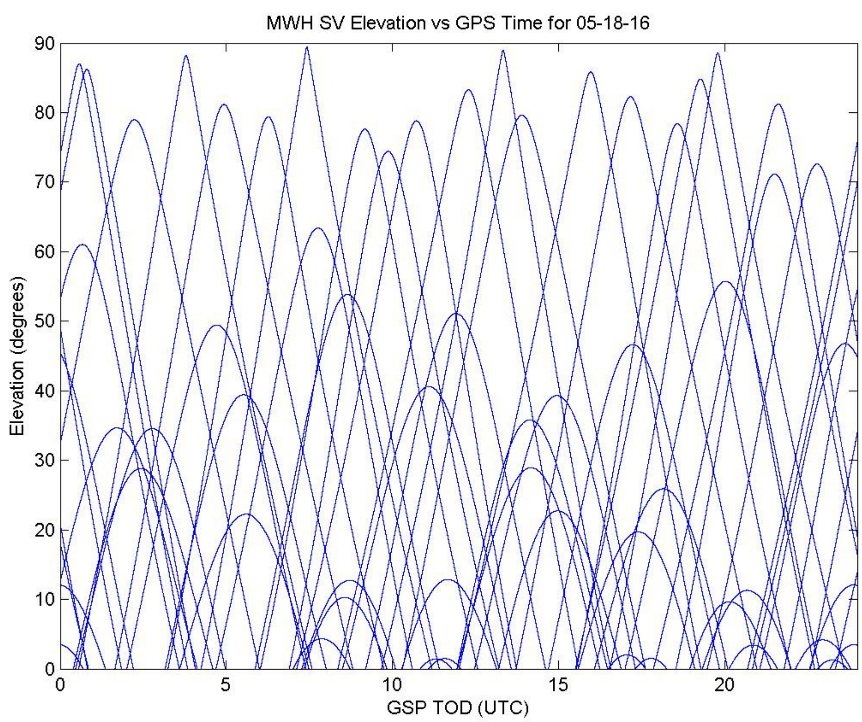


**Figure 17 - MWH SV Elevation vs GPS time 05/18/16**

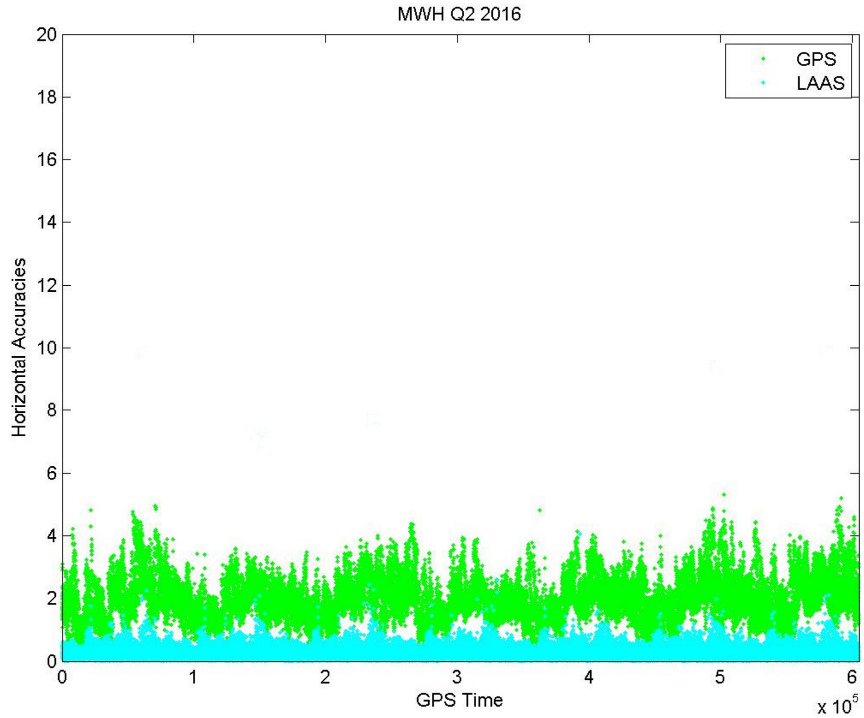


**Figure 18 - MWH Horizontal Accuracy**

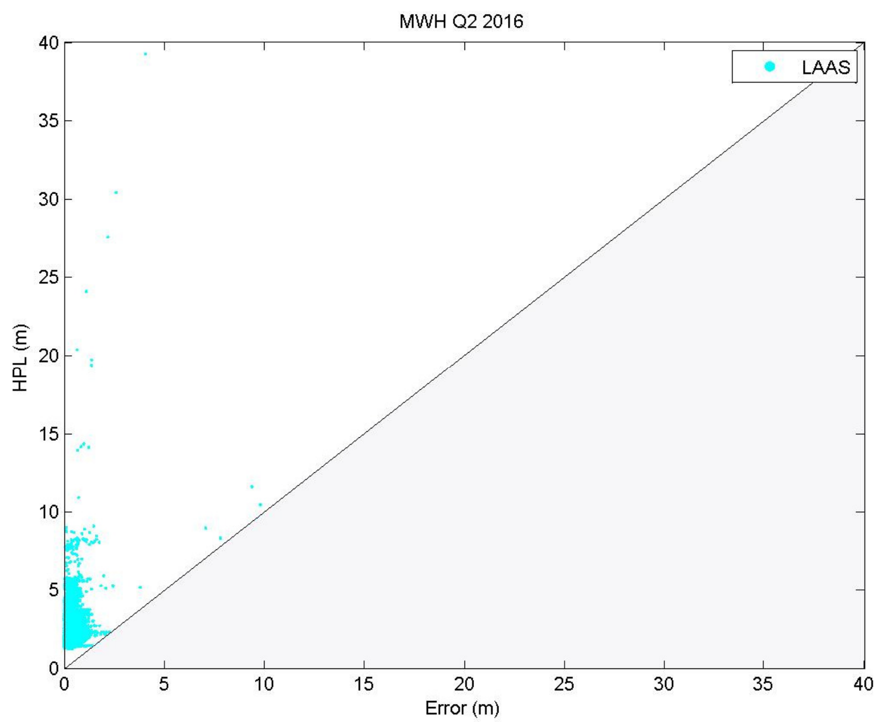


**Figure 19 - MWH Horizontal Protection Level vs. Error**

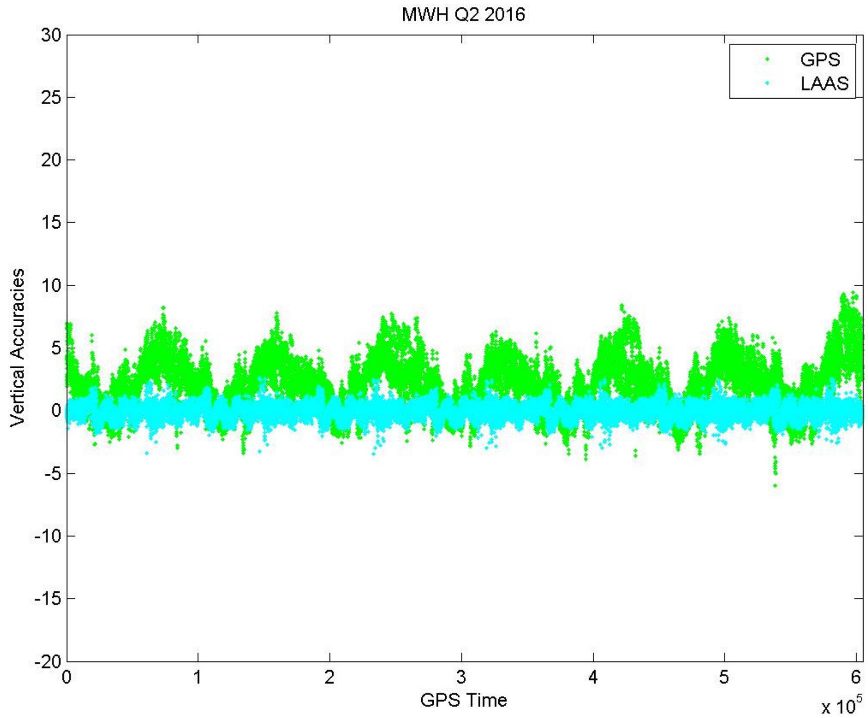


**Figure 20 - MWH Vertical Accuracy**

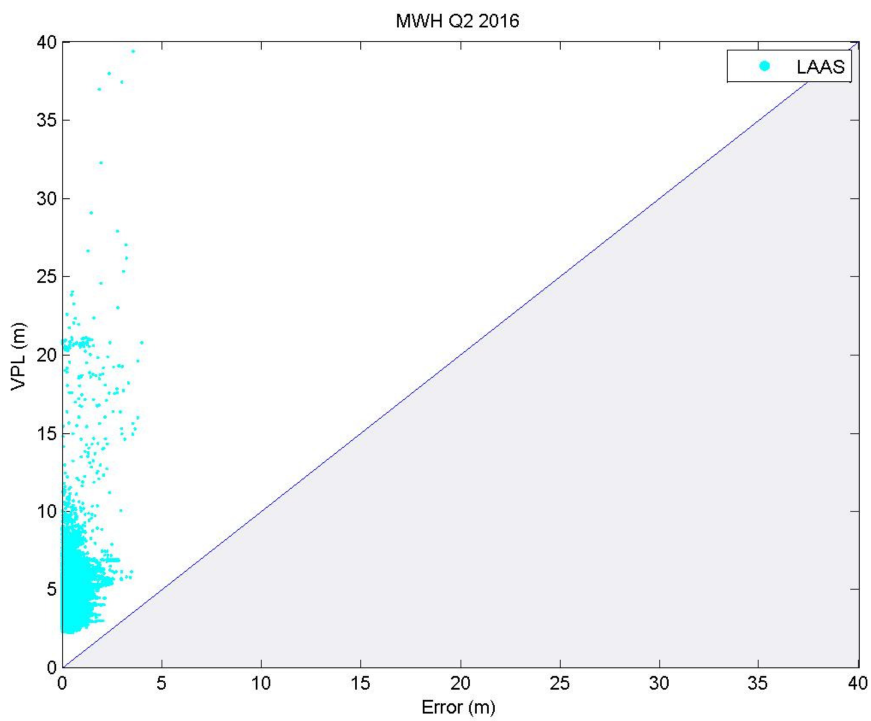


**Figure 21 - MWH Vertical Protection Level vs. Error**

### 2.4 Rio de Janeiro Brazil

- The Rio de Janeiro GBAS is a Honeywell SLS-4000 operating in a CAT I – Block II prototype mode. The site was down due to maintenance issues during all of Q2.
- The antenna on the Brazil GBPM is less robust than the other sites, therefore satellites below 11 degrees may not be tracked as consistently
