ANTI-JAMMING SOLUTION TO NARROWBAND CDMA INTERFERENCE PROBLEM

Rabih ABIMOUSSA and René Jr. LANDRY***

ÉCOLE DE TECHNOLOGIE SUPÉRIEURE
1100 rue Notre-Dame Ouest, Montreal, Québec, H3C 1K3, Canada
Tel.: +1 (514) 396-8506 Fax: +1 (514) 396-8684
e-mail: Abir1211@lca.etsmtl.ca* and Rene.Landry@ele.etsmtl.ca**

KEYWORDS : ADP, CDMA Anti-Jamming, GPS, Adaptive Filtering, Simulink Modelisation, DSP.

SUMMARY

The main objective of this paper is to describe and simulate an adaptive interference cancelling technique named Amplitude Domain Processing (ADP) [1]. The ADP filter will improve the GPS receiver's robustness against all types of interference (coherent CW pulsed or continuous, chirp interference, etc). The ADP filter is designed in Matlab (Simulink) to show its performance and how it can be applied as an adaptive interference canceller to estimate and remove GPS jammers in a real time basis.

1. INTRODUCTION

The amplitude domain processing filter (ADP) is a statistical technique completely adaptive to all types of jammers. It allows the keep all characteristics of GPS signals while improving the signal to noise ratio (S/N) and the overall robustness gain (J/S). The ADP is a non-linear fully digital technique which uses the input down-converted GPS signal at IF (Intermediate Frequency) to detect the statistical properties of non-gaussian interference and to improve the signal to noise ratio by eliminating all interference.

The Matlab simulation allows testing the ADP filter functionality and its integrity with GPS signal and receivers. The main functions and modules of the proposed filter are exposed and the filter is simulated with various types of jammers to discuss the resulting performances. The simulations demonstrate that all sources of jammers can be cancelled using the proposed filter and the results show that the ADP technique brings between 20 to 45dB of improvement on the J/S robustness ratio.

2. OBJECTIVES AND METHODOLOGY

The civil GPS receivers still have jamming problems due to potential intentional and non-intentional jammers and this is the same for any kind of CDMA receivers. In fact, hostile environments reduce the integrity of GPS receivers which force us to search for techniques that improve this integrity (to keep the SNR high even in presence of jammers). The ADP filter is an Electronic Counter Countermeasures (ECCM) technique which acts to improve precorrelation signal to noise ratio and to enhance the anti-jam performance of GPS receivers.

A generic ADP module has been implemented on the Matlab/Simulink simulator to test the performance of this statistical technique and to validate the improvement applied to GPS signal. This paper intends to give first a theoretical overview of the ADP technique for signal to noise ratio improvement in small signal receiver. Moreover, the Matlab/Simulink modelisation of the GPS signal, jammers and ADP filter are exposed. The results of jamming scebnarios will be analysed to bring the final conclusion.

3. BASIS OF ADP TECHNIQUE

The ADP is a non-linear anti-jamming technique, which adapts these parameter to a ECM environment and exploits the statistical properties of non-gaussien jammers to reduce their effectiveness.

3.1 Theoritical basis of ADP filtering

The ADP technique uses the statistical decision theory of the input signal according to which a non-linear optimal processing on the received signal amplitude R (a strong signal jammer and a useful low power signal) is carried out for the improvement of the SNR at the input of the GPS tracking loops.

0-7803-5957-7/00/$10.00 © 2000 IEEE

The ADP technique is applied to the quadrature samples (X_i and Y_i) of an optimum receiver. The detection problem is to decide between H_1, signal present, and H_0 signal absent:

$$\begin{aligned} H_1 &: Z(t) = r(t,\theta) + W(t) \\ H_0 &: Z(t) = W(t) \end{aligned} \tag{3.1}$$

where:
Z(T) is the received bandpass signal plus interference, and
W(T) is the independent noise.

$$r(t,\theta) = s(t)\ \cos(?t+\theta) \tag{3.2}$$

where:
s(t) is the useful signal to be detected, and
? is a random phase uniformly distributed over [0, 2p].

