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Signal Strength Variations and Data Bit Synchronization Issues of High Dynamic NavIC/GPS Receiver During Ascent Phase of a Launch Vehicle Trajectory

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Abstract

One of the most important and challenging part of NavIC/GPS receiver design is the tracking loop realization. NavIC/GPS data bit identification is the terminal phase of tracking loop algorithm. Basic time synchronization between the particular satellite time which is tracked by a channel and receiver local time is achieved using the data bit boundary identification. The probability of inducing error in navigation solution is more if low elevation/low CNDR satellites signal is used for navigation computation. Normally high dynamic GNSS receivers use elevation limit to avoid low elevation satellites, but this may not be always applicable when the receiver is employed in launch vehicles which is having different maneuvers during the trajectory. In such cases when the receiver tracks low elevation satellites, there can be noise induced errors, which lead to misinterpretation of data bits leading to incorrect time synchronization for that particular channel. This leads to error in transmit time computation and further it will affect the position solution as well. The signal strength analysis of a typical NavIC/GPS receiver during the ascent phase of launch vehicle is studied and the possibility of bit synchronization issues during the flight/during ground testing is brought out and mitigation techniques are presented in this paper.

1. Introduction

NavIC/GPS receivers have nowadays become very popular in general navigation applications all over the world. The NavIC/GPS receiver consists of several subsystems, including hardware and software. The signal acquisition and tracking algorithm is generally implemented as the part of GPS navigation software which gets the inputs from the correlator, which in turn is implemented as hardware or software depending up on the receiver design. Acquisition determines the availability of a particular satellite signal, allocated to that particular channel. Once availability of the satellite signal is confirmed, fine synchronization of NavIC/GPS signal with locally generated replica is achieved through tracking algorithm. Tracking algorithm identifies exact code phase and carrier Doppler and maintains lock under variations due to relative velocities between satellite and receiver. The satellite signal shall be continuously tracked for carrier frequency and code phase changes. Tracking is implemented in two dimensions: carrier & code NavIC/GPS data bit frequency is 50Hz. So, every 20ms there may be a data bit change. Once tracking is achieved, sign changes in the correlator accumulator dump indicates data bit change. This can be used for millisecond synchronization of the local clock with the particular satellite signal tracked by the channel.

2. System Architecture

The basic elements in the NAVIC/GPS receiver are: Antenna and RF processing subsystem, Correlation subsystem and the Computing subsystem. The input RF signal to the receiver is down converted, filtered, amplified and digitized by the RF front end. The output of RF front end is given to the digital hardware containing the signal correlation subsection. This section computes the correlator accumulator dump every millisecond. This dump indicates the correlation between the incoming signal and locally generated signal. If the incoming signal is precisely tracked by local signal, good correlator accumulator dump will be achieved. The last section is the processing subsection.

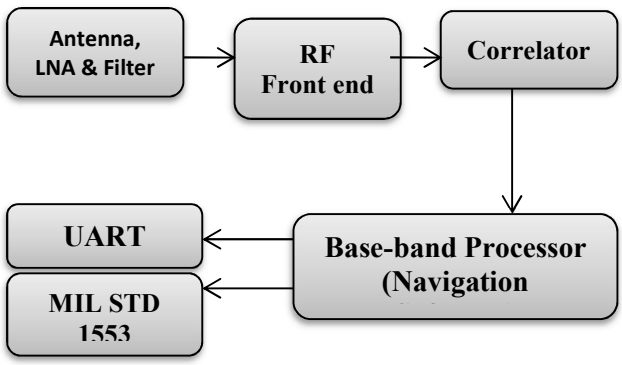

Figure1: block schematics of a typical NAVIC/GPS receiver

The navigation software resides in the processing subsection and does further processing of the correlator accumulator dump and NAVIC/GPS measurements (Code phase, Carrier Doppler) and generation of navigation solution. The RF processing is universally done in hardware and the computation subsystem is usually implemented in a DSP or a Microprocessor. The correlation subsystem has the flexibility of being implemented in hardware or software. The block

schematics of a typical NAVIC/GPS receiver are given in figure1.

