NEW STUDIES ON ACQUISITION AND TRACKING THRESHOLD'S REDUCTION FOR GPS SPACEBORNE AND AERONAUTICAL RECEIVERS

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BIOGRAPHY

René Jr. Landry was born in Montreal, Quebec, Canada in 1968. After graduating (B.Sc.) from the Ecole Polytechnique of Montreal (Canada) in 92, he got the M.Sc. in Satellite Communication Engineering at the University of Surrey (UK) in 93. He received a Diplôme d'Etudes Approfondies (DEA) in Microwave Engineering with a Mastere in Space Electronics in 94, and his Ph.D. degree in Signal Processing in 97 at the Ecole Nationale Supérieure de l'Aéronautique et de l'Espace, ENSAE (Toulouse, France). His dissertation topic concerned anti-jamming technologies applied to the problem of civil aircraft interference using GPS receivers as a primary equipment of navigation. He has been involved in the design of the patented PIRANHA Filter integrated within 2 GPS receivers as a new anti-jamming technology. He is presently a Research Staff in the RadioNavigation Department of the French Space Agengy, CNES (Toulouse, France) where his major interest concerns signal processing for digital receiver technology.

Laurent Lestarquit is graduated from the Ecole Polytechnique of Paris in 94, and then specialised in space telecommunication systems at the Ecole Nationale de l'Aéronautique et de l'Espace, ENSAE in Toulouse, France. He joined the radionavigation department at CNES in 96, where he is currently working on spaceborne GPS receivers for project HETE2 (LEO) and CNES experimental telecommunication satellite STENTOR (GTO and GEO), and on the design of the future SCNS/INES navigation constellation (GNSS2).

Jean-Luc Issler is the head of the Radio-Navigation Department at CNES. His main works concern spaceborne radionavigation receivers (DORIS, DORIS NG, GPS, GNSS1) and generators (GNSS1, GNSS2), and associated simulators. Ground GNSS receivers and generators involved in space systems are also his concern.

SUMMARY

This paper proposes a robust method for threshold's reduction taking into account features both concerning GPS receiver modification and real gain on the performances improvement. This method involves two steps. First, we use the strong channels of the GPS receiver which are actually tracking satellites for velocity aiding the other channel trying to acquire or track satellites presenting a low signal over noise ratio due to lower elevation or masking conditions. Second, according to the theory and the characteristics of the digital internal loops of the GPS receiver, the predetection bandwidth is reduced to the lowest value permitted by the velocity aiding accuracy. This technique allows to improve the GPS accuracy and robustness. The paper shows first a large panorama of all potential threshold's reduction techniques both for acquisition and tracking processes. It proposes and identifies the automatic model of a velocity aided loop. Furthermore, to allow the validation of the described threshold reduction method, the technique is proposed to be inserted and validated into the new GPS MATNAV simulator, which is a generic digital MATLAB GPS receiver model. The work is intended to be applied for space and aeronautical applications.

1. INTRODUCTION

The spaceborne GPS receivers are classically used in low earth orbit, with good GPS visibility conditions. However, some space missions require a GPS receiver operating with poor link budget. Such missions are for instance reentry capsule or shuttle (after radio black-out), high altitude spacecraft, GPS attitude determination, degraded pointing modes, radio-occultations and interference environment scenario. These applications need quick reacquisition of the GPS satellites, GPS receivers build-in robustness technology and better GPS visibility conditions than normal GPS navigation.

The aeronautical navigation GPS receivers need also acquisition and tracking threshold's reduction, for the following reasons :

- ✓ improvement of resistance to jammers, navigation availability and satellite's visibility.
- ✓ augmentation of accessible pseudorange measurements (improvement of RAIM).
- ✓ augmentation of accessible carrier phase measurements (improvement of phase tracking navigation).

The integrity is one of the major requirement for aeronautical mission. The objective is to maximise the number of tracked SV (Satellite Vehicle), even in the presence of interference. For a space mission where the C/N_o may be low, we are more concerned with the number of satellites that could be tracked. But, in orbit, the dynamic (acceleration) is always very small (for free orbital trajectories) and predictable. In these 2 domains of application, it is possible to reduce the threshold of GPS signal acquisition and tracking.

Also, in many situations, the acquisition process may be too long and/or the tracking loops of a GPS receiver may loose the lock of the signal during special conditions such as low satellite elevation angle or high dynamic manoeuvring. To improve the GPS acquisition time and the tracking performance an investigation is conducted on the use of additional internal GPS velocity aiding information.

The main acquisition and tracking threshold reduction technique presented consist in supplying a pseudovelocity aiding to the carrier and/or the code loop, this pseudovelocity aiding is provided by the navigation filter itself (aeronautical PVT filter, or orbital Kalman filter, such as DIOGENE developed by CNES, where DIOGENE is « Determination Immédiate d'Orbite par GPS et Navigateur Embarqué », Immediate Orbit Determination with GPS and OnBoard Navigator). The promising technique named TASAP, « Acquisition and Tracking Threshold Reduction Techniques » enables to reduce the C/N_o thresholds below 20 dBHz, without any external aiding, other than a tight coupling between an aeronautical or orbital navigator and the signal processing loops inside the GPS receiver.

OBJECTIVES AND METHODOLOGY

Many experiments are presently being carried out on the future DGPS-based approach and landing systems to improve the quality of aircraft navigation. The use of C/A-code receivers for aeronautical and spaceborne applications requires high reliability and integrity. Low visibility and satellite elevation angle during phases of flight can present problems for GPS reception of the channels presenting low C/N_o. The study of satellite missions and aeronautical environment show that GPS receiver must be provided with a strategy to reduce the acquisition and tracking thresholds to improve the navigation integrity, availability and performances, required for these missions.

