Effect of a GPS Anomaly on Different GNSS Receivers

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BIOGRAPHY

Anne-Laure Vogel graduated as an electronics engineer from ENAC, Toulouse, in 2003. She has been working for two years in SOFREAVIA (Toulouse) for DSNA/DTI, the French air traffic service provider, especially on EGNOS performance and operational implementation of NPA/GPS and APV approaches.

Christophe Macabiau graduated as an electronics engineer in 1992 from ENAC (Ecole Nationale de l'Aviation Civile) in Toulouse, France. Since 1994, he has been working on the application of satellite navigation techniques to civil aviation. He received his Ph.D. in 1997 and has been in charge of the signal processing lab of the ENAC since 2000.

Norbert Suard is an Engineering Expert in the CNES Navigation System Division where he has over 15 years of experience in development, studies, performances analysis of navigation system augmentation like CE-GPS, EURIDIS, ESTB and now EGNOS.

ABSTRACT

On January 1st 2004, a GPS clock failure occurred suddenly onboard the GPS satellite PRN23 at around 18:30 UTC with the signal being transmitted for hours after that. The Unhealthy flag of its navigation message, used by the receivers to discard its measurements from the navigation position computation, was raised a few hours after the occurrence of this event.

It was observed that the estimated user position was impacted in different manners depending on the different technology/firmware embedded in the receivers, and on the integrity monitoring information available to the receiver.

Indeed, depending on the technology/ firmware used to track the signals and produce the raw measurements from the received GPS signal, the measurements and thus the position is affected differently.

The integrity monitoring mechanism, depending on whether the receiver is GPS only, RAIM or SBAS for example also has an influence. For SBAS receivers, the reaction with WAAS and ESTB (the EGNOS demonstrator) was analyzed. The behavior of GPS only and RAIM receivers was also studied thanks to real data and was replayed using a signal generation tool.

Following our investigation of these different observations, and using the information given on the onboard failure, this type of event was characterized and a simulation scenario using a GPS signal generator has been defined. This scenario will be used to reproduce both satellite effect and receiver behavior in order to test the reaction of other different receiver technology in front of the same event. The resulting behaviors of the receivers are in line with the actual observations made by three receivers on Jan 1st, and the failure has been tested successfully using a Septentrio receiver. So this simulation can be used as a benchmark for receiver validation or prediction of its behavior.

This paper starts with the presentation of the actual observations made with GPS only, SBAS and RAIM receivers. Then, we show results of the investigation carried out to understand the effect of the failure on different receivers and more particularly on Novatel OEM3 and OEM4. Next, we present the simulation results obtained for the same two types of receivers. Then, we present the results obtained with an other type of receivers. Following this, we discuss the work that now can be done on EGNOS system behavior. Finally, we propose a conclusion on the reuse of the simulation scenario.

1. INTRODUCTION

An important anomaly of the GPS system occurred on January 1, 2004, starting at around 18h30 UTC, and affecting time and position estimates on a very wide zone illustrated in figure 1.

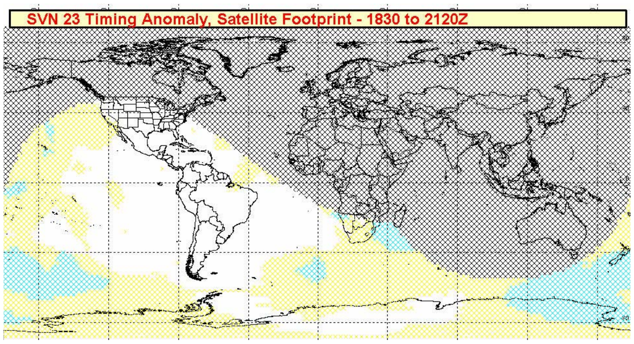

Figure 1: Affected area shown in gray [RD1]

This anomaly was due to a failure of the atomic clock system on the satellite PRN 23. The satellite PRN 23 was declared unusable at 21h18 UTC through transmission of the corresponding SV Unhealthy flag in its navigation message. This failure induced very important errors on the pseudo-range of the satellite 23 as depicted in figure 2.

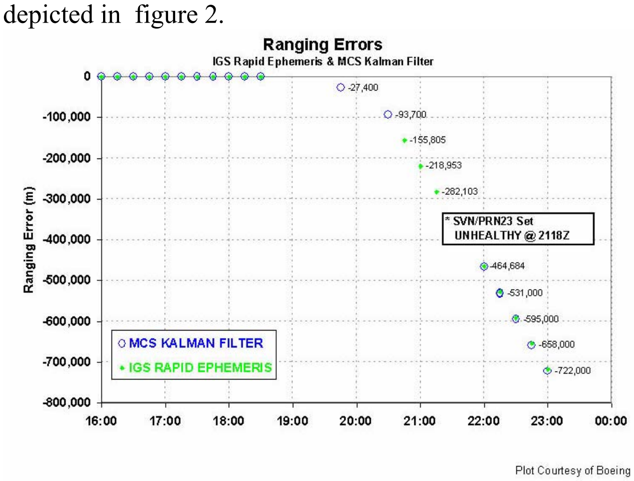

Figure 2: Pseudo-range error on the PRN 23 [RD1]

In this paper, several sections report different analyses that deal with :

- the impact of this failure on receivers without integrity, as well as the behavior of a standard RAIM algorithm and the way in which a SBAS responded to the failure;
- the signature of the failure as its impact on the received pseudo-range in order to perform simulations with the receivers previously analyzed;
- the behavior of other types of receivers that were submitted to the scenario reproducing the failure;
- the future work and the possible reuse of the simulation scenario.