The application of the optimum detection theory [4] brings us to a non-linear function $g(x_i,y_i)$ on X_i and Y_i channels.

$$g_x(x,y) = \frac{\partial f_{nn}/\partial x}{f_{nn}} = \frac{\partial f_{nn}/\partial r}{f_{nn}}(x/r) \tag{3.3}$$

$$g_y(x,y) = \frac{\partial f_{nn}/\partial y}{f_{nn}} = \frac{\partial f_{nn}/\partial r}{f_{nn}}(y/r) \tag{3.4}$$

This structure is still difficult to implement because it requires both full knowledge of the joint I and Q noise probability density function (PDF). The translation from the cartesian representation (x, y) to polar (R, θ) resolve this problem and the signal processing will be only on the R channel instead of the X and Y channels.

The incoming waveform is resolved into in-phases (I) and quadrature (Q) components from the RF-to-baseband converter, and digital samples are transformed to polar representation in magnitude (R) and phase (θ).

The useful non-linear ADP function become:

$$g(r) = -\frac{\partial f_n(r)/r \big/ \partial r}{f_n(r)/r} = -\frac{\partial}{\partial r}\left(Ln\frac{f_n(r)}{r}\right) \tag{3.5}$$

This non-linear function is based on the probability function density (f_n) of the signal amplitude at the AGC output. However, the PDF of the input jammed signal is primarily the same as the jammer. In fact, the power of the jammer is much higher than the useful signal, so that:

$$f_{s+n}(r) \cong f_n(r) \tag{3.6}$$

The input magnitude and phase are delayed to be synchronized with the estimator g(r) processor. This processing consists of a PDF estimation and the subsequent derivation of the non-linear function used to reassign a properly weighted value to each input sample. The stored phase is then attached to these samples which are then retransformed to quadrature from prior to final correlation and data detection (see figure 3-1). The application of the non-linear function g(r) to the input signal improves the signal to noise ratio (SNR) and eliminates non-gaussian jammers in real time basis.

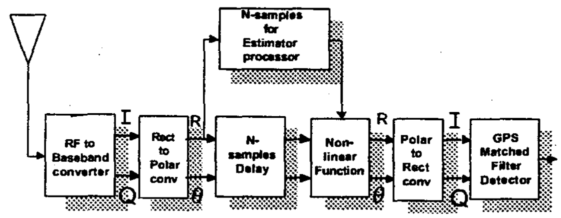

Figure 3-1: ADP interference suppression concept.

3.2 Signal to noise ratio improvement using ADP

The ADP module is intended to be integrated in an optimum receiver to increase the signal to noise ratio. The optimum receiver ratio will be a reference to additional improvement. An optimum linear receiver signal to noise ratio is given by :

$$SNR_L = \frac{E[s^2(T)]}{E[w^2(T)]} \tag{3.7}$$

where:
$E[s^2(T)]$ is the signal power, and
$E[w^2(T)]$ is the noise power.

The signal to noise ratio calculation can be based on a single channel (x or y), and on both channels (R) after conversion to polar representation.

3.2.1 Single channel SNR calculation

The input signal includes signal with noise.

$$z(t) = s(t) + w(t) \tag{3.8}$$

where:
$s(t)$ is the useful signal, and
$w(t)$ is the independent noise (thermal noise and jammer).
The output signal is the application of non-linear function to the input signal [3].

$$g(z(T)) = g(s(T) + w(T)) \tag{3.9}$$

with:

$$g(x) = -\frac{\partial f_{nn}(x)/\partial x}{f_{nn}(x)} = -\frac{f_{nn}'(x)}{f_{nn}(x)} \tag{3.10}$$

$$g'(x) = -\frac{\partial^2 f_{nn}(x)/\partial x^2}{f_{nn}(x)} + g^2(x) f_{nn}(x) \quad (3.11)$$

A limited development by supposing the useful signal is negligible compared to the noise gives:

$$g(z(T)) = g(w(T)) + g(w(T)) \cdot s(T) \quad (3.12)$$

where:

$g(w(T))$ is the filtered noise, and

$g'(w(T)) \cdot s(T) = s_g(T)$ is the useful signal after ADP filtering.