This paper intends to give first an overview of all potential techniques well suited for Threshold's Reduction. Moreover, a Generic GPS Receiver has been implemented on the MATLAB software to validate the Threshold's Reduction Technique described in this paper. The aim of the Simulations is to compare the Velocity Aiding Performances with traditional processing.

The threshold reduction performance is evaluated versus the signal processing parameters of the receiver and the pseudovelocity aiding characteristics. Different models of this pseudovelocity aiding are presented, for the aeronautical and spaceborne applications. The main characteristics and theoretical performances of the aided processing loops are derived from these models. Numerical simulations of a GPS receiver provided with internal velocity aiding are also presented and compared with normal operation.

2. THRESHOLD'S REDUCTION TECHNIQUES PANORAMA

The following analysis brings some details of some potential reduction techniques based on signal processing which can reduce the limitation of present day acquisition and tracking threshold.

The next section identifies and describes some threshold's reduction techniques for GPS receivers.

2.1 Suppression of Data Demodulation

A servo loop, using a discriminator which can work without the data demodulation process, can bring 3dB improvement on the C/N_o threshold.

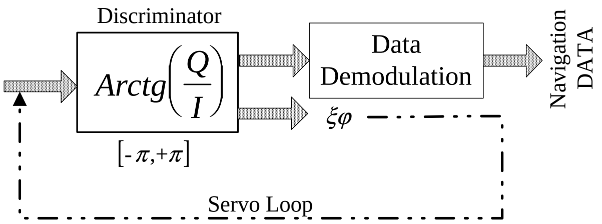

Figure 2-1 : Suppression of Data Demodulation.

The suppression of data demodulation in the loop can remove the C/N_o limitation of 27dBHz which is necessary to obtain the BER better than 10^{-5}. This data demodulation can be done in parallel at the output of the arctg discriminator, for example, but outside the loop as shown in Figure 2-1.

The extension of the discriminator domain outside]-kπ,+kπ[is not any more possible but since the steady state error is small for aeronautical & space missions, this restriction is not embarrassing.

2.2 The Data Wipping Variant 1, 2 and 3

Known as Data Wip, the Data Wipping consist of slightly reducing the predetection filter bandwidth increasing the linearity of the loop at low SNR. This technique uses the a priori knowledge of the navigation message to reduce the predetection bandwidth B_{FI} of the carrier and code loops reducing at the same time the noise measurements. The carrier noise variance σ_{PLL} in this case is given by the following expression :

$$\sigma^2_{PLL} = \frac{\gamma_o \cdot B_L}{P_s} \cdot \left(1 + \frac{\gamma_o \cdot B_{FI}}{2 \cdot P_s}\right) \quad [rad^2] \qquad \textbf{(2-1)}$$

γ_o : spectrum noise density (input thermal noise),
B_L : loop bandwidth,
B_{FI} : data pre-detection bandwidth,
P_s : power of the useful signal.

In the case of code loop, the code noise variance is :

$$\sigma^2_{DLL} = \frac{1}{2} \cdot \frac{\gamma_o \cdot B_L}{P_s} \cdot \left(1 + \frac{2 \cdot \gamma_o \cdot B_{FI}}{P_s}\right) \quad [chip^2] \qquad \textbf{(2-2)}$$

The term $\frac{\gamma_o \cdot B_{FI}}{P_s}$ correspond to the quadratic losses even though $\frac{P_s}{\gamma_o}$ represents the signal to noise ratio in 1Hz. It can be shown here that we can reduce the noise variance on measurement by reducing the predetection bandwidth B_{FI} to its minimum value. By this way, the quadratic losses are minimum and the loop will track at lower SNR.

2.2.1 Variant #1 of Data Wipping

This technique uses a different process which consist in memorising the I and Q samples on more than 20msec and removing the data modulation depending of the received data demodulated in parallel.

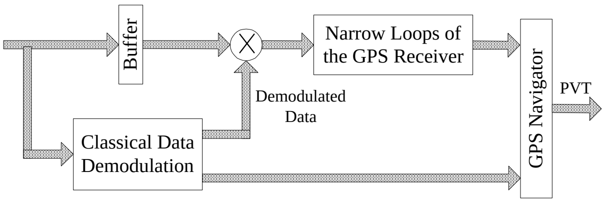

Figure 2-2 : Data Wipping ; Variant #1.

This process introduces a delay in the loop which is important to take into account in the phase correction filter of the loop.

The main advantage of Data Wipping #1 is to accept stronger dynamic at same SNR. This variant may brings a good improvement to loop robustness to steady state problem.

2.2.2 Variant #2 of Data Wipping

This version allows to avoid the difficulties linked with the correction phase filter. It is based on the fact that the content of the navigation message is varying slowly and/or the main information can be predictable in a short term.

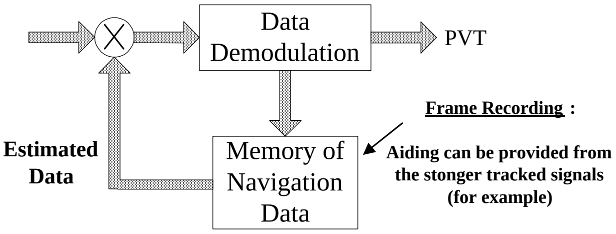

Figure 2-3: Data Wipping ; Variant #2

The data demodulation is thus removed in real time with an error rate low enough for cumulating the I and Q samples over 1 word, 600msec.

This variant supposes that one or several channels of the receiver are tracking GPS signal and that the reception quality is decreasing.