2. ACTUAL OBSERVATIONS MADE WITH GPS ONLY, RAIM AND SBAS RECEIVERS

The data from several receivers installed at Toulouse in different premises (DSNA/DTI/SO/3, IGN, CNES, Alcatel) were analyzed. In addition, the data of the receivers used in the ESTB RIMS network or in the Eurocontrol Data Collection Network were also analyzed to consolidate the observations. Detailed analyses can be found in [RD2], [RD3] [RD4].

As a support to these analyses, different tools were used to make cross-correlation of the results :

- the analysis function of the tool AREOPAGE Mk2 developed by the DSNA/DTI/SO/3 (French ATSP).
- some functions of the EGNOS Performances Observatory (EPO) toolkit developed by CNES
- different functions of PEGASUS tool developed under Eurocontrol contract.

2.1. Behavior of standalone GPS receivers

2.1.1. Behavior of the NOVATEL OEM3(DSNA) :

Starting from 18h29min53s (that is to say 412193 sec. in GPS time), we note that the horizontal and vertical position errors increase quickly to 150m as shown on figure 3. These values are in conformity with those observed by CNES [RD 3].

Approximately 200 seconds after the appearance of the incident (GPS time 412409s), the receiver provides positions with horizontal and vertical errors becoming again normal. It seems that the receiver fails to track the satellite 23.

For receivers which succeeded in tracking the satellite 23 and incorporated its measurements in the position solution, it was noted very important position errors (several kms) as reported here after.

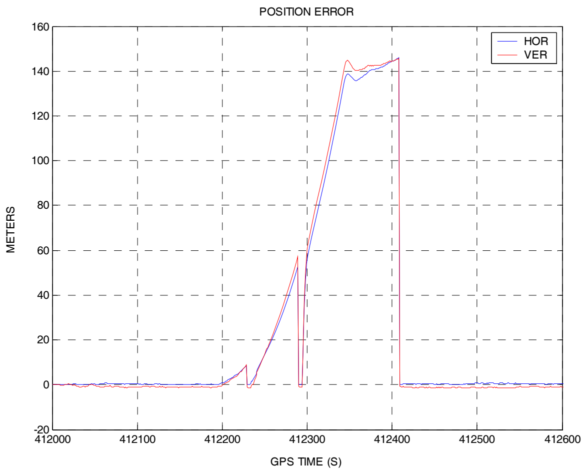

Figure 3: Horizontal and vertical position error from 18h26min40s to 18h36min40s (GPS time)

2.1.2. Behavior of the LEICA RS500 - IGN :

On the site of Toulouse, the PRN 23 was visible the day of the failure above the horizon until 20h30min UTC approximately.

We present in this section the analysis of 4 hours data starting at 18h00min UTC recovered on the ftp site of the Permanent GPS Network (RGP) of the IGN for the site of Toulouse (Météo France). Figure 4 shows the latitude, longitude, altitude and horizontal position errors of this receiver over these hours (magenta curve).

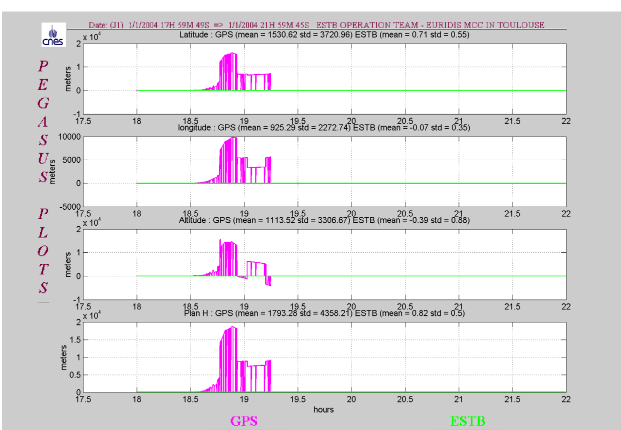

Figure 4: Latitude, Longitude, Altitude and Horizontal errors from 18h00 to 22h00 UTC

In this case, as the receiver of the IGN station continued tracking the satellite 23, we observe positioning errors of several km.

Looking at the data, it can be noted that the number of tracked satellites changes very often. That is due to the satellite PRN 23 signal being tracked with difficulty by the receiver.

At 19h15min UTC, the receiver of the IGN station stopped to deliver PRN 23 measurements and position estimates became correct again. It is also the same phenomenon that occurred for the majority of the permanent GPS reference stations.

2.1.3. Behavior of the Novatel OEM4 - CNES :

Data is not plotted here, but it was demonstrated that even if the technology is partly different from the OEM3 model, the main observation was identical: drift on the pseudo-range measurement and first loss of PRN23 tracking occurring at epoch 412229s. This receiver was able to re-lock on and off the PRN23 during some minutes, till epoch 412408s, and then definitively loses track of the PRN 23 signal.