The signal to noise ratio after ADP treatment becomes:

$$SNR_{ADP} = \frac{E[s_g(T)]^2}{E[g^2(w(T))]} = s^2(T) \frac{E[g'(w(T))]}{E[g^2(w(T))]} \quad (3.13)$$

After simplification, the equation becomes:

$$SNR_{ADP} = s^2(T) \cdot E[g^2(w(T))] \quad (3.14)$$

Compared to optimum receiver, the gain becomes:

$$G_{ADP} = \frac{SNR_{ADP}}{SNR_L} = E[g^2(w(T))] E[w^2(T)] \quad (3.15)$$

3.2.2 Two channels signal to noise calculation

After conversion to polar representation (R,θ), the ADP treatment is applied to the amplitude R. The signal phase θ will be simply delayed without any treatment. Then we define the value K as fallows [4]:

$$K = \frac{K_m^2}{K_v} \quad (3.16)$$

$$K_m = \pi \int_0^{+\infty} g(r) \frac{\partial f_{nn}(r)}{\partial r} r dr \quad (3.17)$$

$$K_v = \pi \int_0^{+\infty} g^2(r) f_{nn}(r) r dr \quad (3.18)$$

The signal to noise values (SNR_{ADP}) is given by [4]:

$$SNR_{ADP} = \frac{S^2 KN}{2} \quad (3.19)$$

$S^2/2$ is the signal power and N is the number of accumulated samples. The gain factor G_{ADP} which is the ratio SNR_{ADP}/SNR_L becomes:

$$G_{ADP} = \frac{SNR_{ADP}}{SNR_L} = K\sigma_n^2 \quad (3.20)$$

where σ_n^2 is the noise variance on either the sampled I or Q channel.

The gain factor G_{ADP} calculated above is coming from the ADP treatment on the amplitude (R) channel. The ADP filtering on R is considered as a two channels signal treatment which gives a better result than a single channel process (x or y), and it is easier to implement compared to similar duplicated treatment on x and y channels.

3.3 ADP modulation and software simulation

The modelisation and simulation of the ADP filter is the ideal step providing important information concerning the filter reaction and integrity to jamming. The simulations provide us with quantization studies, parameter ajustments, gain factor measurements and its behavior in front of several scenarios of jammers.

3.3.1 Input signal modulation and characteristics

As we know, GPS systems use the spread spectrum to transmit their data. The ADP input signal is the sum of three signal generators; the useful CDMA signal generator, the gaussian noise generator and the jammer generator. The noise generator is a simple simulink block that generates a random numbers having a gaussian distribution. The sequence produced has a mean and a variance which can be specified by the user.

The useful signal generator (GPS signal) is a gold pseudo-random generator. This block produces the same sequence as the GPS which is the signal we are trying to retrieve after signal's jamming. The gold code generator is made with a series of shift registers, having a specified feedback that define the output sequence number.

The harmful types of jammer to a GPS receiver depend of their spectral position compared to GPS line spectrums. The worst interference problems can be resumed in three types of jammers which are simulated on simulink to test the ADP filter behavior to these types of jammers. The simulation can be made with one or multiple jammers combined together. These jammers are mainly continuous wave interference (CWI), pulsed wave interference (PWI) and chirp interference to estimate the Doppler. The signal is compressed at 3s using an AGC, and the signal is quantified to 8 bits. This signal representation accurate an error of –52.8dB [1].

3.3.2 ADP filter modulation

The ADP filter is a sequential type of signal processing applied to the input signal. Statistic estimation is made on 2048 samples to determine the probability density function (PDF) of the input samples. A series of mathematical operation is realized to continuously determine the non-linear function g(r). The histogram is realized via a Matlab function for which we can specify the parameters (size, number of points, etc). The estimated histogram is irregular and non-useful without an appropriate filtering and smoothing process (see figure 3-1).

A smoothing operations is applied to achieve a regular useful histogram by applying the raw histogram to a FIR filter composed from 5 symetric stages and a ponderation process. A compromise is made between the filter complexity and its effectiveness to reach a simple implementation for real time processing and to assure a good smoothing. The histogram ponderation consists to take a% from the new histogram and (1-a)% from the old histogram.