2.2.3 Variant #3 of Data Wipping

Data Wipping Variant 3 is similar to Variant 2 but this version can be used in a very bad environment (low C/N_o) for some special applications. For a better understanding of its principle, let's examine Figure 2-4.

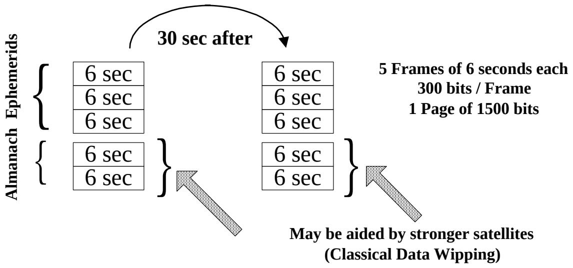

Figure 2-4: Navigation Message Frame for DW Variant 3.

Let's suppose that the link with a satellite is too bad to retrieve the data. The idea is to use the other strong channels to collect the almanach and ephemerid data of the weak channel. This can be useful for attitude control application knowing that position can be obtain with an accuracy of about ±500m using only almanach data.

2.3 External Velocity Aiding using INS

Relations (2-1) and (2-2) show that it is possible to reduce the threshold of the loop by reducing the prediction bandwidth. This is possible if an external velocity aiding is provided (Figure 2-5). Such a process is detailed in many papers.

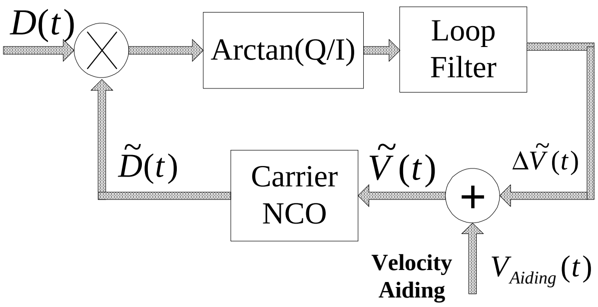

Figure 2-5: Loop with External Velocity Aiding.

The mode of operation is frequently used in military operation using integrated INS.

3. ANALYSIS OF LOOP PERFORMANCES

3.1 Noise Measurement

For the code loop with a programmable chip spacing, the standard deviation of the pseudorange noise measurement standard deviation (1σ) is approximated by :

$$\sigma_{PR}(m) = \frac{c}{R_c}\sqrt{\frac{B_{nm}\cdot C_s}{2\left(\frac{C}{N_o}\right)}\cdot\left[1+\frac{2B_{FI}}{\left(\frac{C}{N_o}\right)}\right]} \qquad \textbf{(3-1)}$$

c = 3x10^8 m/s ; speed of light,
R$_c$ = 1.023Mchip/sec ; C/A code speed,
C$_s$ = 1 chip ; chip spacing (1/2, 1/4, 1/8, etc),
B$_{nm}$ = 1 Hz ; code loop bandwidth,
B$_{FI}$ = 50 Hz ; data predetection filter bandwidth,
C/N$_o$: signal to noise spectral density power ratio.

<u>**Numerical Application:**</u>

B$_{FI}$ = 50Hz, B$_{nm}$ = 1Hz et C/N$_o$ = 40dBHz
we obtain, **σ$_{PD}$ = 2meters**.

The standard deviation of the pseudovelocity error measured on the carrier is given by :

$$\sigma_{PV}(m/s) = \frac{c}{\sqrt{2}\pi f_t T_D}\sqrt{\frac{B_{np}}{\left(\frac{C}{N_o}\right)}\cdot\left[1+\frac{B_{FI}}{2\left(\frac{C}{N_o}\right)}\right]} \qquad \textbf{(3-2)}$$

f$_t$: transmitted frequency (F$_{L1}$, F$_{L2}$ or others),
T$_D$ = 1 sec ; Doppler integration time,
B$_{np}$ = 5 Hz ; carrier loop filter bandwidth,

<u>**Numerical Application:**</u>

B$_{FI}$ = 50Hz, B$_{np}$ = 10Hz, C/N$_o$ = 40dBHz et T$_D$ = 0.6s, we obtain **σ$_{PV}$ = 0.35cm/s**.

One other possibility to measure the standard deviation of the code pseudospeed error is given by :

$$\sigma_{PV_{code}} = \frac{\sqrt{\sigma^2_{PR_k}+\sigma^2_{PR_{k+1}}}}{t_{k+1}-t_k} = \frac{\sqrt{2}\cdot\sigma_{PR}}{\Delta t} \qquad \textbf{(3-3)}$$

with $\sigma_{PR_k} = \sigma_{PR_{k+1}} = \sigma_{PR}$, $t_{k+1}-t_k = \Delta t$
and t$_i$ = date of pseudorange measurement, with instantaneous standard deviation σ_{PR_i} .

<u>**Numerical Application:**</u> $\sigma_{PVcode} = \frac{\sqrt{2}\cdot 2}{0.6} \cong 4m/s$

3.2 Code Loop Threshold on Tracking

The code loop condition to stay in lock is given by :

$$a\cdot\sigma_{PR} \le \frac{\Delta}{2}(m) \qquad \textbf{(3-4)}$$

From equation (3-1), we obtain the following condition, with C$_s$ = 1 :

$$\frac{C}{N_o} \ge a^2 B_{nm}\cdot\left(1+\sqrt{1+\frac{4B_{FI}}{a^2\cdot B_{nm}}}\right) \qquad \textbf{(3-5)}$$

For B$_{FI}$ = 50Hz, B$_{nm}$ = 1Hz and a = 3, we have :

$$\left[\frac{C}{N_o}\right]_{Boucle} \ge 17dBHz \qquad \textbf{(3-6)}$$

For B$_{FI}$ = 250Hz instead of 50Hz, we have :

$$\left[\frac{C}{N_o}\right]_{Boucle} \ge 20dBHz \qquad \textbf{(3-7)}$$

These values may be adjusted in function of the velocity aiding. Figure 3-1 shows the tracking threshold versus B$_{FI}$ in function of B$_{nm}$.