- The FAA-owned Ground-Based Performance Monitor (GBPM) remained in normal operation throughout Q2.

#### 2.4.1 Real Time Performance Data

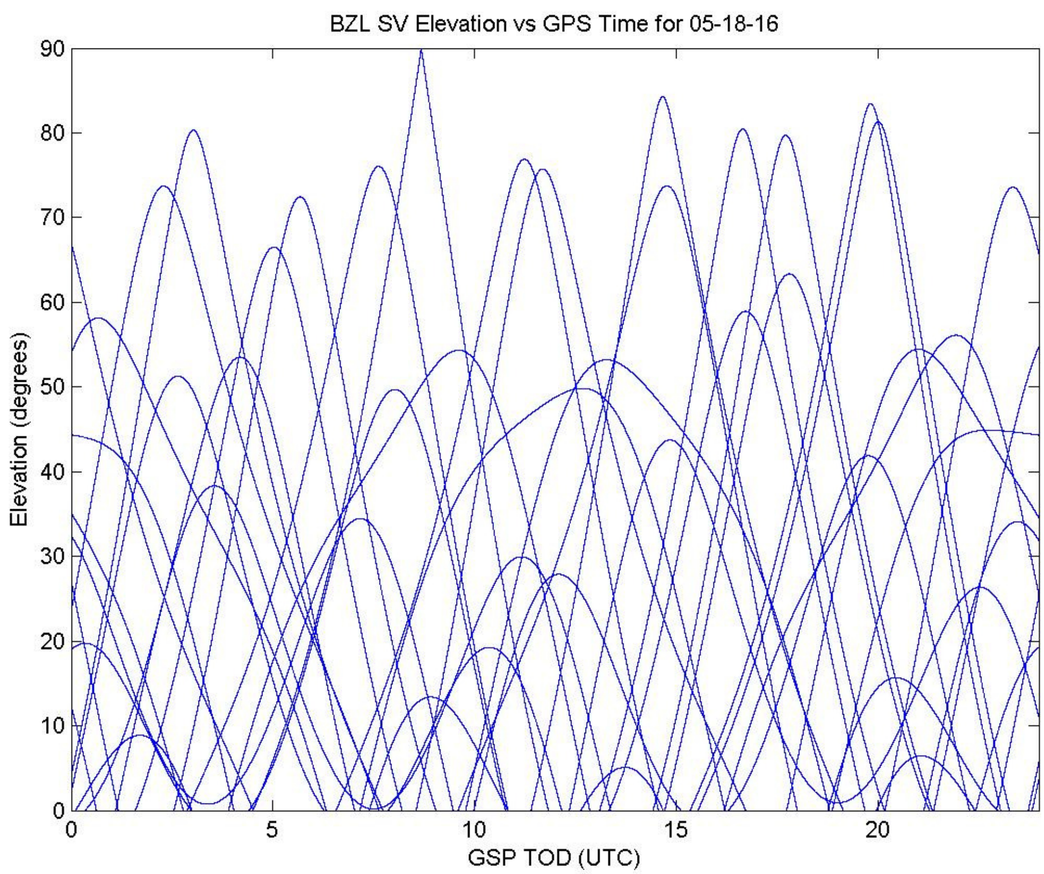


**Figure 22 - BZL SV Elevation vs GPS time 05/18/16**

### 2.5 ACY SLS

- The KACY ground station operates in either CAT-I Block II mode, or in CAT-III prototype mode.
- RSMUs 5 & 6 are not used in CAT-I mode and are part of the GAST-D/CAT-III prototype system.
- NOTE: Due to flight testing at the FAA William J. Hughes Technical Center, a total of sixteen (16) days were removed from the ACY Real Time Performance Data plots shown in **Section 2.5.1**. This also includes configuration down-time in preparation for said flight tests. Other data that was removed includes routine maintenance of the Honeywell SLS-4000 Ground Station.
- See **Section 3.4** for additional details on the tests performed this quarter.