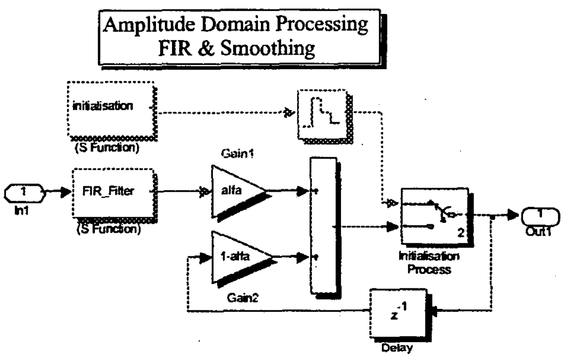

Figure 3-1 : FIR Filter and ponderation.

The histogram is the first function to measure from the input amplitude signal. It gives the distribution form of the input signal amplitude and guides the process to reach the non-linear function g(r). Good estimation allows a better non-linear function and more reliable filtered output. Histogram function based on 2048 input samples is estimated via a Matlab function. These samples produce a raw histogram.

Several operations are applied to the measured histogram before obtaining to the non-linear function g(r). First, the histogram is divided by its abcisse [-1,1] shifted to be centred at 120 instead of zero [5]. This process allows us to avoid a division by zero and it doesn't affect the output signal. Then, undergoing the natural log operation and numerical derivation, the non-linear function g(r) becomes ready to be applied to its input signal samples block and gives to the input samples a new and more appropriate values. By this way, the frequency spectrum is smoothed.

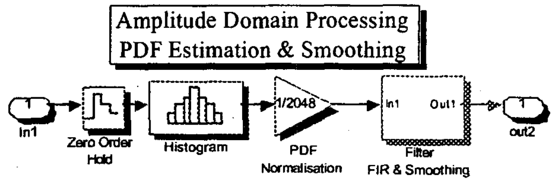

Figure 3-2 : PDF estimation and filtering.

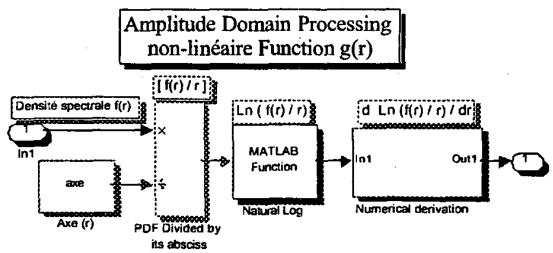

Figure 3-3 : Non-linear function calculation.

Applying the input signal to its non-linear function gives every sample a new value depending on the statistics made on the entire block of 2048 samples and the previous ones. The application of the input signal using g(r) is a simple process. The non-linear function g(r) is memorized in a lookup table, and the input samples address the lookup table to determine the output samples. These new output samples are the ADP filtered signal. Matlab S-function is programmed to realize this operation. Every sample takes its g(r) abcisse value as a new value. For example, if the sample value is 5 then its new value is g(5).

4. ANALYSIS OF ADP PERFORMANCES

The ADP performances can be verified by several methods depending on the input signal and the jamming scenario. The measured performance is derived from a Matlab/Simulink system designed specially for ADP evaluation. Variable jammers and GPS signal having defferent frequency, SNR and J/S ratio have been simulated within a test senario. During execution of each test scenario, these signals are processed through the ADP filter and then forwarded to be analysed. The maltab/simulink simulations confirm the jammers rejections. The signal spectrums at input and output of ADP filter (Figures 3-4, 3-5, 3-6, 3-7) show the jammers cancellation for all types of jammer.

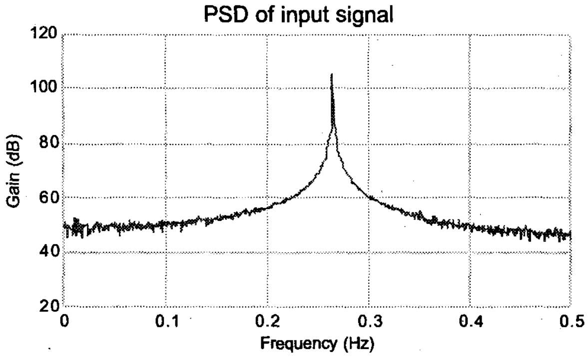

Figure 3-4: CWI jammer interference at 5.3MHz.