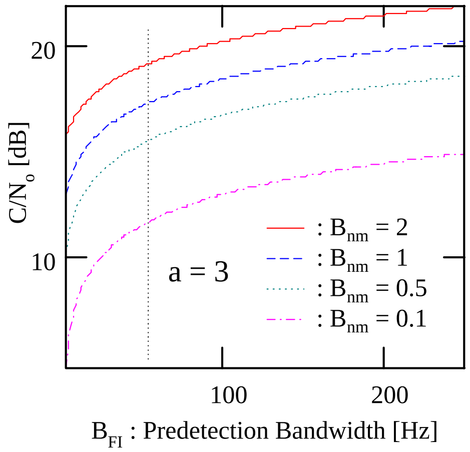

Figure 3-1: C/N$_o$ versus B$_{FI}$ (Variation of B$_{nm}$).

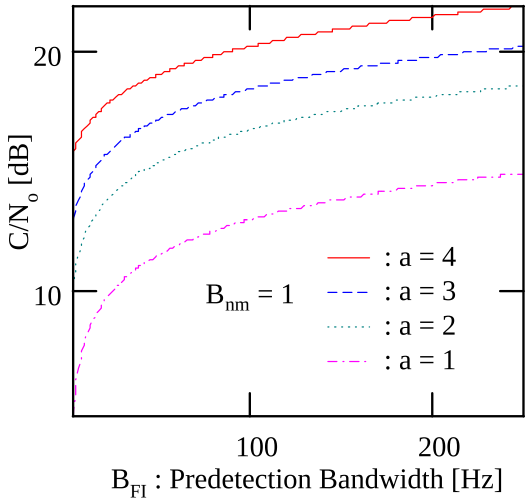

Figure 3-2: C/N$_o$ versus B$_{FI}$ (Variation of a).

3.3 Carrier Loop Threshold on Tracking

The behaviour of the carrier loop and C/N$_o$ threshold are linked to the quality of data demodulation which depends on the required BPSK modulation BER of the following form :

$$BER = \frac{1}{2}\left[1 - erf\left(\sqrt{\frac{C/N_o}{D_r}}\right)\right] \qquad (3\text{-}8)$$

where D$_r$ is the data rate (50Hz),
C/N$_o$ is the signal to noise spectral density power ratio,
and the error function is given by :

$$erf\,(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-u^2}\,du \qquad (3\text{-}9)$$

For example using (3-8), if it is not tolerate to have more than one bit of error each 30 minutes, with a data rate D$_r$ = 50bits/s, the maximum specified BER is 10^{-5} corresponding to a C/N$_o$ of 26.5dBHz.

Introducing τ, the time response of the loop (τ = B$_L$), and assuming a loop bandwidth of 5Hz with the assumption that one bit error will occur every 3τ·B$_L$ (limit of operation), we obtain a limit to the bit error probability of 6.67×10^{-3} (20ms/3τ·5). This corresponds to a C/N$_o$ ≥ 24 dBHz (3-8). Bellow this threshold, the instance of bit error cause the loop desynchronisation. Using an operational margin of 3dB explain the reason why the GPS receiver switch to signal reacquisition or Code-Only mode when C/N$_o$ is bellow 27 dBHz. This level is the typical actual tracking threshold of GPS receivers.

4. MATHEMATICAL MODEL OF AN AIDING LOOP

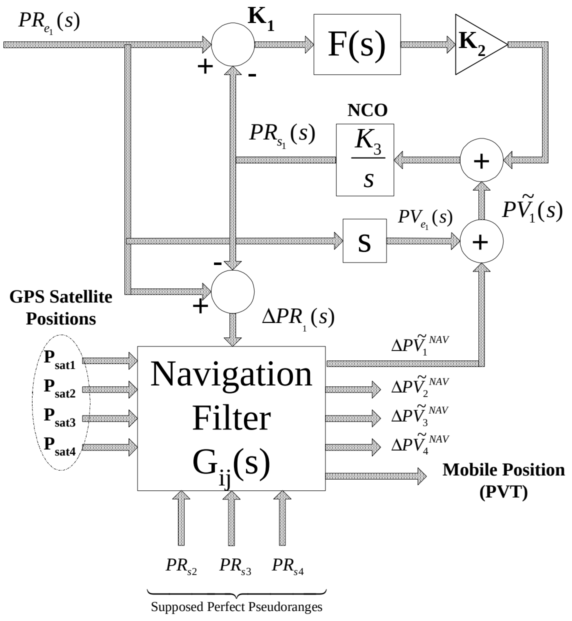

Figure 4-1: Mathematical Modelling of the Loop with autonomous velocity aiding providing from GPS navigator (Code ONLY).

4.1 Definition and Elaboration of the AVIA Model

The expression of the pseudorange measurement (PR) is generally written as :

$$PR_i^{Useful} = R_{r_i} + c\cdot\Delta T_i \qquad (4\text{-}1)$$

where c is the speed of light, R the radial distance between the GPS satellite and the mobile and ΔT the time difference between the receiver and satellite clock.