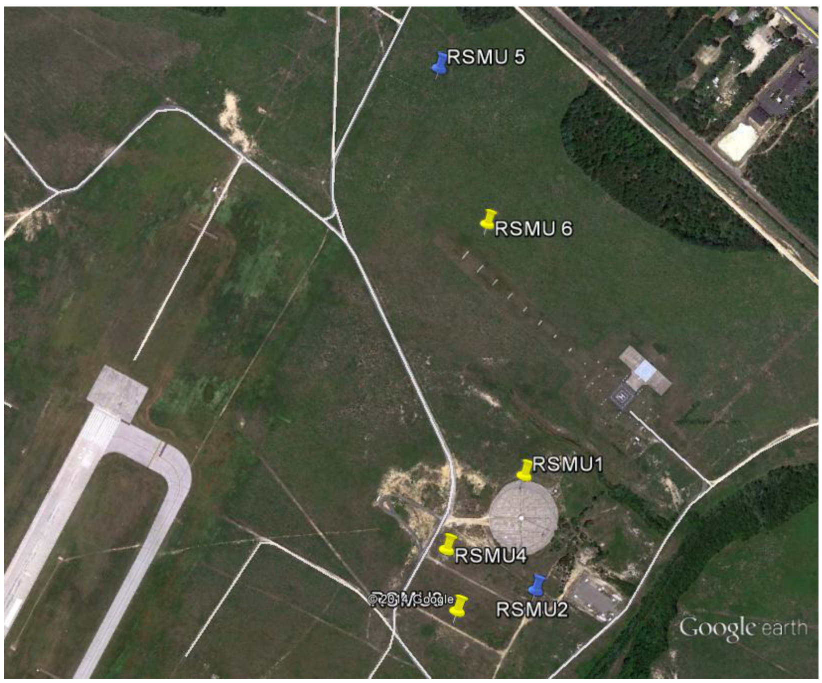


**Figure 23 - ACY SLS-4000 Configuration**

### 2.5.1 Real Time Performance Data

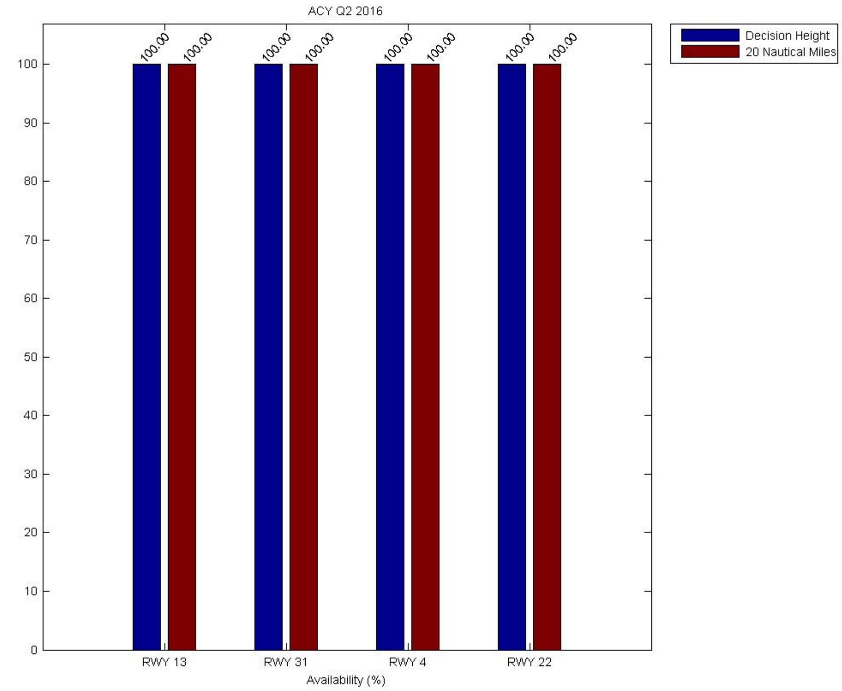


**Figure 24 - ACY Availability - The data shown is based upon times when the SLS was transmitting in a nominal mode**

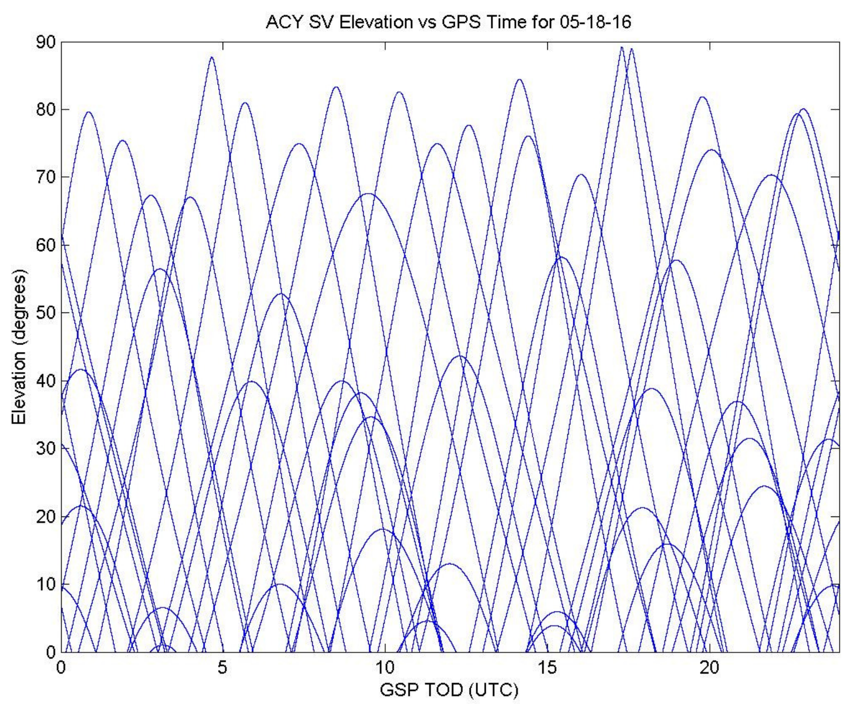


**Figure 25 - ACY SV Elevation vs GPS time 05/18/16**

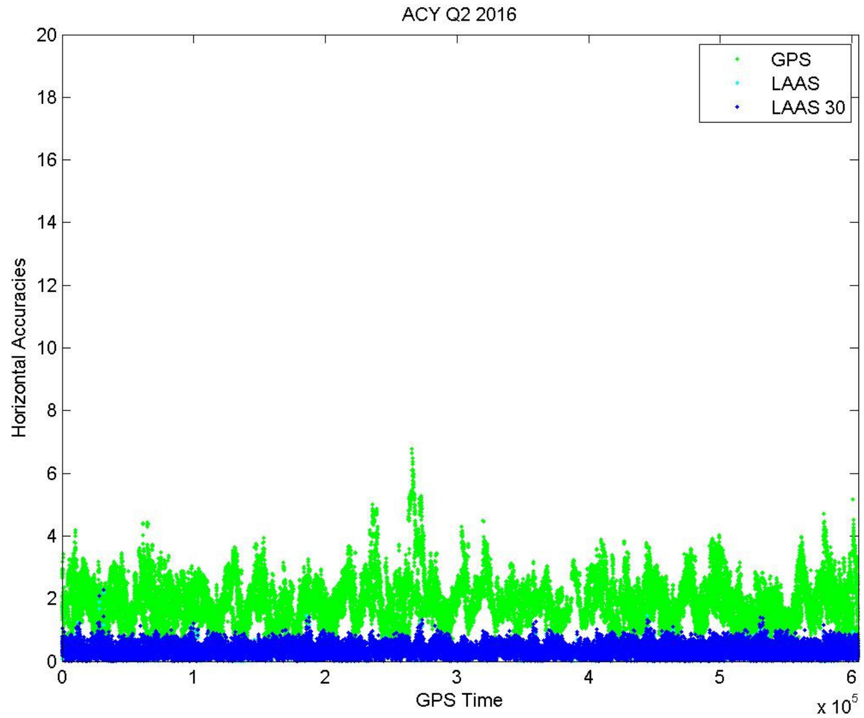


**Figure 26 - ACY SLS Horizontal Accuracy**

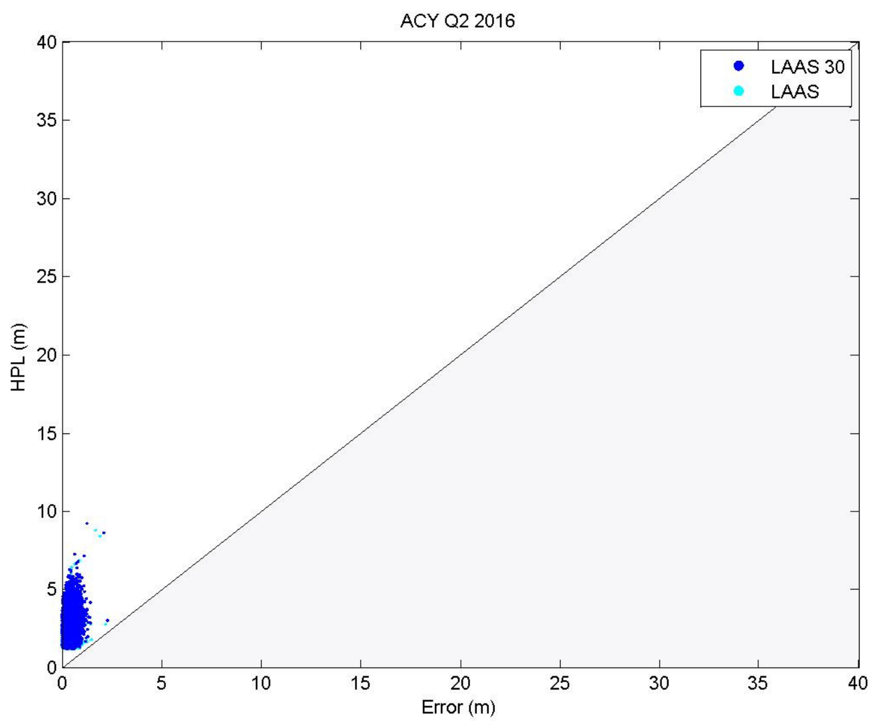


**Figure 27 - ACY SLS Horizontal Protection Level vs. Error**

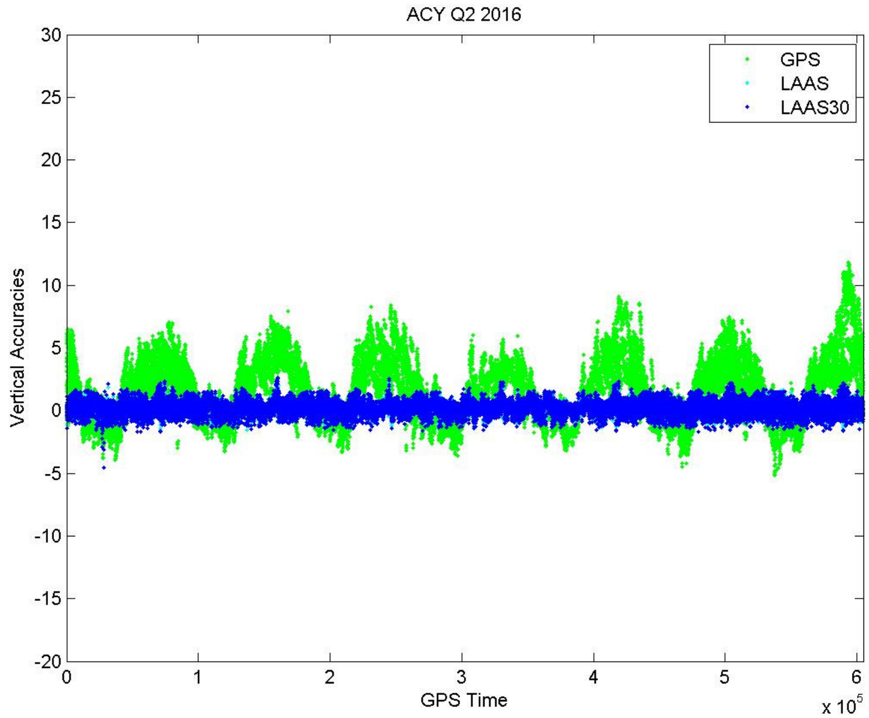


**Figure 28 - ACY SLS Vertical Accuracy**

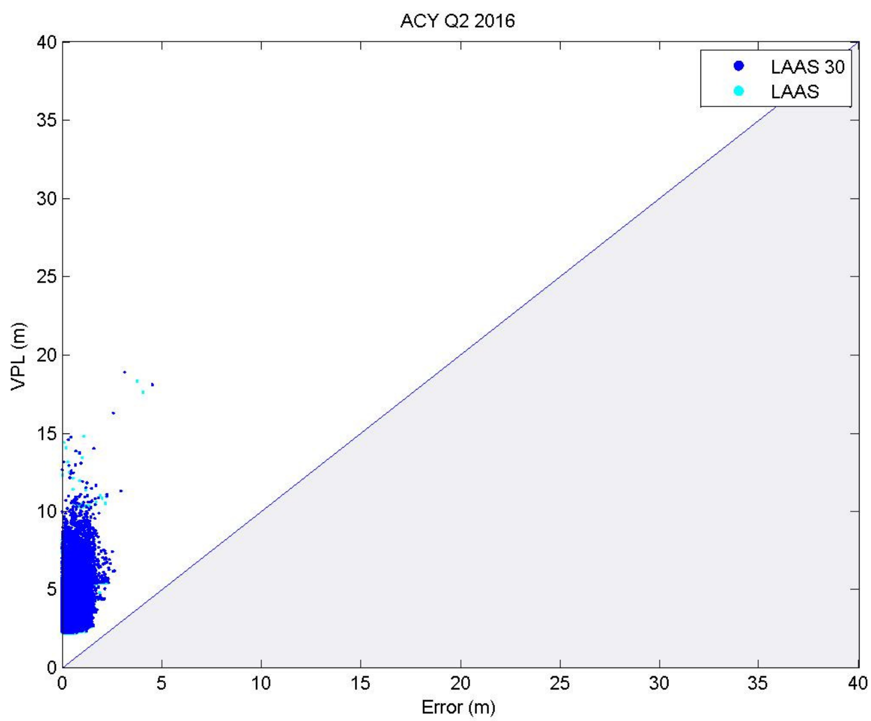


**Figure 29 - ACY SLS Vertical Protection Level vs. Error**

## 2.6 LTP ACY

- At the time of this reporting, the LTP is being used in limited capacity for testing purposes only.
- The LTP was used to broadcast the Undesired Signal during the VDB Interference Flight Testing at the FAA William J. Hughes Technical Center. The Flight Tests were ongoing starting on 04/05/2016 through 07/07/2016. See **Section 3.4** for additional details.
- See Appendix C for a full description of the LTP configuration.

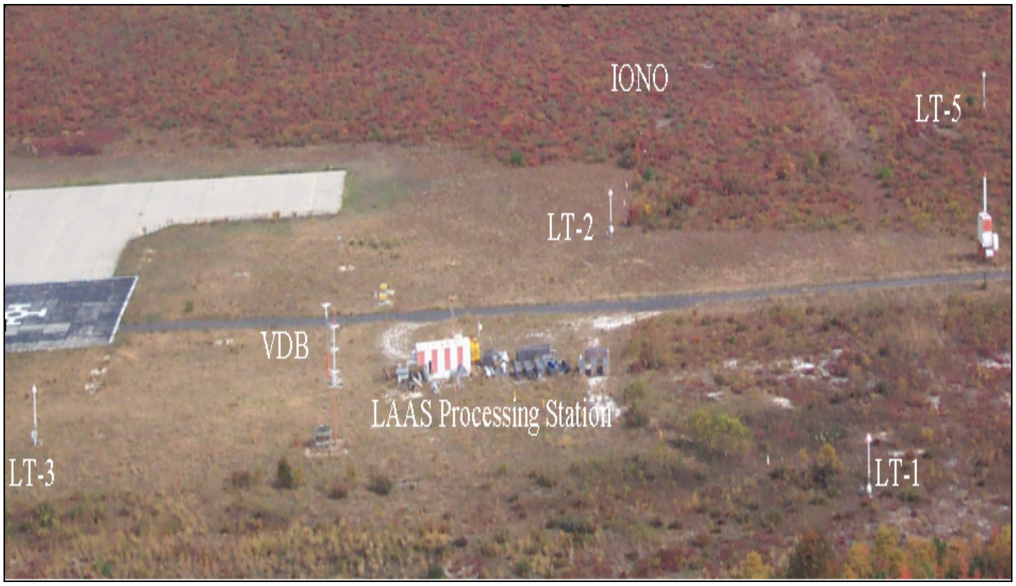


**Figure 30 - Aerial View of LTP Configuration**

# 3. Research, Development, and Testing Activities

## 3.1 GBAS GAST-D Validation Status Update

ANG-C32 has continued its efforts in supporting the ICAO Navigation Systems Panel (NSP) GBAS Working Group (GWG) Ionospheric Gradient Monitoring (IGM) Ad-Hoc teleconferences in support of final validation of the ICAO draft GAST-D SARPS this quarter. Papers prepared by the IGM ad-hoc group were presented at the GWG meeting in Montreal, Canada the week of June 1st. ANG-C32 led preparation of several working and