3. Software Architecture

The correlator accumulator dump is used in the acquisition and tracking module to identify the satellite, track the signal and to identify the data bit.

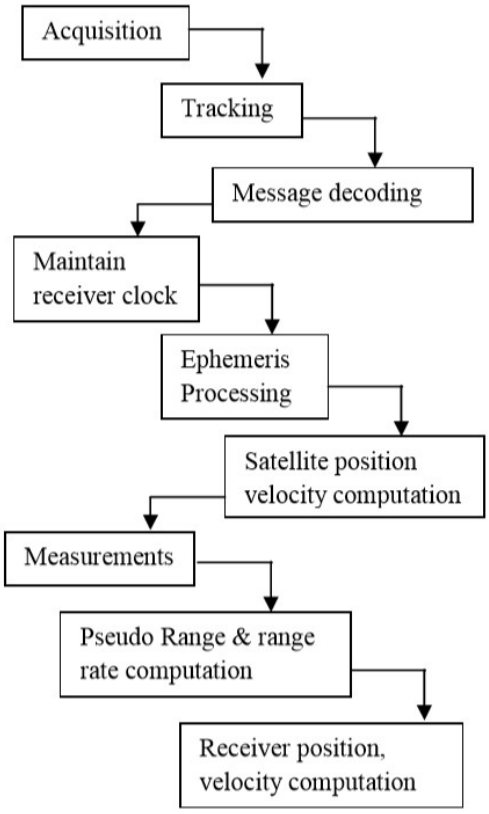

Figure2:Software Architecture of NavIC/GPS Receiver

The data bits are combined together to form the messages and is further used for decoding messages and compute satellite ephemeris data. The ephemeris is used for computing satellite position. The receiver clock is updated based on the clock information from satellite and receiver estimated clock bias. The NAVIC/GPS measurements are taken and are used to compute the pseudorange and range rate. The pseudo ranges of four or more satellites along with the satellite position are used to compute the receiver position

4. Standard Millisecond Synchronization Scheme

Millisecond synchronization algorithm synchronizes the receiver clock and satellite time within 1ms limit for a particular channel. Conventionally the incoming data bit sign is used for initial millisecond synchronization. Millisecond synchronization is attempted in the initial cycles of successful tracking.

The common algorithm adopted is to check the sign of correlator accumulator dump for continuous cycles. When there is assign change happens, it is considered as a data bit change.

In order to strengthen the synchronization logic and avoid any synchronization slip, continuity of same sign for 20milliseconds is verified, to ensure that during one data bit duration, the correlator accumulator output sign is not changed

5. Carrier to Noise Density Ratio (CNDR) Analysis during fight of a launch vehicle

The change in the CNDR of a satellite channel could be due to setting of a tracked satellite or due to change in visibility of the satellite due to maneuver of the launch vehicle due to the trajectory. A typical CNDR of a GPS satellite during ascent phase of a launch vehicle (Telemetry data) is given below

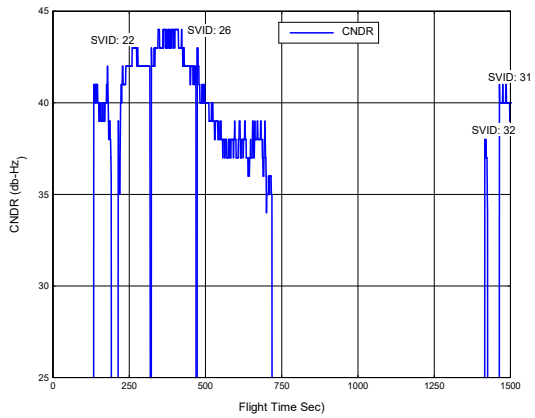

Figure3: CNDR of a GPS channel in ascend flight of launch vehicle

It is to be noted that the satellites are tracked and lost very quickly compared with a static receiver. This is due to the following facts