After derivation, we obtain the expression of the real useful pseudovelocity (i.e. without error) :

$$PV_i^{Useful} = \frac{dPR_i^{Useful}}{dt} = \frac{dR_{r_i}}{dt} + c\cdot\frac{d\Delta T_i}{dt} = V_{r_i} + c\cdot\frac{d\Delta T_i}{dt} \qquad (4\text{-}2)$$

where V_r is the radial speed of the receiver versus the transmitter,

and $c \cdot d\left(\frac{\Delta T_i}{dt}\right)$ is the pseudovelocity due to the drifting shift of the clock between the receiver and the satellite i, noted also PV_i^{Clock}.

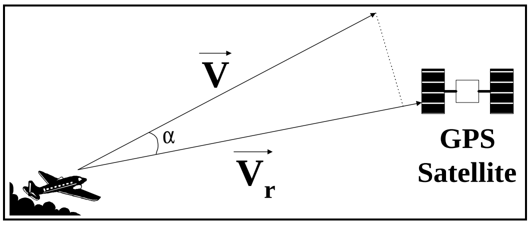

Figure 4-2: Mobile Radial Speed vs GPS Satellite.

$$PV_i^{Useful} = V_{r_i} + PV_i^{Clock} \qquad \text{(4-3)}$$

The orbital navigator supplies an estimation $P\tilde{V}_i$ of the pseudovelocity corresponding to the aiding velocity noted :

$$PV_i^{Navigator} = P\tilde{V}_i^{Useful} = \tilde{V}_{r_i} + c \cdot d\left(\frac{\Delta \tilde{T}_i}{dt}\right) \qquad \text{(4-4)}$$

where $c \cdot d\left(\frac{\Delta \tilde{T}_i}{dt}\right)$ is the estimated clock pseudovelocity of satellite i noted also $P\tilde{V}_i^{Clock}$.

Moreover, we introduce the raw measurement from the GPS receiver with the notation $PV_i^{Observable}$ corresponding to the pseudovelocity which can effectively be observed by the loops of the receiver, perturbed by the global error sources represented by the notation $\Delta PV_i^{Observable}$.

$$PV_i^{Observable} = V_{r_i} + PV_i^{Clock} + \Delta PV_i^{Observable} \qquad \text{(4-5)}$$

where $V_{r_i} + PV_i^{Clock} = PV_i^{Useful}$ is the real useful pseudovelocity, from the navigator estimation.

The term $\Delta PV_i^{Observable}$ represent notably the perturbations due to SA (Selective Availability), to ionosphere, to multipaths and to jammers.

The SA is a voluntary degradation which is today's present in all applications (aeronautical and space).

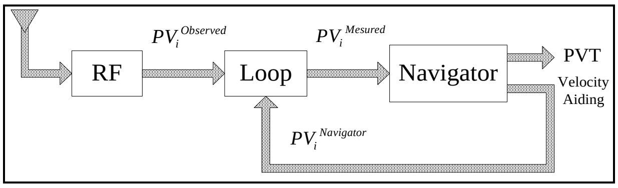

Figure 4-3: Relation between the PseudoVelocity Notations.

Reminding that the $PV_i^{Observable}$ is a characteristic of the received signal, it consists of physical pseudovelocity while $PV_i^{Mesured}$ contains the steady state error of the loop such as the potential error reductions due to multipath coming from the loop and the thermal noise of the loop. N.B. The measurement $PV_i^{Mesured}$ is of course available only when the loop is in tracking mode.

Let's have a look on the GPS receiver visibility :

$$PV_i^{Navigator} = \tilde{V}_{r_i} + P\tilde{V}_i^{Clock} + \Delta PV_i^{Navigator} \qquad \text{(4-6)}$$

where $\Delta PV_i^{Navigator}$ is the estimation error of the useful pseudospeed. The error on the aiding velocity supplied by the navigator and seen by the loops of the GPS receiver is notified by ΔPV_i^{Loop}. We obtain :

$$\Delta PV_i^{Loop} = PV_i^{Observable} - PV_i^{Navigator} \qquad \text{(4-7)}$$

after some developments, we obtain :

$$\begin{aligned} \Delta PV_i^{Loop} &= V_{r_i} + PV_i^{Clock} + \Delta PV_i^{Observable} \\ &\quad - (V_{r_i} + PV_i^{Clock} + \Delta PV_i^{Navigator}) \end{aligned} \qquad \text{(4-8)}$$

after simplification :

$$\Delta PV_i^{Loop} = \Delta PV_i^{Observable} - \Delta PV_i^{Navigator} \qquad \text{(4-9)}$$

The $\Delta PV_i^{Observable}$ represents the physical perturbation of the GPS signal notably due to the SA.

Examples of $\Delta PV_i^{Navigator}$ are presented bellow. It is known that the performance of orbit calculation of the Orbital Navigator such as DIOGENE are dependent on the type of orbit. Generally, we consider three types of orbit which are :

- Low Earth Orbit (LEO considered here at an altitude of 1000Km),
- Geostationary Orbit (GEO),
- Geostationary Transfer Orbit, after injection (GTO).

The performance of orbit calculation is :

Type of Orbit	**Clock Class**	**Precision**
LEO	Short Term : ΔF/F=10^{-7}	Position 100m (3σ), speed 0.1m/s (1σ).
GEO	ΔF/F=10^{-9},	Position 250m (3σ), speed 0.015m/s (1σ).
GTO	ΔF/F=10^{-9},	Position 500m (3σ), speed 0.08m/s (1σ).

Table 4-1 : Performance of Navigator vs Type of Orbit.

4.2 Analyse of AVIA Loop Model

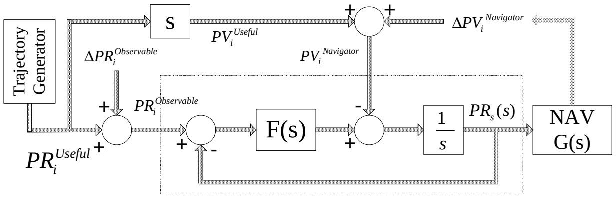

Figure 4-4: Mathematical Model of Autonomous Velocity Aiding Loop (AVIA Loop).