2.1.4. Synthesis

For a receiver without GNSS integrity monitoring information, the positioning error due to the failure of PRN 23 could reach several kms. It has also been noted that for the different Novatel OEM3 receivers, PRN23 tracking was lost at the same epoch (412229s) at different locations spread over Europe or Africa [RD3] [RD4].

2.2. Behavior of a RAIM receiver

The behavior of a RAIM receiver was simulated thanks to the analysis function of the tool AREOPAGE Mk2.

Indeed, on top of the position calculation, a RAIM detection criterion computation is carried out, tuned with the NPA requirements, which thus makes it possible to distinguish the acceptable from the unacceptable drifts for that phase of flight for a supplemental GPS receiver.

Starting from 18h31min43s (412303s), the flag of RAIM integrity is activated. At this time, the altitude error reached 54 meters and the horizontal error 45 meters (values obtained using the analysis tool).

On the following figure, the graph on the left-hand side gives information on the observed RAIM availability obtained by comparing the HPL (Horizontal Protection Level) with the NPA HAL (Horizontal Alert Limit):

- when the value is 0, the RAIM is available,
- when the value passes to 1, there is a RAIM unavailability.

The graph on the right-hand side gives information on RAIM integrity:

- when the value is -1, that means that there is a RAIM unavailability and thus no calculation of detection of non-integrity is carried out,
- when the value is 0, no non-integrity is detected,
- when the value jumps to 1, that means a RAIM detection of non-integrity.

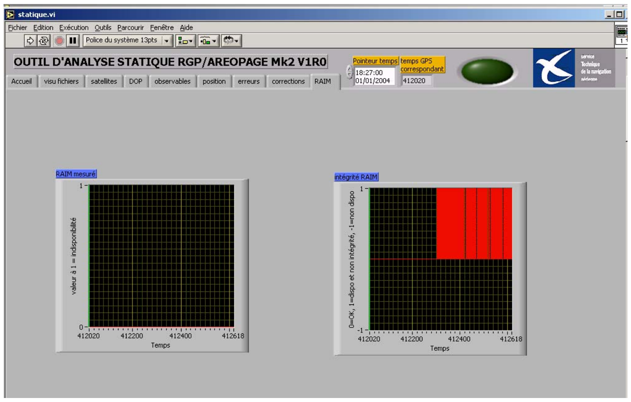

Figure 5: « RAIM » functionality from 18h27 to 18h37 – GPS time

Synthesis

The RAIM detection criterion which is calculated by AREOPAGE Mk2 and which emulates the RAIM of a standard supplemental TSO C129 receiver, such as necessary for NPA-GPS (LNAV) approaches, detected the failure as soon as the error reached a too large value, 110 seconds after the beginning of the failure in that case.

The behavior of the RAIM was completely in agreement with the requirements expected for this type of GNSS augmentation.

2.3. Behavior of a SBAS receiver

These investigations were carried out by CNES using PEGASUS and EPO tools [RD3], [RD5].

2.3.1. ESTB performance [RD3]

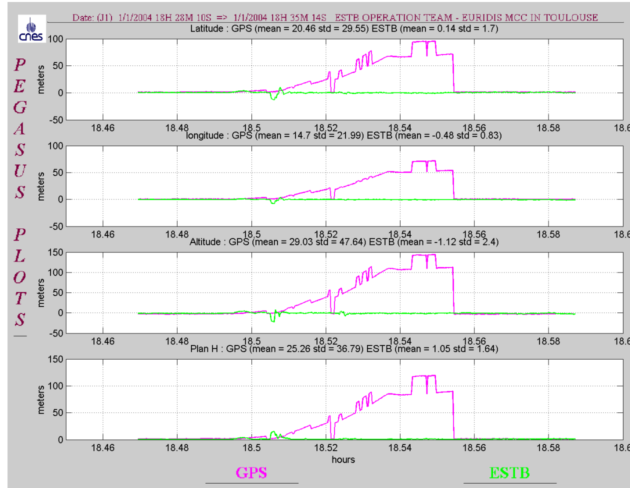

Figure 6: Positions errors (Lat, Lon, V, H) observed with ESTB (green) and GPS only (magenta) functions.

The receivers using ESTB also underwent drifts of position when the failure appeared. These errors reached a maximum of 15m in horizontal and 25m in vertical and only lasted less than 5 seconds, then the PRN23 was excluded in the internal ESTB time reference. These errors are definitely lower than those of standalone GPS receivers. Moreover, the satellite PRN23 was excluded by the ESTB system at 412228s (35 seconds after beginning of the failure).

Two significant points can be identified :

- Some rare losses of integrity, MI type, were noted for APV applications, but they are due to the algorithm of calculation of ESTB time (ENT) and to the deduction of the fast corrections (Fast PRC). This phenomenon had already been reported to ESA and industry before this event. This algorithm is designed differently for EGNOS, therefore this problem is not expected on EGNOS. Let us recall indeed that the losses of integrity MI type are not considered to be dangerous for a user by standard ICAO (they reveal that integrity boundaries xPL did not limit the error of position, but the error of position remained under the alarm value) and that ESTB was not conceived to treat this type of event.