information papers on threshold analysis for a proposed airborne DSIGMA monitor, monitor and time independence work, updates to SARPS guidance material, and a potential Monte Carlo simulation approach to completing validation in bubble threat regions. Details on current ICAO validation status can be found in the GWG meeting summary report in **Section 4.1**.

## 3.2 Honeywell SLS-4000 Block II

A system design approval letter for Honeywell's Block II update to their approved CAT-I capable system, the SLS-4000, was issued in October 2015. This update is expected to provide greater system availability in CONUS via updates to the Signal Deformation Monitor (SDM) that will allow use of PRNs 11 and 23 and thru finer multipath masking. These changes should alleviate the majority of brief service outages seen with the Block I version of the system. This update also allows for optional SBAS integration requiring a hardware update consisting of a WAAS-capable receiver and antenna. Use of SBAS for real-time ionospheric monitoring will allow the GBAS to not assume it's operating in a worst-case ionospheric environment at all times. This change should further increase system availability by lowering Protection Limit (PL) values. Honeywell also believes that use of the SBAS option could pave the way towards approval of auto-land and CAT-II capabilities. In addition, updates have been made to accommodate the system's use in low-latitude regions, though these updates will not be used in CONUS.

Operational approval of Block II updates at existing sites, Newark Liberty Int'l Airport (EWR) and George Bush Intercontinental Airport (IAH) will not be allowed until an MOA between the FAA and Honeywell Int'l to accommodate funding for FAA inspector training is finalized. This item is being actively worked.