We are searching :

$$H_1(s) = \frac{PR_s(s)}{PR_i^{Useful}(s)} \tag{4-10}$$

$$PR_s(s) = \frac{[PR_e(s) - PR_s(s)] \cdot F(s)}{s} - \frac{PV_i^{Nav}(s)}{s} \tag{4-11}$$

$$PR_s(s) = \frac{PR_e(s) \cdot F(s)}{s} - \frac{F(s) \cdot PR_s(s)}{s} - \frac{PV_i^{Nav}(s)}{s} \tag{4-12}$$

$$\left[1 + \frac{F(s)}{s}\right] \cdot PR_s(s) = PR_e(s) \cdot \frac{F(s)}{s} - \frac{PV_i^{Nav}(s)}{s} \tag{4-13}$$

We have also :

$$PR_e(s) = \frac{\left[s \cdot PR_i^{Useful}(s) + \Delta PV_i^{Obs}(s)\right]}{s} \tag{4-14}$$

and :

$$PV_i^{Nav}(s) = s \cdot PR_i^{Useful}(s) + \Delta PV_i^{Nav}(s) \tag{4-15}$$

After some development, using (4-14) and (4-15), we obtain :

$$\left[1 + \frac{F(s)}{s} + \frac{G(s)}{s}\right] \cdot PR_s(s) = \left[\frac{F(s)}{s} - 1\right] \cdot PR_i^{Useful}(s) + \frac{F(s) \cdot \Delta PR_i^{Obs}(s)}{s} \tag{4-16}$$

where

$$G(s) = \frac{\Delta PV_i^{Navigator}(s)}{PR_s(s)} \tag{4-17}$$

is the transfer function of the Navigator for one channel.

The function can be analysed for several type of sinusoidal perturbations, noted :

$$p_i(t) = b_i \cdot \sin(\omega_i t) \tag{4-18}$$

Assuming the following perturbations :

$$\Delta PV_i^{Nav}(s) = \frac{b_1 \cdot \omega_1}{s^2 + \omega_1^2} = P_1(s) \tag{4-19}$$

This perturbation can represent the theoretical navigator harmonic error, for instance.

$$\Delta PV_i^{Obs}(s) = \frac{b_2 \cdot \omega_2}{s^2 + \omega_2^2} = P_2(s) \tag{4-20}$$

This perturbation can represent the selective availability, for instance.

Using $F(s) = \frac{K \cdot (s+a)}{s}$, and plugging in (4-16), we have :

$$\left[\frac{s^2 + Ks + a}{s^2}\right] \cdot PR_s(s) = PR_i^{Useful}(s) \cdot \left[\frac{-s^2 + Ks + a}{s^2}\right] + P(s) \tag{4-21}$$

where

$$P(s) = \frac{1}{s^2} \cdot \left[\frac{K \cdot (s+a)}{s} \cdot P_2(s) - s \cdot P_1(s)\right] \tag{4-22}$$

ie :

$$P(s) = \frac{1}{s^2} \cdot \left[\frac{K \cdot (s+a)}{s} \cdot \left(\frac{b_2 \cdot \omega_2}{s^2 + \omega_2^2}\right) - s \cdot \left(\frac{b_1 \cdot \omega_1}{s^2 + \omega_1^2}\right)\right] \tag{4-23}$$

Simulation of this model will be perform on the MATLAB GPS Receiver Simulator.

5. PERFORMANCES OF TASAP IN ACQUISITION MODE

5.1 Synthesis & Improvement of Signal Acquisition

5.1.1 Cold Start or Classical Acquisition Mode

The acquisition thresholds are mainly linked to the value of the integration constant, τ, and to the chip sweeping speed α.

The classical acquisition process is a complete and continuous search for energy among the 1023 chip positions of a GPS C/A code (Figure 5-1).

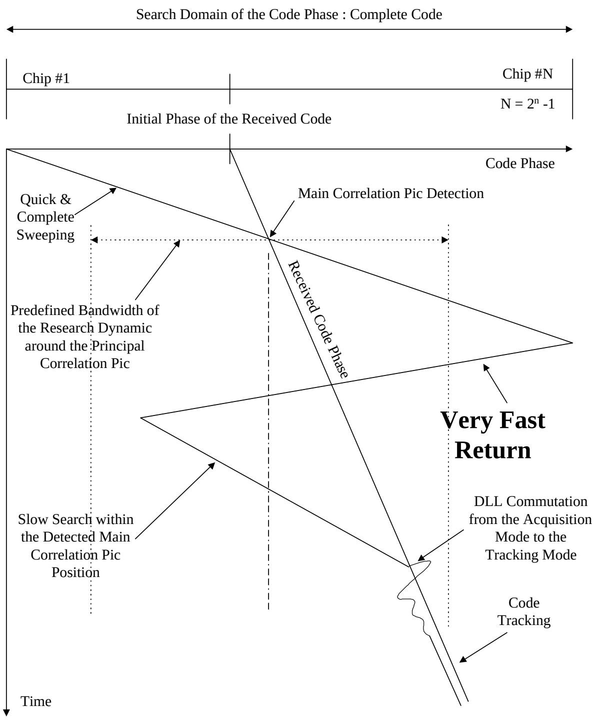

Figure 5-1: Cold Start or Classic Acquisition Process.

This concerns both cold start or classical aided acquisition. The difference between these 2 cases is mainly the number N_{db} of explored Doppler positions.