1. Due to high velocity of launch vehicle (Typically 7km/s), the visible range is covered quickly
2. Due to roll/yaw/pitch maneuver of the launch vehicle, the line of sight may be lost leading to outage of the signals
3. Due to high shock/vibration during stage separation of launch vehicle, temporary signal outage is expected. This is especially applicable for the receivers which use low quality TCXO which doesn't support high shock values
4. Due to temporary visibility loss due to masking of antenna due to flume of retro rockets
5. Due to physical blockage due to payload faring separation system.

A close look at the variation of signal to noise density ration shows the variations as given below (Flight data). The corresponding correlator accumulator dump (Simulated) is given in the figure

6. Problem Description

When a low elevation satellite is used for position computation, abrupt error is seen in position. However, all

the tracking parameters are valid. The case is given in figure 6. The error in position is seen in static test of the receiver using open sky signal.

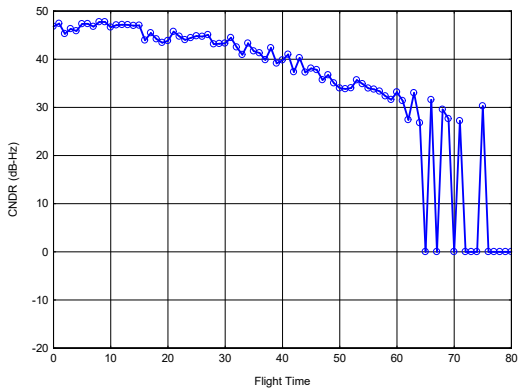

Figure4: CNDR (Zoomed) during satellite loss

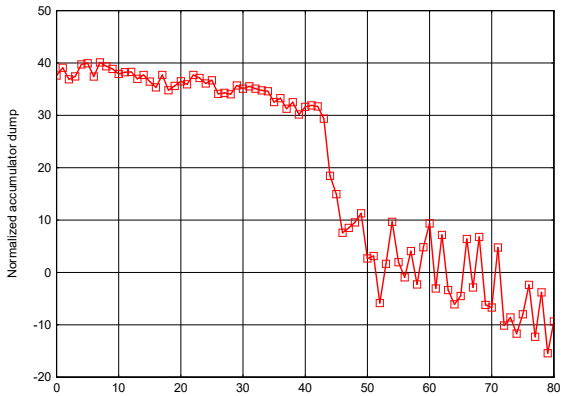

Figure5: Correlator accumulator dump during tracking loss

7. Problem Analysis

The position value deviated from the expected value at time 6827s. At 6826s, only 7 satellites were tracked and used for position computation. But at 6827s, a new satellite is tracked and is also used for position estimation. The elevation of the new satellite
is computed and is seen that it is 2deg, which is in the lower range of elevation. The transmit time of that particular satellite during the above depicted duration is computed and is shown in the figure 7. From the graph it is clear that the newly tracked satellites transmit time computation was in error which in turn lead to the position error.

Once position error happens, it will affect the unit vector computation along line of sight of the satellite from the receiver for the erroneous satellite (α matrix) and that in turn affect the velocity computation, even though the pseudorange measurement has no direct relation with the Doppler measurement.
The position error is computed as around 300km, which is equivalent to the timing error of 1millisecond. Once the new satellite is tracked, it continued for 96 seconds and then that satellite tracking was lost. Again, the same satellite is tracked after some time, but position computation is as expected.