- As also noted on RGP receivers (see figure 4 paragraph 2.1), the RIMS tracked the satellite PRN23 with difficulty, involving the generation of an indicator "NOT MONITORED" instead of an indicator "DON' T USE". It is possible that the instability of the PRN 23 signal led the ESTB to flag this satellite as not monitored, masking the effect of the failure. It is thus interesting to lead investigations more refined to check the exact behavior of the receiver of the RIMS Novatel OEM3. In any event, an ESTB user will have excluded the satellite 23 through the "NOT MONITORED" flag received.

2.3.2. WAAS performance [RD2]

The remarkable points are :

- First of all, there was no loss of integrity related to the algorithm of calculation of time;
- As for ESTB, a flag "NOT MONITORED" was sent instead of "DON' T USE", as we could a priori have expected. But as discussed for the ESTB, this behavior is perhaps normal taking into account the obvious difficulty of the receivers to track this satellite. This flag was repeated 4 times by WAAS as for an alert sequence;
- ESTB and WAAS forced the PRN23 to be excluded from the user's solution in accordance with their reaction time (Time to Alarm) (recall : 6 sec for WAAS/EGNOS, 10 sec for ESTB);
- Finally, in the case of the WAAS, information was broadcast to users by sending four successive MT3 which provides a guarantee on the reception of at least one of these messages for the user. On the other hand, this could also cause an exceeding of the maximum time-to-refresh of the UDREs for some satellites compared to the specifications of the MOPS 229C as permitted in case of alarm.

2.3.3. Synthesis

The ESTB and the WAAS had more or less a similar behavior and in conformity with the requirements of ICAO.

It has to be noted that a DON'T USE flag was expected instead of a NOT MONITORED one, but this can be explained by the fact that the satellite was excluded by both system before DON'T USE limit (Fast Corrections > 256m).

2.4. Section Conclusion

In this first section, we presented the result of investigations done with GPS only, RAIM and SBAS receiver measurements during the failure of GPS satellite PRN 23 of January 1, 2004. That failure induced a drift of SV clock which lasted about three hours before being detected by the control segment of the GPS.

The principal conclusions are the following :

The GPS receivers which do not have integrity monitoring such as defined in ICAO ABAS, SBAS and GBAS standards underwent, to differing degrees, drifts of position and times which could grow very large with the progressive evolution of the drift of clock.

The behavior of ABAS algorithm such as RAIM was analyzed thanks to the analysis function of the tool AREOPAGE, which emulates the RAIM of a standard supplemental TSO C129 receiver such as necessary for NPA-GPS approaches. This behavior was completely in agreement with the requirements expected for this type of GNSS augmentation (exclusion not more than 10 s after horizontal position error is larger than 0.3 Nm).

SBAS systems of type ESTB (prototype of EGNOS) and WAAS had a very close behavior. In particular, ESTB and WAAS users quickly excluded the satellite PRN23, in conformity with ICAO requirements for APV operations. The significant points to note concern :

- the broadcast of "NOT MONITORED" flag in place of "DON' T USE" flag as one could have expected, but it seems that this behavior is primarily related to the difficulty for the receivers to track the PRN 23 which was noted in the first part of the study.
- in the case of the WAAS, information was broadcast through the transmission of four successive messages type 3 against only one for the ESTB, with probably the intention to improve the chances of reception of at least one of these messages for the users as done in case of alarm condition.

3. FAILURE SIGNATURE AND GENERATOR SCENARIO DEFINITION

In order to test the reaction of different receiver technologies in front of this type of failure, the failure effects were first characterized in order to define a replay scenario.

3.1 Characterization of the failure:

As presented in the sections above, we observed that PRN 23 failure is a clock failure. That type of failure is traditionally associated with a drift of the pseudorange measurements made by all receivers tracking that failing satellite. This drift is usually modeled as a first order additional ramp appearing on the pseudorange measurement. However, that type of ramp usually is not assumed to induce any loss of lock. Our goal in this section is to try to determine what was the effect of the failure on the measurements, mainly in order to understand why some losses of lock occurred.

To investigate this, we started with raw receivers data containing the status of the tracking loops. This was available to us through the Eurocontrol Data Collection Network. Then, we went to search for data of receivers that managed to track successfully PRN23 signal during the failure. This was available to us on the IGS data servers.

Eurocontrol has setup in 2004 a data collection and analysis network comprising several stations across Europe. The data from 3 NOVATEL OEM3 receivers in that network were analyzed in depth. The main element that was searched for was the status of the tracking loops of the PRN 23 tracking channel to better understand why lock was lost approximately 30s after the beginning of the clock failure.

Figure 7 is an illustration of the status of the L1 PRN 23 tracking loops, and of the achieved association of L1 and L2 tracking loops during 100 seconds over the time period 412200s…412300s. That time period is an interval situated about 7 seconds after the beginning of the SV clock failure, and includes a period where most OEM3 receivers lost lock twice.