5.1.2 Aided Start with Code Prepositioning (Direct Acquisition)

The acquisition threshold performance can be improved in reducing the local code sweeping time. This is possible if the number of PN code chip positions to explore is reduced. The DLL local code has to be prepositionned within a predicted value of the received code phase (Figure 5-2).

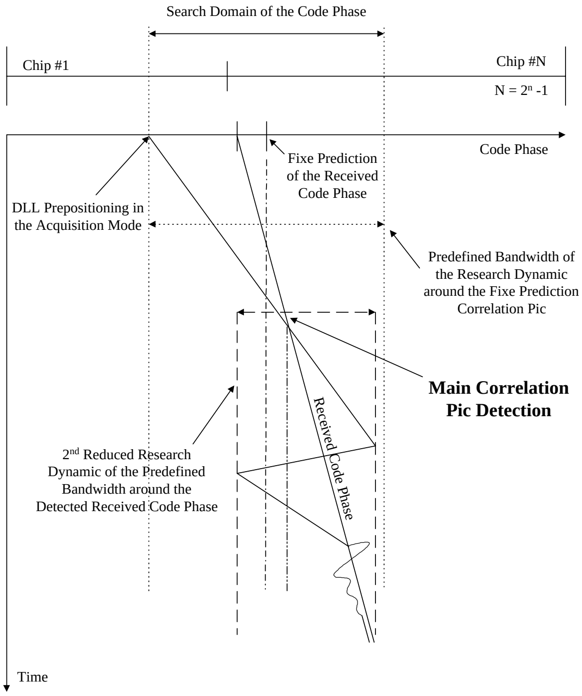

Figure 5-2 : Acquisition with Local Code Prepositioning.

Moreover, the acquisition performance can be still improved, if the local code is prepositionned in a shorter code phase range, pushed by a velocity aiding driving the code NCO. This velocity aiding is the same than for the « code only tracking » mode.

5.1.3 Aided Start with Code Prepositioning and Precise Velocity Aiding

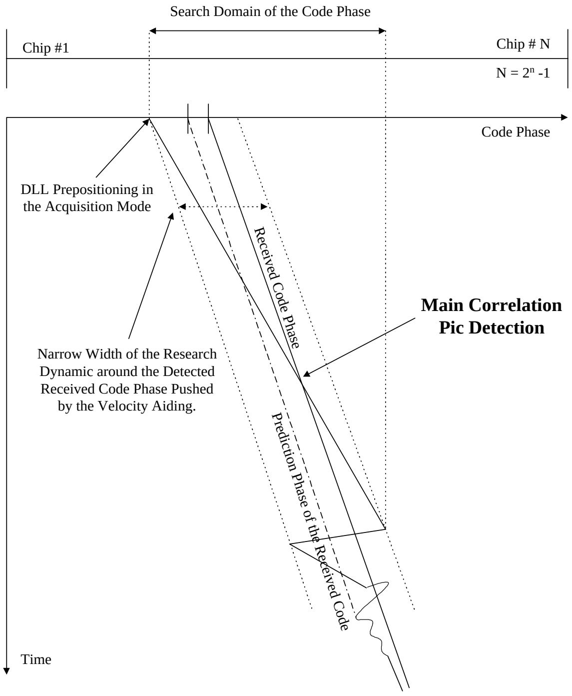

Figure 5-3 : Code ONLY Acquisition Mode.

5.1.4 Acquisition Threshold of the Code Loop

The « Code Only Acquisition » threshold $[C/N_o]_{co}$ is approximated using the following formula :

$$\left[\frac{C}{N_o}\right]_{co} > \frac{2a}{f(N_{cb})\cdot\tau}\left(\sqrt{B_{FI}\cdot\tau\cdot f(N_{cb})}+a\right)\cdot L_{co}\cdot L_{ss} \qquad (5\text{-}1)$$

B_{FI} : Pre-Detection Bandwidth,
B_{nm} : Noise Bandwidth (PR measures),
L_{co} : Code Only threshold losses due to pseudovelocity error ($L_{co}>1$),
L_{ss} : Losses due to the sweeping speed α of the DLL local code,
N_{cb} : Number of channels of the correlator,
$F(N_{cb})$: Function of the number of correlator branch ; $F(N_{cb})=N_{cb}$ or $f(N_{cb})=\sqrt{N_{cb}}$.
DPV : PseudoVelocity error, noted (see),

with :

$$L_{co}(dB) = 10 * \log\left[\frac{\sin\left(\frac{\pi\cdot\Delta PV\cdot f_o}{B_{FI}\cdot c}\right)}{\left(\frac{\pi\cdot\Delta PV\cdot f_o}{B_{FI}\cdot c}\right)}\right]^2 \qquad (5\text{-}2)$$

For $L_{co} < 3$dB :

$$abs[\Delta PV] < \frac{0.443\cdot B_{FI}\cdot c}{f_o} \qquad (5\text{-}3)$$

and

$$L_{ss} = 1 - \frac{\alpha}{2} + \frac{\alpha^2}{12} \qquad (5\text{-}4)$$

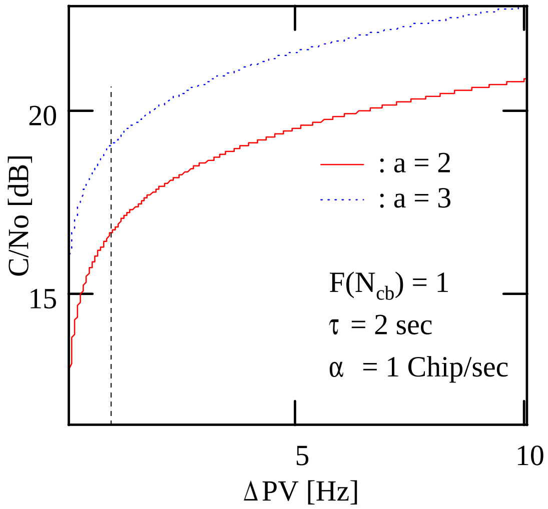

Figure 5-4: C/N_o vs Aiding Velocity Error (ΔPV).