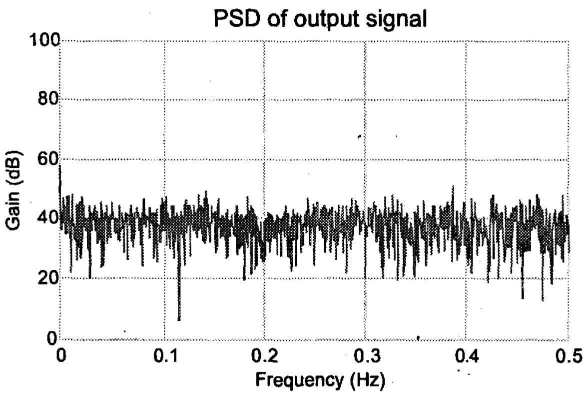

Figure 3-5: CWI jammer suppression.

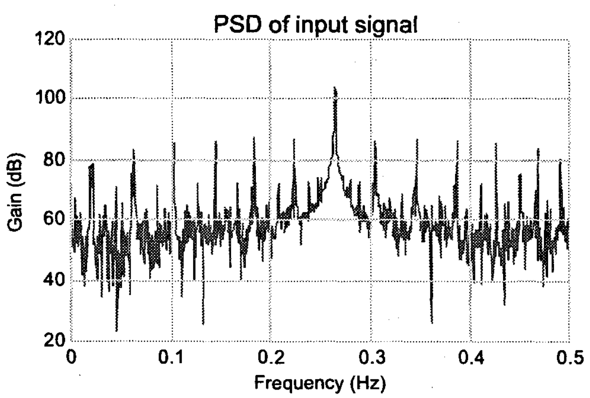

Figure 3-6: 90% Pulsed CW interference at 5.3MHZ.

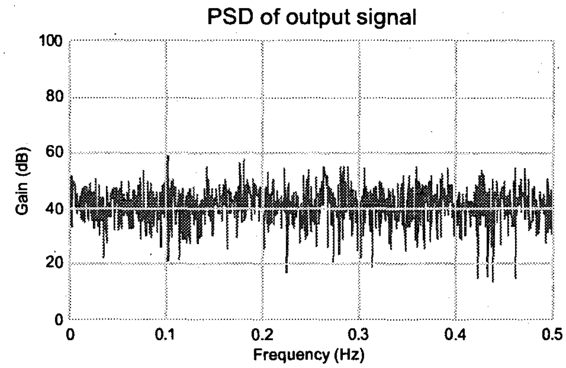

Figure 3-7: 90% Pulsed CW suppression.

The table below resumes all tests made to ADP filter and gain factor G_{ADP} is pulled out.

Jammers type	SNR_{dB}	JSR_{dB}	GAIN FACTOR G_{ADP} (dB)
CWI	-10	35	28
CWI	-10	45	30
Pulsed CW (10%)	-10	45	34
Pulsed CW (50%)	-10	45	42
Pulsed CW (90%)	-10	45	25
Swept 2MHz	-10	45	25
Gaussian noise	-30	0	-1

Table 3-1: Summary of Potential Gain Factor G_{ADP}.

Several test scenarios show the gain factor G_{ADP} when applying ADP technique to the input signal. Jammers cancellation obtained from signal to noise improvement depend on the jammer types and power (JSR).

One of our concern is to have a fast ADP filtering reaction to jammer's appearance. The aim is to suppress jammers in less then 1ms. Our sampling time is at 20Msamples/sec and the PDF estimation is based on a block of 2048 samples; the 1ms reaction time is reached after 10 iterations. The performance reached in 1ms is satisfied compared to the long-term gain.