## 3.3 System Design Approval (SDA) - Honeywell SLS-5000 (GAST-D)

Honeywell International (HI) is moving forward with efforts towards achieving System Design Approval (SDA) of their GAST-D capable GBAS ground system, the SLS-5000, in parallel with final efforts to validate the GAST-D SARPS requirements at ICAO. The ICAO GAST-D GBAS SARPS will be the approval basis for this system as no FAA non-Fed specification exists for the GAST-D system.

Weekly teleconferences are being held between HI and the FAA. These calls address program planning, status and schedule, and technical review of GPS monitoring algorithms and safety analysis documentation. Additional calls are added as necessary to cover special topics. The FAA has also started work on assembling the approval panel for the SLS-5000. This panel will be composed of personnel from all FAA stakeholder organizations and will address issues related to both final approval of the ground system and integration of the system into the NAS.

### *3.4 ILS Localizer and VDB Overflights at FAA William J. Hughes Technical Center*

ILS Localizer Overflights

Flight Tests were conducted in April 2016 at Atlantic City International Airport to measure GBAS VDB receiver performance on the overflight of an active ILS Localizer. Since the guidance for a GBAS approach terminates at the runway threshold the impact of the Localizer on VDB performance has not been considered. There is interest in the impact of overflying the Localizer if GBAS is used for guided departures. The VDB desired to undesired (D/U) signal ratio was determined and the performance of the VDB receiver was reviewed to determine ILS signal impact on VDB messages. The data collected for ACY determined that there was no impact from the Localizer to the VDB performance. The results of the flight tests are shown below in **Figure 31**. ILS and VDB data were collected during these flights; including overflights to the VDB antenna (see VDB Antenna Overflights).

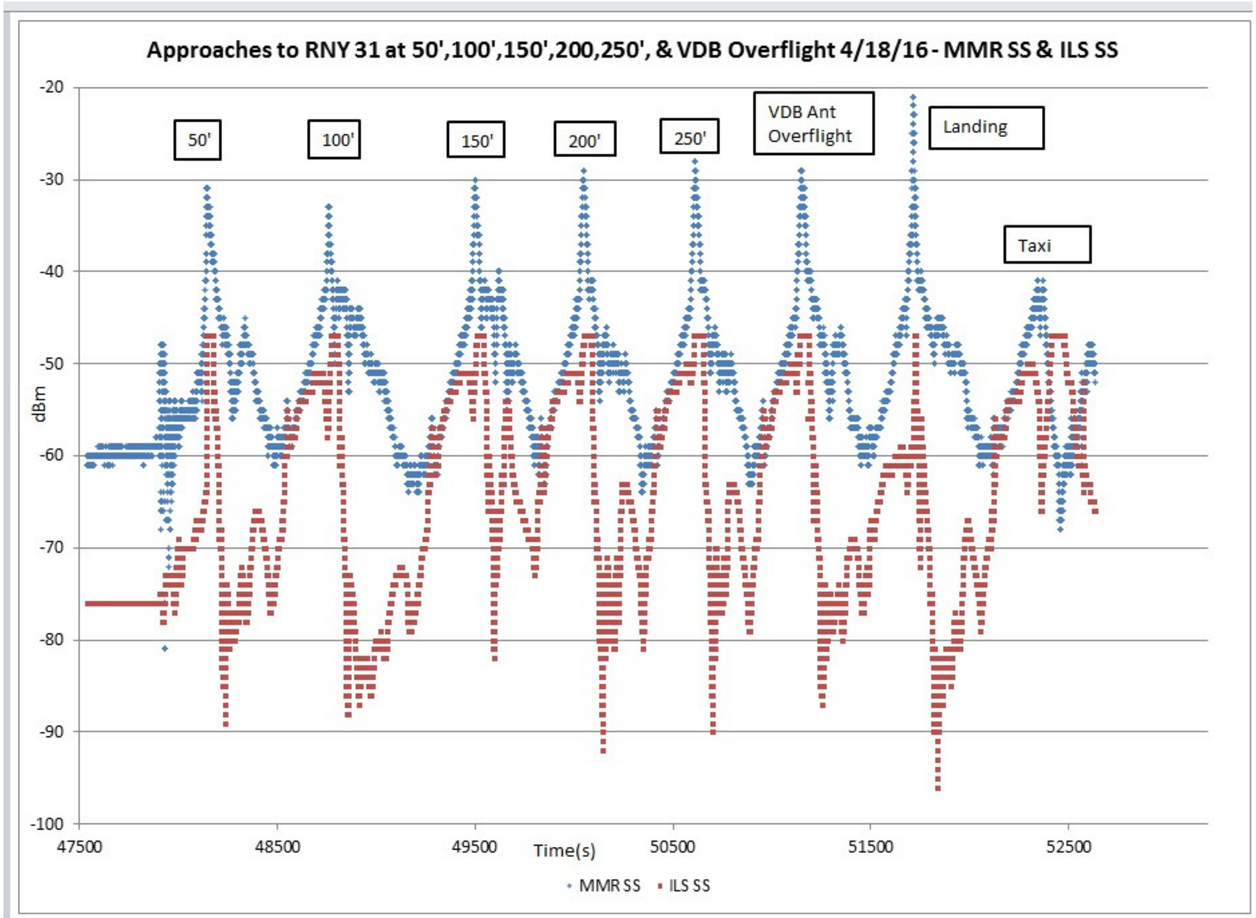


**Figure 31 - ILS Localizer Overflights at 50, 100, 150, 200, and 250 feet.**

VDB Antenna Overflights

Flights were conducted to determine the GBAS VDB signal strength above the VDB antenna and to determine if coverage was continuous during overflight. In theory there should be little useable VDB signal above the antenna but implementation of the design may be different than the theory. A total of eight overflights were made with four directly above and four slightly offset. The height above the VDB antenna ranged from 200 to 300 feet AGL. The data collected demonstrated that the VDB signal was sufficient to provide continuous VDB service during an overflight of the transmitting antenna. **Figure 32** below shows one such overflight of the VDB Antenna.

**Figure 32 - VDB Antenna Overflight, 250 feet AGL, 135 feet Off-set**

# 4. Constellation Conditions

## *4.1 Notice Advisory to Navstar Users (NANUs)*

The GPS constellation is designed to provide adequate coverage for the continental United States for the majority of the sidereal day. A NANU is a forecasted or reported event of GPS SV outages, and could cause concern if the SV outage(s) creates an insufficient geometry to keep the protection levels below the alert limits. See **Table 1** below for a list of NANU types.

NANUs that caused an interruption in service where Alert Limits are exceeded will be highlighted within the NANU summary (see **Table 2**). Although such an interruption is unlikely, the GBAS team closely tracks the NANUs in the event that post-data processing reveals a rise in key performance parameters.

| NANU Acronym | NANU Type | Description |
|---|---|---|
| FCSTDV | Forecast Delta-V | Satellite Vehicle is moved during this maintenance |
| FCSTMX | Forecast Maintenance | Scheduled outage time for Ion Pump Ops / software testing |
| FCSTEXTD | Forecast Extension | Extends a referenced “Until Further Notice” NANU |
| FCSTSUMM | Forecast Summary | Gives exact time of referenced NANU |
| FCSTCANC | Forecast Cancellation | Cancels a referenced NANU |
| FCSTRESCD | Forecast Rescheduled | Reschedules a referenced NANU |
| FCSTUUFN | Forecast Unusable Until Further Notice | Scheduled outage of indefinite duration |
| UNUSUFN | Unusable Until Further Notice | Unusable until further notice |
| UNUSABLE | Unusable | Closes an UNUSUFN NANU with exact outage times |
| UNUNOREF | Unusable with No Reference NANU | Resolved before UNUSUFN issued |
| USABINIT | Initially Usable | Set healthy for the first time |
| LEAPSEC | Leap Second | Impending leap second |
| GENERAL | General Message | General GPS information |
| LAUNCH | Launch | Recent GPS Launch |
| DECOM | Decommission | Removed From constellation |