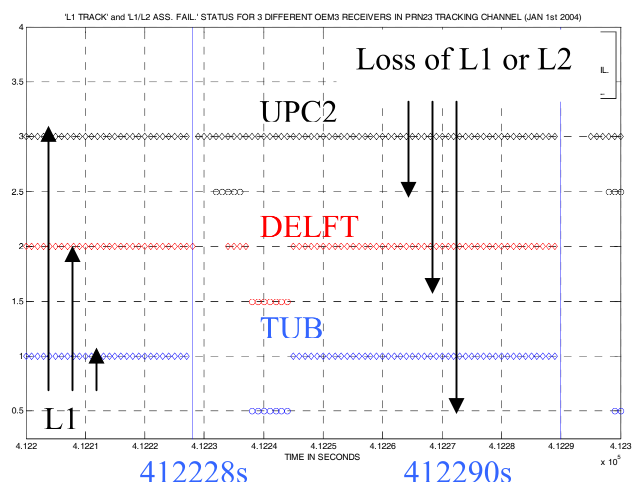

Figure 7: PRN23 tracking status for 3 different OEM3 receivers (TUB, DELFT, UPC2).

As we can see in this figure, TUB and UPC2 receivers lose lock at the exact same time, which is 412228s. DELFT receiver loses lock one second later, at 412229s. Then, UPC2 receiver re-locks on the signal the second after. DELFT receiver regains lock 5 seconds later at 412234s, to lose lock again at 412238s for 6 seconds. TUB receiver regains lock very late, at 412245s.

Then later, at 412290s, all three receivers lose lock at the exact same time.

The main events of these observations are the loss of lock at 412228s, then the loss of lock at 412290s, that both occur at the exact same time +/- 1s for all OEM3 we could analyze.

It is also interesting to note again the wide variety of behaviors of the different receivers after their loss of lock, although they were all OEM3 receivers. This can be explained by different firmware versions being run by the receivers themselves, as well as by different environmental conditions for these receivers, like noise and multipath effect at that time, but also like the number of satellites being tracked by the receiver at that time.

Generally speaking, as the observed loss of lock is detrimental for a network of ground monitoring receivers that is supposed to inform users on SIS non-integrities, we tried to determine what was the reason for these losses of lock. We suspected something in the radiated signal was not inducing a simple ramp on the range measurements, as these ramps are usually easy to track for a GPS receiver, provided their slope is reasonable. We thus went to look for data from receivers that managed to track the PRN23 signal on Jan. 1st 2004.

This data was found in the IGS GPS data servers, and we used these measurements to determine the effect on the range measurements, then to re-create that effect using a GPS signal generator.

To create the scenario to reproduce the failure of the PRN23 clock, data without any loss of tracking of the PRN23 were found : data from Villafranca and Maspalomas (Spain), recorded by IGS with an Ashtech Z-XII3 receiver having a Cesium atomic clock, were used.

The signature of the failure is indeed retrieved by comparing the recorded pseudorange in Villafranca / Maspalomas to the simulated one without any failure using the SPIRENT GPS signal generator.

The signature of the failure in each case is shown in figure 8:

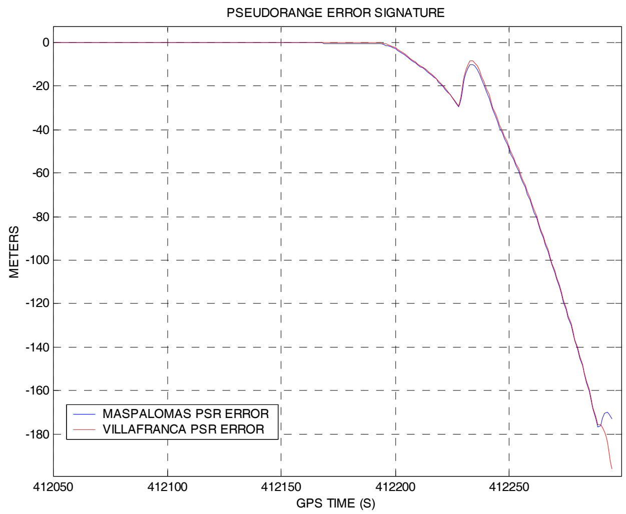

Figure 8: Pseudorange error signature.

This figure shows that most of the receivers lose PRN23 at GPS time 412228s (or 412229s depending on the type of receiver) on the first of January 2004. It could explain that the SBAS sent a “Not Monitored” flag instead of a “Don’t Use” one, as the ground station receivers also lost lock. At the beginning of the failure, the slope of the pseudorange error does not explain a loss of tracking. But at 412228s, a real discontinuity in the slope (as shown on the two following figures representing the first and second order derivative) made it very difficult to track PRN23 any longer. Some receivers, as the ones used to characterize this failure, succeeded in tracking PRN23 during this discontinuity. At this moment, we can’t explain why these receivers didn’t lose PRN23.