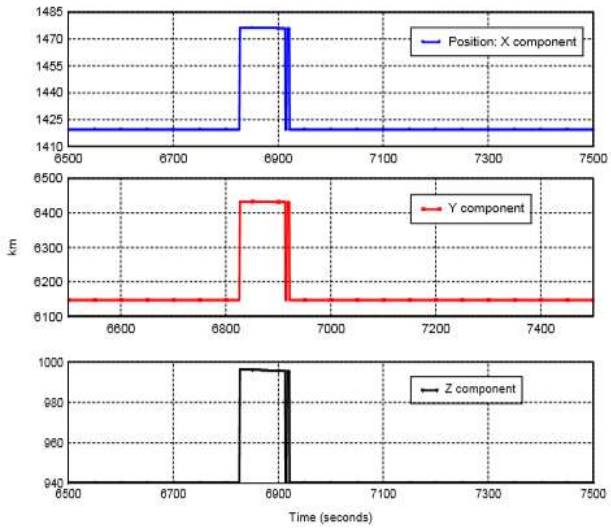

Figure6: position components of the receiver using low elevation satellites

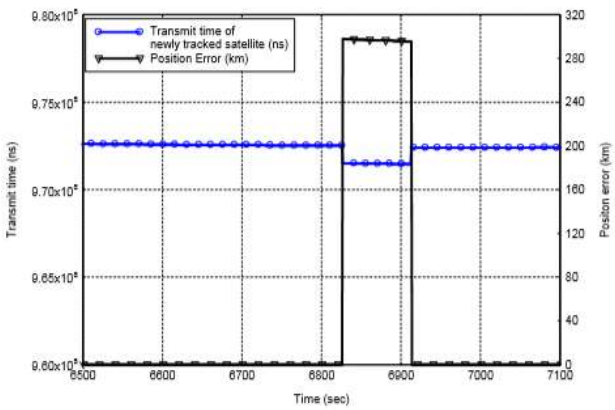

Figure7: Computed transmit time of erroneous satellite Vs position error plot

The difference in transmit time between the two instances is computed and is seen as 0.00099914seconds, which is equivalent to the computed position error during the erroneous period. So the same satellite measurement is isolated as erroneous measurement.

The analysis shows that the time synchronization of the particular satellite was not in order at the first tracking. But it becomes correct after second tracking. The carrier to noise ratio (CNR) of that particular channel is analyzed and it found that the channel had very low carrier to noise ratio at the instant when it is first tracked. The CNR of the satellites are given in figure8. The elevation of the satellite is also computed using the ephemeris and time data and it is seen that the satellite has very low elevation (~2deg)
When very low CNR (~30dBW) is available for a channel and is in low elevation condition, the noise of that channel will be quite high. This could cause more error in correlator accumulator dump.

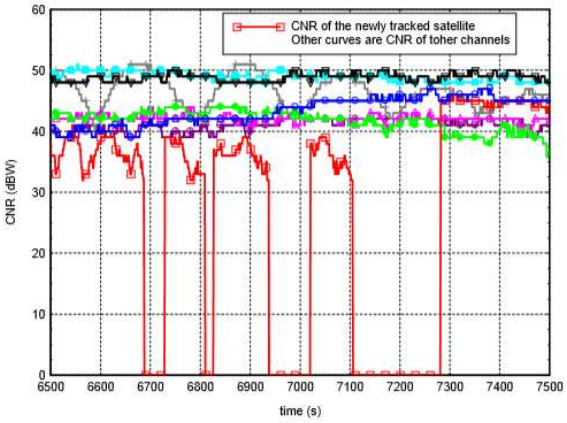

Figure8: CNR comparison of all the satellites at the duration when error occurred

The normal behavior of correlator accumulator dump of a satellite channel when it is tracked with good CNR gives clear distinction between the data bit one and zero. That is '1' will be clearly positive and '0' will be clearly negative. When the channel is highly noisy the accumulator dump may be inconsistent for one millisecond among 20 milliseconds. And if this happens at boundary of a 20millisecond period and the data at next 20millisecond is different from the current 20 millisecond period, then millisecond synchronization slip may occur. A typical such situation is shown in figure9. The actual data bits considered in the case is 100. The correlator accumulator dump is wrong during the 20th millisecond of first data bit, which is considered as the start of second data bit and starts synchronization at the end of second bit duration.