**Table 1 - NANU Types and Definitions**

| NANU | TYPE | PRN | Start Date | Start Time (Zulu) | End Date | End Time (Zulu) |
|---|---|---|---|---|---|---|
| 2016027 | FCSTDV | 22 | 04/19/2016 | 1500 | 04/20/2016 | 1500 |
| 2016028 | FCSTSUMM | 22 | 04/19/2016 | 1509 | 04/19/2016 | 2209 |
| 2016029 | GENERAL | N/A | 04/19/2016 | 220 | N/A | N/A |
| 2016030 | FCSTDV | 32 | 05/19/2016 | 0850 | 05/19/2016 | 2050 |
| 2016031 | FCSTSUMM | 32 | 05/19/2016 | 0923 | 05/19/2016 | 1402 |
| 2016032 | FCSTDV | 02 | 05/26/2016 | 2300 | 05/27/2016 | 1100 |
| 2016033 | FCSTSUMM | 02 | 05/26/2016 | 2305 | 05/27/2016 | 0537 |
| 2016034 | FCSTDV | 05 | 06/23/2016 | 2235 | 06/24/2016 | 1035 |
| 2016035 | FCSTSUMM | 05 | 06/23/2016 | 2244 | 06/24/2016 | 0417 |

**Table 2 - NANU Summary**

# 5. Meetings and Conferences

## *5.1 ICAO Navigation Systems Panel GBAS Working Group (GWG)*

The ICAO Navigation Systems Panel GBAS Working Group (GWG) met in Montreal from May 31 to June 3. The primary subject of the meeting was the continuing work to complete validation of the GAST D GBAS SARPs. The main technical issue that still needs to complete validation is related to the mitigation of anomalous ionospheric gradients. The plan is to complete technical validation at the GWG meeting in August. Following are summaries of issues discussed at the meeting.

Ionospheric Gradient Monitoring

There was good progress towards completing validation of the GAST D SARPs regarding ionospheric gradient monitoring as documented in 9 working papers that were reviewed at the meeting. There is high confidence that validation will be complete by the August GWG meeting. Only a few relatively minor technical issues remain. The GWG agreed that the “wedge model”, representing a worst case assumption, is sufficient to close the validation activity for the SARPs. Work will continue in developing a plasma bubble threat model as well as a Monte Carlo statistical evaluation method. These will not be used as part of the formal SARPs validation.

VDB Compatibility

The GWG reviewed two papers concerning VDB compatibility and frequency planning. An RTCA ad-hoc group is developing a proposed MOPS change for rejection beyond the third adjacent channel. The latest results of SESAR frequency planning modeling were reviewed, which evaluated GBAS/ILS/VOR frequency compatibility. The results have indicated a high success rate in assigning GBAS frequencies for inter-airport scenarios. However, for intra-airport scenarios the results indicate that when there are D/U criteria for all frequency offsets, compatibility cannot be achieved. This may require compatibility between navaids at the same airport to be handled at the local level and not in internationally standardized criteria. This issue is continuing to be worked in coordination with the Spectrum Working Group and RTCA SC-159 WG 4.

VDB Siting

The VDB Siting ad-hoc group proposed additional SARPs guidance material for VDB siting. The primary intent of the guidance is related to maintaining the 80 meter distance restriction between the VDB and aircraft (to ensure compliance with maximum signal strength requirements).

GAST D Downgrade

Additional SARPs guidance material was proposed to describe how a GAST D ground subsystem would downgrade from GAST D to C. In addition, it was found there are several missing paragraph references in the GCID requirements. It was also noted that RTCA SC-159 Working Group 4 is working on a revision to DO-253C to require the airborne equipment to attempt to downgrade to GAST C when GAST D is no longer supported. There was general agreement to including the proposed guidance material and the changes to the SARPs.

Authentication and Multiple VDB Transmitters

The GWG reviewed two working papers regarding the use of multiple VDB transmitters and issues with the authentication requirements. An ad-hoc group was formed to review alternative approaches to addressing the issues. One of the issues is whether to allow for more than two VDB transmitters. The ad-hoc group will present a proposal at the August GWG meeting.

Extended Service Volume

The GWG agreed to continue work on development of standards associated with Extended Service Volume (ESV) Option 4, which proposes a decoupling of the precision approach service volume from the broadcast Dmax parameter. This change will achieve operational behavior more similar to ILS. The ESV ad-hoc group will not pursue other options at this time due to schedule limitations. Annex 10 changes to implement Option 4 will be proposed at the August GWG meeting.

Reference Receivers

A SARPs change was proposed to allow more flexibility in the use of alternate reference receivers. The GWG reviewed and accepted a revision to the change.

Ephemeris Bound

The GWG reviewed a proposed change to the ephemeris protection level bound requirements. The intention is to make the SARPs consistent with DO-253. The changes were accepted following some minor changes.

Interference

The GWG accepted in principle to include a requirement in the SARPs defining the interference mask for ground reference receivers. A revision of the proposal will be prepared for the August GWG meeting.

Sensitive Areas

Based on test results presented at the meeting and previous meetings the GWG discussed including SARPs guidance material indicating that GBAS does not require sensitive areas as does ILS. A small group was formed to review this and propose SARPs guidance material.

# Appendix A – GBAS Overview

## *A.1 GBAS Operational Overview*

A GBAS is a precision area navigation system with its primary function being a precision landing system. The GBAS provides this capability by augmenting the GPS with real-time broadcast differential corrections.

A GBAS ground station includes four GPS Reference Receivers (RR) / RR antenna (RRA) pairs, and a Very High Frequency (VHF) Data Broadcast (VDB) Transmitter Unit (VTU) feeding an Elliptically Polarized VDB antenna. These sets of equipment are installed on the airport property where a GBAS is intended to provide service. The LGF receives, decodes, and monitors GPS satellite pseudorange information and produces pseudorange correction (PRC) messages. To compute corrections, the ground facility compares each pseudorange measurement to the range measurement based on the survey location of the given RRA.

Once the corrections are computed, integrity checks are performed on the generated correction messages to ensure that the messages will not produce misleading information for the users. This correction message, along with required integrity parameters and approach path information, is then sent to the airborne GBAS user(s) using the VDB from the ground-based transmitter. The integrity checks and broadcast parameters are based on the LGF Specification, FAA-E-3017, and RTCA DO-253D (Airborne LAAS Minimum Operational Performance Standards or MOPS).

Airborne GBAS users receive the broadcast data and use it to compute standardized integrity results. When tuning the GBAS, the user also receives the approach path for navigation with integrity assured. The GBAS receiver applies corrections to GPS measurements and then computes ILS-like deviations relative to the uplinked path providing guidance to the pilot. Airborne integrity checks compare protection levels, computed via the integrity parameters, to alert levels. Protection levels were determined based on allowable error budgets. The horizontal alert limit is 40m and the vertical is 10m at the GAST-C decision height of 200m. If at any time the protection levels exceed the alert limits, calculated deviations are flagged and the approach becomes unavailable. With the current constellation horizontal protection levels are typically 2.3m and vertical protection levels are typically < 5m with resulting availability of 100%.

One key benefit of the GBAS, in contrast to traditional terrestrial navigation and landing systems (e.g., ILS, MLS, TLS), is that a single GBAS system can provide precision guidance to multiple runway ends, and users, simultaneously. Only the local RF environment limits this multiple runway capability. Where RF blockages exist, Auxiliary VDB Units (AVU) and antennas can be added to provide service to the additional runways.

**Figure 33** is provided as an illustration of GBAS operation with major subsystems, ranging sources, and aircraft user(s) represented.