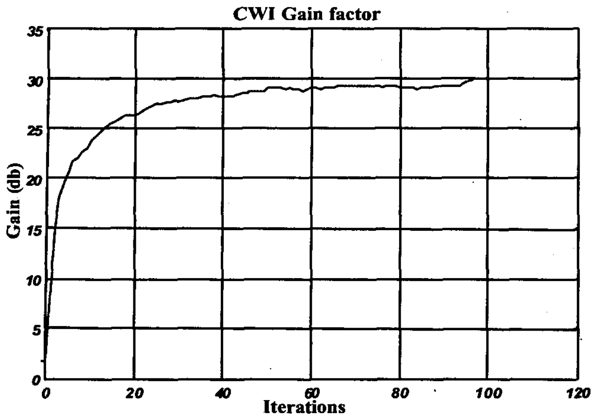

Figure 3-8: ADP Gain factor response to CWI.

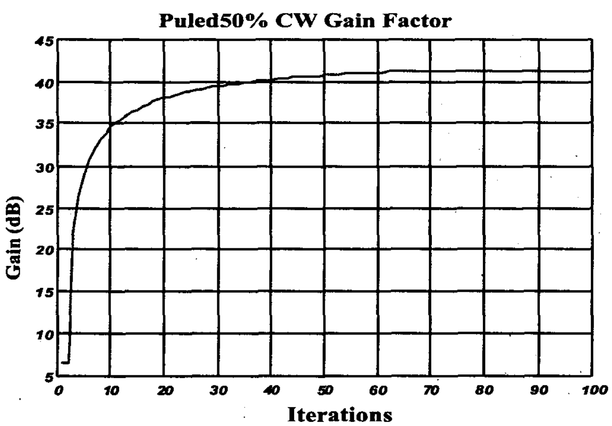

Figure 3-9: ADP Gain factor response to pulsed 50% CW.

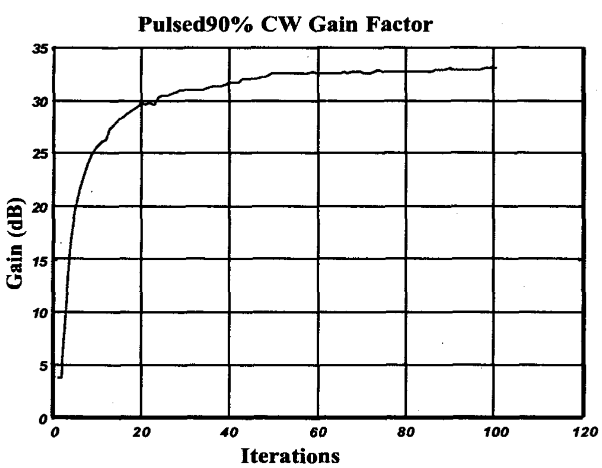

Figure 3-10: ADP Gain factor response to pulsec 90% CW.

5. General Conclusion

One of the main concerns with the use of GPS is the ability to operate in all condition and maintain integrity in hostile environment. The paper intends to expose an anti-jamming solution technique, and to explain the modelisation of this technique with software simulation. The ADP filter has been shown to provide significant improvement to GPS receivers (JSR). This ECCM precorrelation technique adapt to the jammers changing characteristics and provide near-optimal suppression of all strong jammers except for broadband gaussian. The ADP has been demonstrated in software simulation (Matlab/Simulink) to significantly suppress CW, pulsed CW and swept CW jammers.

The ADP technique can provide enhanced baseline ECCM processing for future GPS systems, and a simple ASIC insertion can provide an efficient near-term performance upgrade in current GPS receivers or any kind of CDMA receivers.

References

[1] R.Jr.Landry, « ***Technique de Robustesse aux Brouilleurs pour les Récepteurs GPS*** », PhD dissertation, SUPAÉRO-ONERA/CERT, Toulouse, 16th december 1997.

[2] R.Jr.Landry, « ***Modélisation d'un Récepteur GPS sur MATLAB : MATNAV V1.0*** », Post-Doc Report at CNES, Version 2.1, Toulouse, 5th September 1998.

[3] Algazi and Lerner, « ***Optimum Binary Detection in non-Gaussian Noise*** », MIT Lincolin Lab Report, DS-2138, 1965.

[4] J.Capon, «***Optimum Coincident Procedures for Detecting Weak Signals in Noise***», IEEE Transaction on Information Theory, 1960.

[5] Balboni, E., Dowdle, J., Przyjemski, J.,Advanced « ***ECCM Techniques for GPS Processing*** ». AGARD No. 488, Feb 1991.