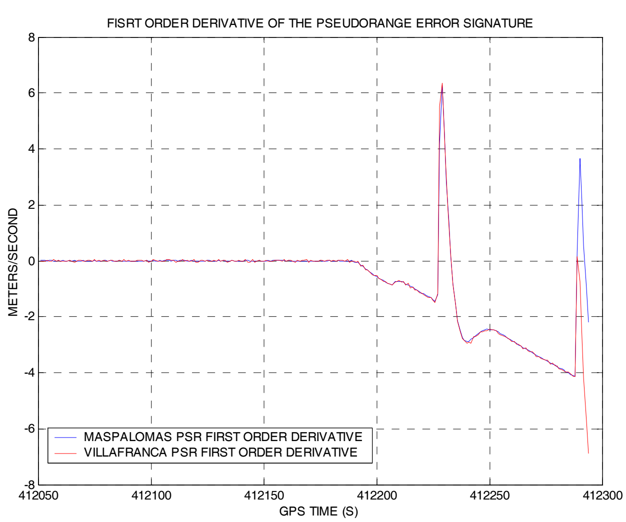

Figure 9: First order derivative of the pseudorange error signature.

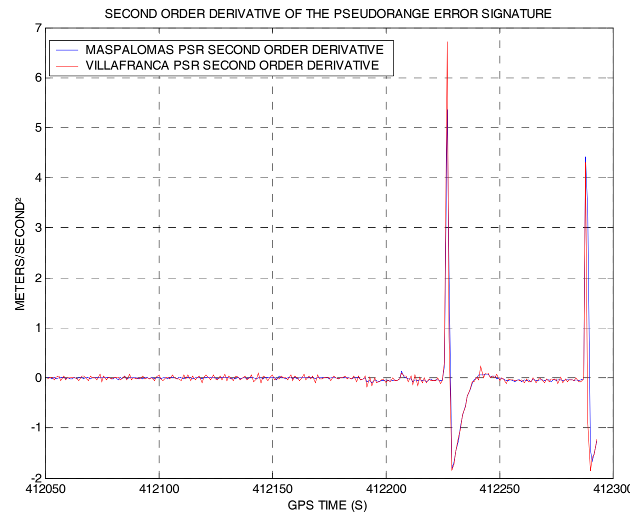

Figure 10: Second order derivative of the pseudorange error signature .

On the previous figures, two impulsions in the slope are visible. But the second one does not present exactly the same shape if we look at data coming from Villafranca or Maspalomas. In fact, the receiver in Maspalomas lost PRN23 tracking just after the second slope discontinuity and the PRN23 pseudorange could therefore have been affected in a different manner. That is why we focused our attention on the first slope discontinuity.

3.2. Simulation scenario definition

In the previous section, we presented the impact of the clock failure on the PRN23 pseudorange. Analyzing PRN23 pseudorange when all data were available permitted to retrieve the error shape that has to be introduced on the PRN23 pseudorange simulation scenario for the GPS signal simulator (either a SPIRENT STR4760 or a STR4500, having the same characteristic).

Retrieving the shape of the pseudorange received took a long time because the impact of the receiver makes the observed pseudorange rather different from the received one.

After having tried different scenarios with introduction of different shapes of pseudorange errors, with or without a stop of signal emission, the best failure generated was a ramp on the pseudorange combined with a strong jump (about 30 meters in 4 seconds) without any stop in the emission as shown on the next figures (11 and 12).

4. RESULTS OF GENERATOR SCENARIO REPLAY

Different receivers were connected to the SPIRENT simulator running the scenario defined to reproduce the PRN 23 clock failure.

4.1. Behavior of a Novatel OEM3

On the first of January 2004, a Novatel OEM3 was recording data in the DSNA/DTI laboratory as already mentioned. Using the shape of the failure presented in the previous section, it is important to note that the same Novatel OEM3 receiver was included in the simulation chain in order to take benefit of the possibility to compare not only the pseudo-range, but several receiver data in both cases (recorded during the failure occurrence or during a simulation).

Using the same receiver eliminated any potential effect due to a difference. Other data such as Doppler and tracking status were also analyzed to make a complete validation of the scenario. To make this validation, some data coming from the simulator were also analyzed.

On the next figure are represented :

- The STR4760 generated pseudorange error, i.e. the difference between the PRN23 pseudorange generated by the STR4760 with and without failure (blue curve);
- The OEM3 pseudorange error, i.e. the difference between the PRN23 pseudorange output by the OEM3 when connected to the SPIRENT signal generator and the one generated by the SPIRENT simulator (red curve);
- The pseudorange error calculated from observed IGS data and pseudorange generated by the SPIRENT without failure (black curve);
- The actual OEM3 pseudorange error, i.e. the difference between OEM3 recorded data in DTI laboratory on the first of January 2004 and the SPIRENT generated pseudorange without failure (magenta curve);

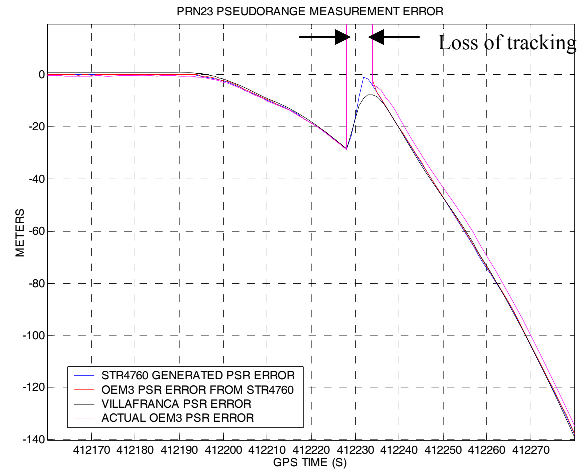

Figure 11: PRN23 pseudorange measurement error.