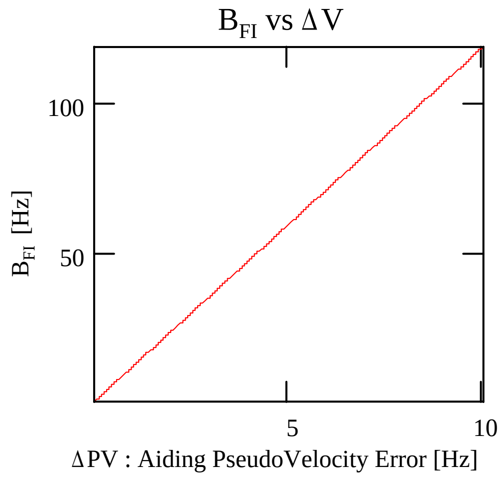

Figure 5-5: B_{FI} vs ΔV.

There is actually other investigations at CNES and SEXTANT Avionique on the acquisition threshold's reduction for the carrier loop. The next section concerns one of our current studies.

5.2 Improving GPS Acquisition in Software

Figure 5-6 shows a typical carrier loop configuration where the I and Q samples from the ASIC at 1msec (1KHz predetection bandwidth) are integrated on 20msec.

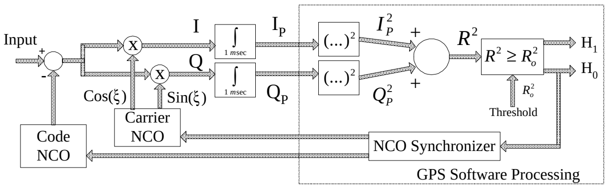

Figure 5-6 : Typical GPS Carrier Loop.

During acquisition process, if no aiding velocity is available, one can process the I and Q channels to divide the complete predetection bandwidth in a smaller slot (Figure 5-7).

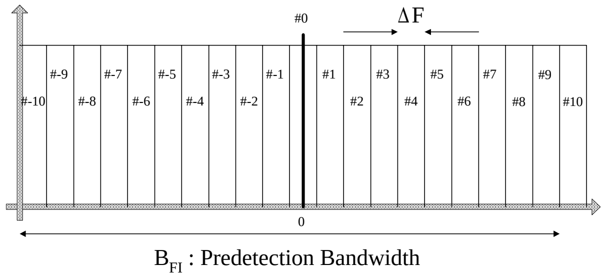

Figure 5-7 : Predetection Bandwidth Reduction.

This can be done at low rate using the following algorithm inside the GPS signal processor :

$$\begin{aligned} I_{P20}^{N} &= I_P\cdot\cos(N\cdot\Delta f\cdot t)+I_P\cdot\sin(N\cdot\Delta f\cdot t)\\ Q_{P20}^{N} &= Q_P\cdot\cos(N\cdot\Delta f\cdot t)+Q_P\cdot\sin(N\cdot\Delta f\cdot t)\end{aligned} \qquad (5\text{-}5)$$

N is all integer between -10 and +10.

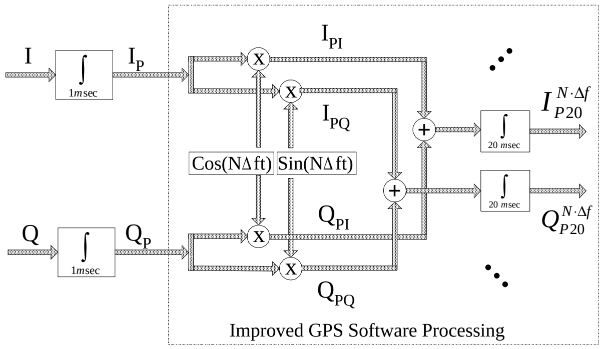

Figure 5-8 : Improved Acquisition Technique.

6. GENERAL CONCLUSION

One of the main concerns with the use of GPS is the integrity and availability of the receiver being used. The paper intends to bring a solution to improve the performance of the receiver for the channels presenting low signal to noise ratio signals. By using a velocity aiding compensation which matches the code-loop dynamic characteristic, the steady state error performance on the measured pseudorange is improved. The existing external carrier-aided code loop is typically designed with loop-bandwidth B_L = 0.5Hz, and is thus less sensitive to velocity aid errors. The results obtained show that sensibility to code-loop error is considerably reduced using internal velocity aiding. The limitations of the technique concern mainly the mission of the mobile.

Table 6-1 shows a summary of all potential threshold's reduction techniques for aeronautical and space applications.

Potential Threshold's Reduction Techniques	**ADVANTAGES**	**DRAWBACKS**
Suppression of Data Demodulation	2 or 3 dB of Threshold Reduction.	GPS Receiver Architecture Modification.
Data Wipping #1	Tracks High Dynamic Scenario	Needs SNR > 12dB and Phase Correction Filters.
Data Wipping #2	No Phase Correction.	Limited Applications
Data Wipping #3	Attitude Control	Never used.
External Velocity Aiding using INS	Tracking High Dynamic.	Expensive No Space Application.
TASAP	Autonomous	Needs Precise Velocity Aiding

Table 6-1 : Summary of Potential Threshold's Reduction.

Some application is actually requiring precise measurements and large integrity. By reducing the acquisition and tracking thresholds the GPS signals will allow to increase the range of potential applications.

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