In the above depicted case, 1 is wrongly interpreted as 0 for the 20th millisecond of first bit considered. The same can happen if a 0 is wrongly interpreted as 1 also. The considered situation is when the erroneous data bit is coming before the 20millisecond boundary. The same issue can happen, when a data bit is interpreted one millisecond after actual arrival of the data bit also.

8. Simulation Studies

Simulation studies are done in two phases. In the first phase one millisecond synchronization error is manually created in the software and the error is verified. The position, velocity error of similar range is observed in the simulation. In the second phase of simulation, RF constellation simulator is used. The similar situation is created in NAVIC/GPS constellation simulator with same almanac with same satellites. Carrier to Noise Ratio is varied to study the effect of low CNR in the receiver performance. When CNR is reduced, the same issue is repeated in the receiver.

9. Protective Software Design for Millisecond Synchronization

Two level protection is done in software to remove this type of error in NAVIC/GPS navigation solution. The first is to strengthen the synchronization scheme by ensuring the continuity of data bits and identification of data bit boundary. Second is to revise the threshold for identifying the sign of correlator accumulator dump. The millisecond synchronization logic is revised to verify a particular pattern for consecutive 3 cycles (60 millisecond), and then confirm the synchronization. 101 or 010 pattern is chosen. If either of this pattern is seen, then only millisecond synchronization is assumed to happen. The advantage is it will reduce the probability of false alarm. The second method of strengthening is by revising the threshold. The original design was, if the correlator accumulator dump is negative, it is taken as 0 and if it is positive it is taken as 1, assuming that once tracking is achieved, the correlator accumulator dump will be clearly distinguishable for data 0 and 1. Instead of these a non-zero thresholds is designed,

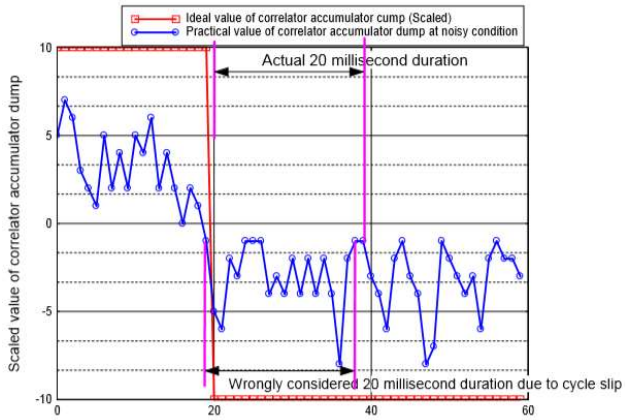

Figure9: Correlator accumulator dump and data bit identification: Erroneous scenario

considering the noise probabilities. If the accumulator dump is beyond the positive threshold. It is taken as 1 and if it is less than the negative threshold, it is taken as 0. If the correlator accumulator dump is within the positive threshold and negative threshold, that cycle data will be discarded and fresh attempt is made for millisecond synchronization. The revised logic completely eliminates the possibility of false synchronization and induced navigation error.

10. Conclusions

Analysis is done on millisecond synchronization slip related issues in NAVIC/GPS navigation solutions. The cause of the millisecond synchronization in common software design is brought out. Simulation studies are completed and protective algorithm design is completed.

11. Acknowledgements

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12. References

[1] Pratap Misra, Per Enge, "Global Positioning System: Signals, Measuremetns and Performance"
[2] Biju VS, Anand Shankar OT, Mohammad Basim, Vinoj V S "Functional Requirements Document on Navigation Software for NavIC Receiver in NNP for MINS-6S"
[3] James Bavo-Yen Tsui, "Fundamentals of Global Positioning System Receivers a Software Approach"