Close-up on the break :

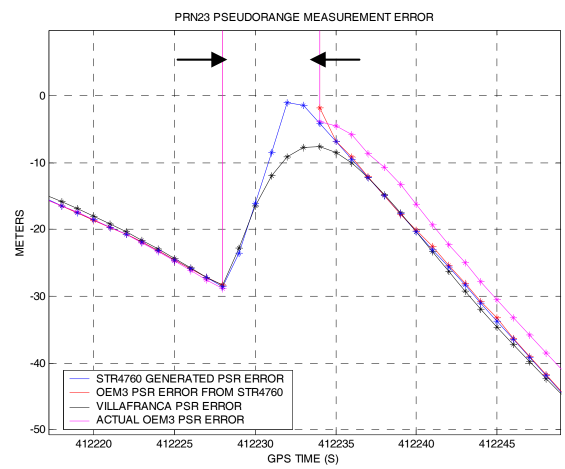

Figure 12: Zoom on PRN23 pseudorange measurement error.

Regarding this figure, the main conclusions are :

- A rupture in the slope of the failure is responsible for the loss of tracking of PRN23 for the Novatel OEM3;
- The OEM3 used for the simulation effectively loses PRN23 tracking during 5 seconds before reacquiring it again which is in line with what was observed.
- The magenta curve, representing the actual OEM3 PRN23 pseudorange error, is biased after the break : in fact for these data, the clock bias was not available and the pseudorange is therefore not corrected from that error. The break may have introduced a little jump in the clock bias (about 5 meters certainly coming from a divergence of the internal clock of the receiver) explaining that this curve is not superimposed on the other ones.

- The comparison of all these curves permits to validate the scenario used to reproduce the failure that happened on the first of January 2004.

This scenario is then used to analyze the behavior of other receivers in front of such a failure.

4.2. Behavior of a Novatel OEM4

The same scenario was then used to analyze the behavior of a Novatel OEM4. We also have data recorded in CNES by a Novatel OEM4 permitting to compare the results obtained with the simulation to recorded data.

On the next figure are represented the OEM4 pseudorange error which is the difference between the SPIRENT generated one and the one obtained with the recorded data.

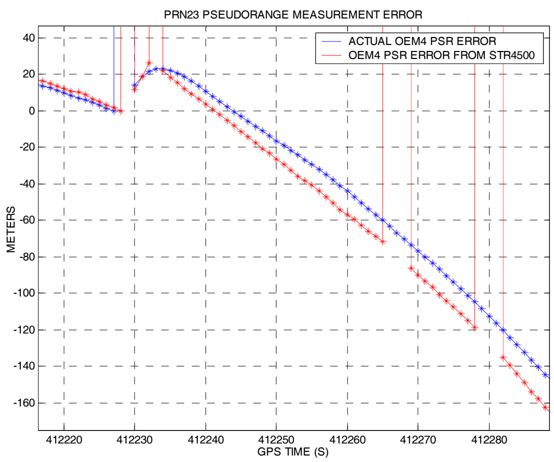

Figure 13: OEM4 PRN23 pseudorange measurement error.

Again, the shape of the two curves is very similar. The main differences are due to the fact that :

- The OEM4 used during the simulation loses the PRN23 a bit longer than the one from CNES, but this could be explained by the use of different OEM4 receivers, having different firmware.
- As for the OEM3, a bias is present after the slope discontinuity. This time, we had the clock bias but its estimation by the receiver is not precise enough and it creates a divergence of the pseudorange regarding time.

4.3. Behavior of a Septentrio receiver

The same scenario has been used to observe the behavior of a Septentrio receiver. No real data were available to make a comparison, but with the scenario, the Septentrio also loses the PRN23 at GPS time 412229s during 6 seconds (figure 14). But when plotting the results, the problem of the estimation of the bias was worse than with the Novatel OEM4, and the divergence of the pseudorange was too large to well see the impact of the failure on the following figure.

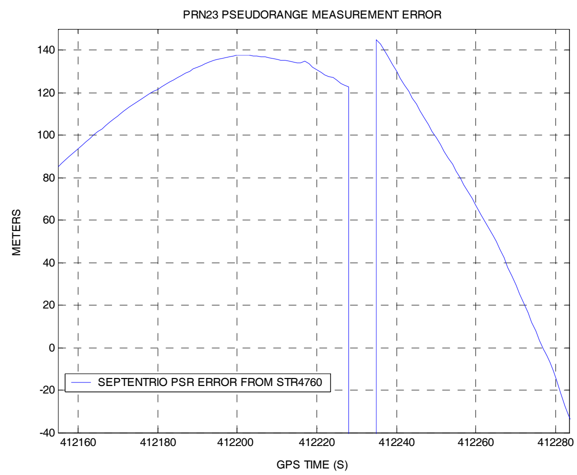

Figure 14: Septentrio PRN23 pseudorange measurement error.