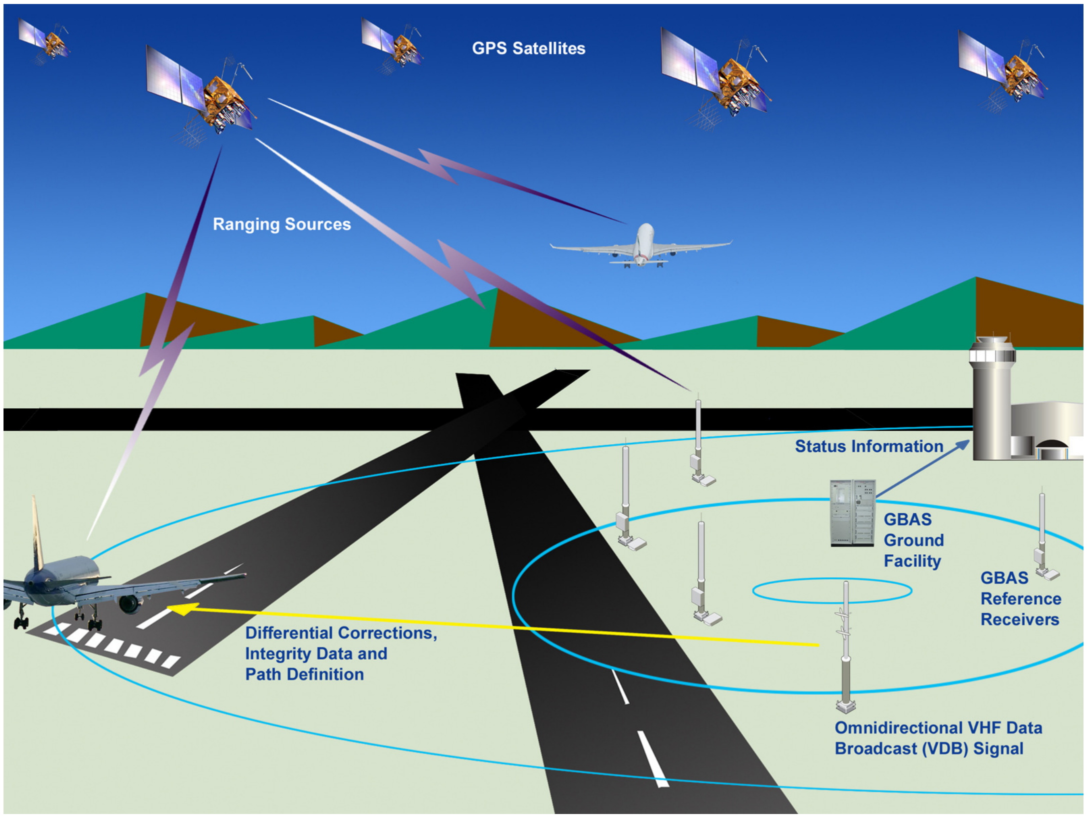


**Figure 33 – GBAS Architecture Diagram**

# Appendix B - GBAS Performance and Performance Type

## *B.1 Performance Parameters and Related Requirements Overview*

The GPS Standard Positioning Service (SPS), while accurate, is subject to error sources that degrade its positioning performance. These error sources include ground bounce multipath, ionospheric delay, and atmospheric (thermal) noise, among others. The SPS is therefore insufficient to provide the required accuracy, integrity, continuity, and availability demands of precision approach and landing navigation. A differential correction, with short baselines to the user(s), is suitable to provide precision guidance.

In addition to accuracy, there are failures of the SPS that are possible, which are not detected in sufficient time and can also cause hazardous misleading information (HMI). GBAS provides monitoring of the SPS signals with sufficient performance levels and time to alarm to prevent HMI.

The relatively short baselines between the user and the GBAS reference stations, as well as the custom hardware and software, is what sets GBAS apart from WAAS. Use of special DGPS quality hardware such as employment of MLA's serves to mitigate the multipath problems, while the GBAS software monitors and corrects for the majority of the remaining errors providing the local user a precision position solution.

The LAAS Ground Facility is required to monitor and transmit data for the calculation of protection parameters to the user. The GBAS specification also requires monitoring to mitigate Misleading Information (MI) that can be utilized in the position solution. These requirements allow the GBAS to meet the accuracy, integrity, availability, and continuity required for precision approach and landing navigation.

There are three Performance Types (PT) defined within the LAAS Minimum Aviation System Performance Standards (MASPS). The three performance types, also known as Categories, (i.e., Cat I, and Cat II/III), all have the same parameters but with different quantity constraints. For the purposes of this report, the LTP assumes Cat I Alert Limits and hardware classification.

## *B.2 Performance Parameters*

This section highlights the key parameters and related requirements used to depict GBAS system performance in this report. In order to provide the reader a clearer understanding of the plots provided, a little background is being provided below.

Cat I precision approach requirements for GBAS are often expressed in terms of Accuracy, Integrity, Availability, and Continuity. For clarity the use of these four terms, in the context of basic navigation, are briefly described below:

- **Accuracy -** is used to describe the correctness of the user position estimate that is being utilized.
- **Integrity** – is the ability of the system to generate a timely warning when system usage should be terminated.

- **Availability** - is used to describe the user's ability to access the system with the defined Accuracy and Integrity.
- **Continuity** - is used to describe the probability that an approach procedure can be conducted, start to finish, without interruption.

### *B.2.1 VPL and HPL*

Vertical and Horizontal Protection Levels (VPL and HPL) parameters are actively monitored since the GBAS is required to perform with a worst case constellation and geometry scenario. VPL / HPL parameters are directly tied to constellation geometry and when combined with pseudorange errors affect the SPS position estimate and time bias. Monitoring the VPL and HPL in the GBPM gives a valid picture of what the user is experiencing. The protection levels are compared against the alert limits of the appropriate GBAS service level (GSL). In the event the protection levels exceed the alert limit, an outage will occur (See section 6 for GBAS site specific outages).

### *B.2.2 B-Values*

B-values represent the uncorrectable errors found at each reference receiver. They are the difference between broadcasted pseudorange corrections and the corrections obtained excluding the specific reference receiver measurements. B-values indicate errors that are uncorrelated between RRs. Examples of such errors include multipath, receiver noise, and receiver failure.

### *B.2.3 Performance Analysis Reporting Method*

For a given configuration, the LTP's 24-hour data sets repeat performance, with little variation, over finite periods. The GBAS T&E team can make that statement due to the continual processing of raw LTP data and volume of legacy data that has been analyzed from the LTP by the FAA and academia. Constellation and environmental monitoring, in addition to active performance monitoring tools such as the web and lab resources provide the GBAS T&E team indications for closer investigation into the presence, or suspicion, of uncharacteristic performance.

Data sets from the LTP ground and monitoring stations are retrieved on a weekly basis and processed immediately. A representative data-day can then be drawn from the week of data to be formally processed. The resultant performance plots then serve as a snapshot of the LTP's performance for the given week. These weekly plots are afterward compared to adjacent weeks to select a monthly representative set of plots.

# Appendix C - LTP Configuration and Performance Monitoring

## *C.1 Processing Station*

The LTP Processing Station is an AOA-installed operational GBAS system. It is continually operational and is used for flight-testing, in addition to data collection and analysis summarized in this report. As an FAA test system, the LTP is utilized in limited modified configurations for various test and evaluation activities. This system is capable of excluding any single non-standard reference station configuration from the corrections broadcast. The performance reporting of the system is represented only from GBAS standard operating configurations.

### *C.1.1 Processing Station Hardware*

The processing station consists of an industrialized Central Processing Unit (CPU) configured with QNX (a UNIX-type real time OS). It then collects raw reference station GPS data messages while processing the data live. It also collects debugging files and special ASCII files utilized to generate the plots found in this report. These collected files are used for component and system level performance and simulation post processing.

The CPU is also configured with a serial card that communicates in real time with the four reference stations through a Lantronix UDS2100 serial-to-Ethernet converter. The reference stations continuously output raw GPS messages to the CPU at a frequency of 2 Hz. Data to and from the reference station fiber lines is run through media converters (fiber to/from copper). The CPU then generates the GBAS corrections and integrity information and outputs them to the VDB.

The VDB Transmitter Unit (VTU) is capable of output of 80 watts and employs a TDMA output structure that allows for the addition of auxiliary VDBs (up to three additional) on the same frequency for coverage to terrestrially or structure blocked areas. The LTP's VTU is tuned to 112.125 MHz and its output is run through a band pass and then through two cascaded tuned can filters. The filtered output is then fed to an elliptically polarized three bay VHF antenna capable of reliably broadcasting correction data the required 23 nautical miles (see Protection Level Maps at http://laas.tc.faa.gov for graphical representation).

Surge and back-up power protection is present on all active processing station components.

### *C.1.2 Processing Station Software*

Ohio University (OU) originally developed the GBAS code through an FAA research grant. Once the code reached a minimum of maturity, OU tested and then furnished the code to the FAA (circa 1996). It was developed using the C programming language under the QNX operating system. QNX was chosen because of its high reliability and real-time processing capability. This LTP code has been maintained by the GBAS T&E team since that time and has undergone numerous updates to incorporate evolving requirements, such as the inclusion of Cat III.

