IMPACT OF INTERFERENCE ON THE NEW COSSAP GPS RECEIVER AND MITIGATION TECHNIQUES EVALUATION

René Jr. Landry
Supaero / ONERA-CERT
10 Av. Edouard Belin
31055 Toulouse Cedex, France
e-mail: landry@supaero.fr
Tel.: +33.5.62.17.80.80 Ext.: 9525
Fax: +33.5.62.17.83.30

Vincent Calmettes
Supaero, Laboratory of Electronics and Physics, Toulouse, France
Tel.: +33.5.62.17.80.80 Ext.: 9525
Fax: +33.5.62.17.83.30

Alain Ducasse
Supaero / ONERA-CERT
10 Av. Edouard Belin
31055 Toulouse Cedex, France
e-mail: landry@supaero.fr
Tel.: +33.5.62.17.80.80 Ext.: 9525
Fax: +33.5.62.17.83.30

BIography

The author is presently a final year PhD Research Student at the ONERA-CERT / SUPAERO, Toulouse, France. René Jr. Landry received a Diplôme d'Études Approfondies (DEA) in Microwave Engineering from the ENSAE in 94, an MSc in Satellite Communication Engineering from the University of Surrey (UK) in 93 and has graduated from the École Polytechnique de Montréal (Canada) in 92. He is currently a trainee staff member at ESTEC-ESA (Noordwijk) where his major activity consists of testing a new interference suppression filter on different GPS Receivers.

Vincent Calmettes is an Engineer at SUPAERO, Laboratory of Electronics and Physics. He manages, within the laboratory, the division « Signals, Communications and Navigation » and teaches signal processing and communications. His work includes the research, for applications in Digital communications and Signal processing, of solutions with DSP processors and Programmable logic devices or ASICs.

Alain Ducasse was born in France in 1971. He received the Dipl. degree in electrical engineering from the École Nationale Supérieure d'Électronique, d'Électrotechnique, d'Informatique et d'Hydraulique de Toulouse in 1993, and the Ph.D. degrees in Signal Processing from the National Polytechnics Institute of Toulouse in 1997. He is actually doing one's military service in the École Nationale Supérieure de l'Aéronautique et de l'Espace. His technical interests are estimation theory and digital signal processing.

Nevertheless, it appears in many papers and reports that GPS Receivers may be perturbed by several kinds of interferences [1],[4]. These interferences are already known at this time, since the near future civil projects of aircraft navigation using the GPS System and their impact is becoming to be well understood [2]. However the Mitigation Techniques to reject these interferences and to improve the pre-correlation signal-to-noise ratio are still to be developed to enhance the GPS Receiver robustness.

This paper starts with a short review of the GPS Receiver phase of perturbations and a synthesis amalgam of potential Pre-Correlation mitigation solutions for the GPS Receiver. Our study is an investigation of one potential mitigation technique for electromagnetic interference rejection on the GPS C/A-code of a receiver operating in aeronautical environment.

Section II shows the basic principle of one way of implementing the Adaptive Transversal Filter Solution.

In order to evaluate an anti-jamming filter for civil use, a GPS Receiver Simulator was found to be useful. Because the software-based receiver is more flexible, less expensive and more accurate compared with the hardware receivers in receiver designs and GPS Application System Analysis, a Generic GPS Receiver has been implemented in a software, named COSSAP, to validate the technique developed in this paper.

Section III of this paper describes the COSSAP Generic GPS Receiver design for this application. Using Monte-Carlo Simulations, the Pre-Correlation DSP solution is tested to show the performances and the improvement.

It appears that using a notch filter in DSP just after the ADC (Analogue-to-Digital Converter) and before the numerical loops (DPLL and DDLL) permits large improvements over the normal configuration. Attenuation of CWI's (Continuous Wave Interference) from 30 to 55dB have been measured.

ABSTRACT

Over the past few years, many projects using CDMA techniques have been studied and now already exist or are under construction. Civil GPS navigation represents only one potential application of CDMA in Signal Communication. These Systems are known to have many advantages over FDMA and TDMA, one being its robustness against interferences.

1 GPS: Global Positioning System.
This paper is not restricted to the GPS community but intends to give an overview of the Notch Filtering well suited for Code Division Multiple Access as a potential Mitigation Technique. The paper applied the technique to a GPS Receiver to show the feasibility of the work and the last section shows the testbed of a hardware filter connected to a GEC Plessey GPS Receiver (Builder Kit II) and the results obtained in this configuration.