4.4. Section conclusion

In this section, we presented the behavior of different types of receivers facing the failure of the first of January 2004 that was replayed with a GPS signal simulator.

The main conclusions are:

- The loss of PRN23 is not due to a stop of signal emission, or to the steady-state slope of the failed clock, but to a strong jump of the PRN23 pseudorange;
- All the receivers tested (Novatel OEM3&4, Septentrio) succeeded in tracking PRN23 during the first ramp of the failure, but they nearly all lose PRN23 at the same time (412228s or 412229s – GPS time) when the first strong jump appeared.

5. FUTURE WORK

EGNOS system and in particular its RIMS were not running when the GPS 23 failure occurred on the 01/01/2004.

Nevertheless, it is needed to test that the EGNOS Central Processing Facilities will react as expected through the broadcast of an alarm sequence, as demonstrated with simulated RIMS data.

To do that, it is necessary to demonstrate that the data coming from a real receiver included in each RIMS type (RIMS A for the CPF processing set , RIMS B for the CPF check set, RIMS C for evil wave form detection) are coherent with the simulated ones.

Now, as a scenario is available and validated, it is foreseen to implement this scenario on the Assembly, Integration and Validation Platform (AIVP) GPS simulator and to run it as a benchmark for the 3 EGNOS RIMS type.

This is not achieved yet due to the delay to tune and validate the failure scenario as explained in previous sections, but this will be done in the next future in the Performance Assessment and Check Facility, one of the two EGNOS support facilities, located at CNES, Toulouse after having solved some integration problems for the implementation of this scenario in the current AIVP configuration.

6. CONCLUSION

In this paper, we presented:

- the observations made with GPS only, SBAS and RAIM receivers linked to the failure of GPS satellite PRN 23 of January 1, 2004 consecutive to a drift of clock which lasted about three hours before being detected by the control segment of the GPS;
- a characterization of the failure that permitted to see its impact on PRN23 pseudorange in order to reproduce this phenomenon with a GPS signal simulator by creating the adapted scenario. This scenario was validated by comparing real data coming from a Novatel OEM3 receiver with simulated data;
- the behavior of different types of receivers in front of the failure by applying the scenario created to a Novatel OEM4 and Septentrio receiver
- the future work that is planned for the EGNOS RIMS receivers.

The main conclusions of this paper are the following ones:

GPS stand-alone receivers (with no integrity monitoring) were submitted to a very strong divergence of the position calculated going up to about 10 km during the first hour of the failure.

RAIM receivers protected users thanks to an early detection of the failure as soon as the error reached too large a value in agreement with the requirements expected for this type of GNSS augmentation.

SBAS (ESTB and WAAS) systems also protected users by rapidly excluding PRN23. A “Not Monitored” flag meaning that the ground system is not able to track that satellite anymore was sent four times for WAAS and only one time for ESTB. A “Don’t Use” flag was expected but the difficulty to track PRN23 and the absence of a Check Set function in ESTB were responsible for that behavior of this system.

Retrieving data from receivers that kept tracking PRN23 on the first of January around GPS time 412228s allowed to find the signature of the failure that occurred at the beginning of the clock drift. A very remarkable point is the strong break of the slope of the clock drift that happened and that is responsible for the loss of tracking of most of the receivers. Thanks to this analysis, a scenario was created to reproduce the clock drift and break of slope impacts on the PRN23 pseudo-range. An interruption of signal emission was also tested to see its impact on the receiver but this hypothesis was given up as receiver reaction was not in line with observations. The scenario was then validated by comparing data obtained with a Novatel OEM3 connected to a SPIRENT generator and real data recorded by this same receiver.

Different receivers were tested with this scenario to analyze their behavior in front of such a failure. The tested receivers, a Novatel OEM4 and a Septentrio, lost the tracking of PRN23 when the break of slope appeared. Tests for EGNOS RIMS receivers are now planned to verify that these receivers are in line with the EGNOS simulations hypothesis that have demonstrated that EGNOS system, in front of such GPS failure, broadcast an alarm sequence.

This scenario could now be taken as a reference to verify the behavior of receivers and could therefore be used as a benchmark for receiver validation by any manufacturer.

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ACRONYMS

ABAS	Airborne Based Augmentation System
AIVP	Assembly, Integration, Validation Platform
APV	APproach with Vertical guidance
CPF	Central Processing Facility
EGNOS	European Geostationary Navigation Overlay Service
ENT	EGNOS Network Time
ESTB	EGNOS System TestBed
GBAS	Ground Based Augmentation System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HAL	Horizontal Alert Limit
HPL	Horizontal Protection Level
ICAO	International Civil Aviation Organization
MI	Misleading Information
MOPS	Minimum Operational Performance Standard
NPA	Non Precision Approach
PRC	PseudoRange Correction
PRN	Pseudo Random Noise
RAIM	Receiver Autonomous Integrity Monitoring
RGP	Réseau GPS Permanent (Permanent GPS Network)
RIMS	Receiver Integrity Monitoring Station
SBAS	Satellite Based Augmentation System
TSO	Technical Standard order
UDRE	User Differential Range Error
WAAS	Wide Area Augmentation System