The software stores the precise survey data of the four GBAS reference station antennas (all RRA segments). Raw GPS data (i.e., range and ephemeris info) is received via four GPS receivers. The program cycles through the serial buffers and checks for messages, if one is found, it gets passed to a decoding function. From there, it is parsed out to functions according to message type and the information from the messages is extracted into local LTP variables. Once the system has received sufficient messages, the satellite positions are calculated in relation to the individual reference receivers. Type 1, 2, 4, 11 messages containing differential corrections, integrity values, GS information, and approach path data are then encoded and sent to the VDB via a RS-232 connection. Each of the four message types are encoded separately and sent according to DO-246D standards.

### *C.2 Reference Stations*

There are four reference stations included in the FAA's LTP as required in the GBAS specification. The LTP's reference stations are identified as LAAS Test (LT) sites; there were originally five LT sites (LT1 through LT5), excluding LT4. LT4 was originally used for the L1/L2 site (**Figure 34**).

Each reference station consists of two major component systems. The first is a high quality, GNSS antenna (ARL-1900) manufactured by BAE Systems. The second is the reference receiver.

**Figure 34 - The BAE GNSS Multipath Limiting Antenna (MLA)**

#### *C.2.1 The BAE ARL-1900 GNSS Multipath Limiting Antenna (MLA)*

The BAE Systems ARL-1900 is an innovative, single feed, GNSS antenna that is approximately 6 feet high, and weighs about 35 pounds. The receiving elements are configured in an array, and when combined allow reception of the entire GNSS (Global Navigation Satellite System) band. This antenna is also capable of the high multipath rejection as required by the LAAS specification.

Multipath is a phenomenon common to all Radio Frequency (RF) signals and is of particular concern in relation to DGPS survey and navigation. It is simply a reflection of a primary signal that arrives at a user's equipment at a later time, creating a delay signal that can distort the primary if the reflection is strong. Reflected multipath is the bouncing of the signal on any number of objects including the local water table. Signals that reflect off the earth surface are often referred to as ground-bounce multipath. In all cases, the path length is increased. This path length is critical in GPS since the ranging is based on the signal's Time of Arrival (TOA). This causes a pseudorange error, for the SV being tracked, proportional to the signal strength. The BAE provides at least 23 dB of direct to indirect (up/down) pattern isolation above 5 degrees elevation. These multipath induced pseudorange errors can translate directly into a differential GPS position solution, which would be detrimental to applications such as GBAS. Multipath limiting antennas, such as the BAE Systems ARL-1900, were therefore developed to address the multipath threat to differential GPS and attenuate the ground multipath reducing the error. The ARL-1900 antenna characteristics also mitigate specular reflections from objects. The antenna's polarization (right hand circular polarized, or RHCP), provides a pattern advantage and reflective LHCP signals, which is left hand circular polarized.

## Appendix D - GBPM Configuration

The Ground Based Performance Monitor is the primary performance monitoring tool for the LTP and the Honeywell SLS-4000 systems. The system uses the received VDB broadcast type 1, 2, 4, and 11 messages from the ground station being monitored along with raw GPS data in order to compute the position of the monitor station. The position calculated from this data is compared to the position of the precision-surveyed GBAS grade GPS antenna, which is used to identify positioning errors.

The GBPM's Novatel OEM-V receiver logs range and ephemeris messages, which provide the necessary pseudorange and carrier phase measurements, as well as satellite position information. VDL messages are then received and separated into each of the DO-246D GBAS message types and decoded.

Data is collected in 24-hour intervals and saved to a .raw file without interruption. This data is used to post-evaluate system performance. In addition to the raw file, live data is transferred from each offsite monitor once per minute to our local database. Users can then access the data through an interactive website by means of tables, charts, and graphs hosted by the Navigation Branch at the FAA. The web address for this service is http://laas.tc.faa.gov.

Analysis of GBPM data is critical for closely observing the LTP and SLS performance behavior. The GBPM data output package contains several plots that can quickly illustrate the overall performance picture of the GBAS. The most useful plots available for performance summary purposes are *Vertical and Horizontal User Error versus Time*. These two plots are often used for preview performance analysis because the "user" GPS sensor position is known and stationary. The known position (precision survey) of the GBPM GPS sensor is compared directly to the computed user position. Typical LTP Vertical and Horizontal user error has an average well within the +/- 1-meter range.

**Figure 35** is one of the GBPM's that was built by the Navigation Branch. Some of the major components include a retractable KVM to check the current status of the monitor, CISCO router with a T1 line back to our lab at ACY for data collection and maintenance, Power Distribution Unit (PDU) for a means remote access to bring power outlets back up if they become unresponsive, Novatel GPS Receiver, Becker VDB Receiver, QNX CPU, and an uninterruptable power supply.

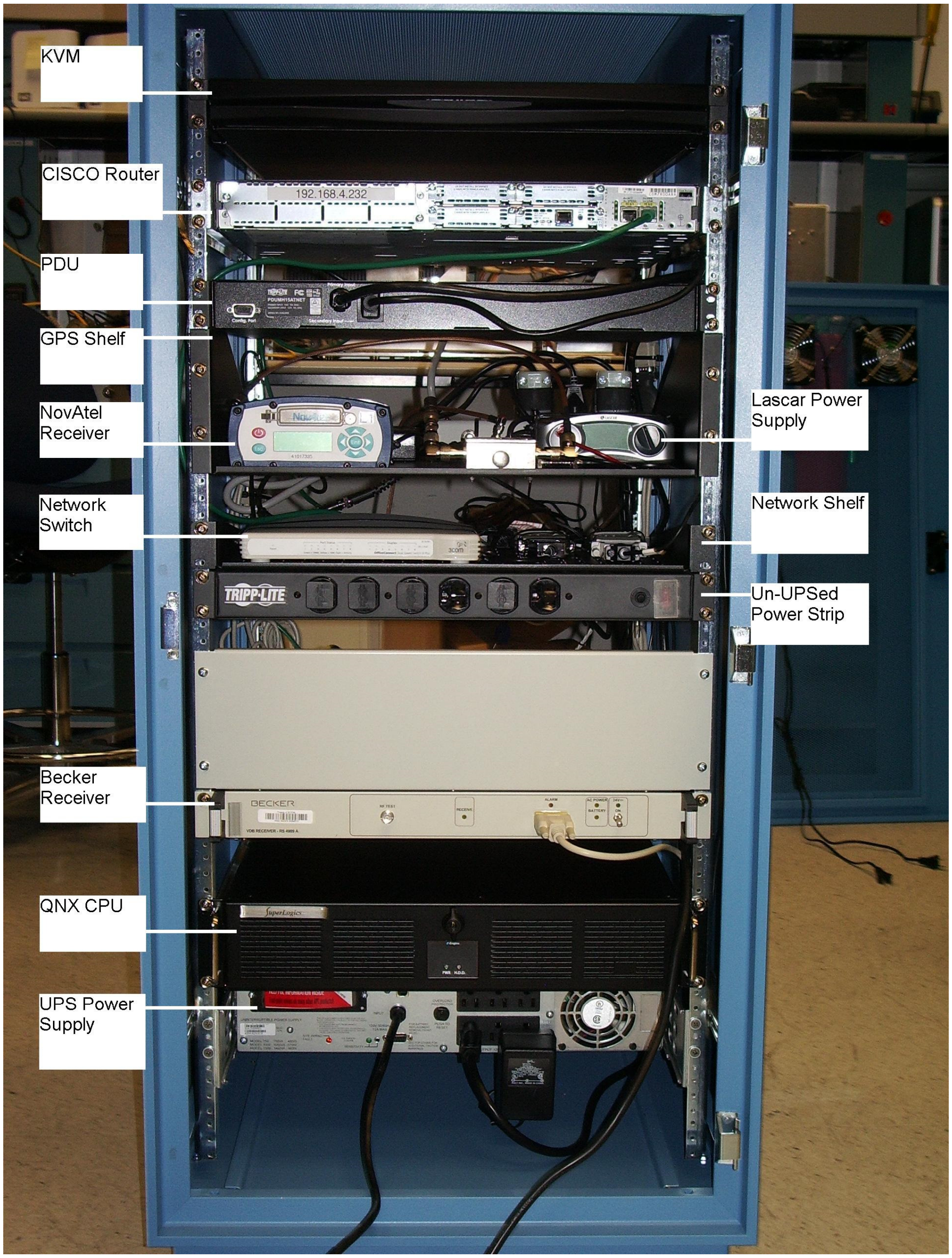


**Figure 35 - Ground Based Performance Monitor (GBPM)**

**Glossary of Terms**

## Index of Tables and Figures

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