1. INTRODUCTION

In the studied configuration, the useful signal is a White Gaussian Noise (WGN known as wide spectrum) which represents the thermal noise of the GPS Receiver, while the interferences (signals to be rejected) are narrowband signals. The modelling of the useful signal by a white gaussian noise is especially interesting for spread spectrum transmissions (GPS, for example). The information is modulated by different spectral lines which have a spectral density power, at the receiver antenna, below the noise level (essentially thermal noise). The de-spreading operation allows the information to be extracted from the noise. Nevertheless, this operation may be highly disturbed by the presence of interferences.

This paper proposes a method for signal rejection taking into account features both in the time and the frequency domains because of the non-stationary interference characteristics. This method involves two steps. First, an LMS (Least Mean Square) Algorithm converges on the central frequency of the interference by minimising the power of the resulting filtered signal. The calculated coefficients of the filter are transferred to the rejection section of the filter to eliminate the interference. This is the main subject of Section II.

Degradation of the Quantification

Figure 1-1: Interference Effects on a GPS Receiver.

Figure 1-1 shows a basic GPS Receiver Architecture with the interference perturbation effects which may occur within the sub-sections of the receiver. In the RF section, the interference may saturate the pre-amplifier and the filters may produce Intermodulation Products (IMP). The AGC (Automatic Gain Control) will degrade the quantification process of the ADC (Analogue-to-Digital Converter) by compressing the IF signal, which may include interference, in the range of the ADC. This last component may enter in saturation region and therefore cut the signal to generate harmonics. All these combining effects may reach the Digital Receiver Channels, affecting the signal to noise ratio and the pseudo-measurements where at this stage of the perturbation, the navigation process is affected due to the BER Degradation.

Sometimes during these phases of perturbations or otherwise occasionally, cycle slips will occur. Furthermore, the loss of DPLL (Digital Phase Lock Loop) and DDLL (Digital Delay Lock Loop) brings the receiver completely out of order.

Table 1-1 is a review of all potential Pre-Correlation Techniques [2]. They are labelled and listed bellow:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
<td>E</td>
<td>F</td>
<td>G</td>
</tr>
</tbody>
</table>

Table 1-1: Review of Mitigation Techniques.

(Pre-correlation DSP)

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - Low cost.</td>
<td>Not good for In-Band Interference</td>
</tr>
<tr>
<td>B - Simple Technology.</td>
<td>Antenna not effective</td>
</tr>
<tr>
<td>C - Good for Out-of-Band Interference</td>
<td></td>
</tr>
<tr>
<td>D - High power In-Band Jammers.</td>
<td>Cycle Slips</td>
</tr>
<tr>
<td>E - Effective against non-gaussian jammers.</td>
<td>Cycle Slips</td>
</tr>
<tr>
<td>D - Effective against any kind of jammers (except gaussian).</td>
<td>Cycle Slips</td>
</tr>
<tr>
<td>E - Good Performance against multiple jammers.</td>
<td>Cycle Slips</td>
</tr>
<tr>
<td>F - Same as ADP.</td>
<td>Cycle Slips</td>
</tr>
<tr>
<td>G - 20 to 35dB of gain for narrow band jammer.</td>
<td>Cycle Slips</td>
</tr>
<tr>
<td>G - Effective against large intentional jammers. (Narrow and wideband)</td>
<td>Cycle Slips</td>
</tr>
</tbody>
</table>
For the Post-Correlation Techniques refer to References [2] & [15] for more details. There can be found a brief description of Extended Adaptive Code Loop, Vector Tracking Loop, Integrated Inertial Aiding and Adaptive Tracking Loop Bandwidth. These Post-Correlation Techniques are complex, they usually need some internal receiver modifications, and, are expensive.

The independence of the cascaded form is discussed in papers [6]-[9] and it is appropriate to characterise the individual second order stages of the form:

\[ H(z) = \frac{1 - 2\cos \omega z^{-1} + z^{-2}}{1 - 2\alpha \cos \omega z^{-1} + \alpha^2 z^{-2}} \]  

(2-2)

where \( 0 < (1 - \alpha) << 1 \).

The Figure 2-1 is a spectral representation of the notch being generated by the Transfer Function \( H(z) \).

![Figure 2-1: Transfer Function of \( H(z) \).](image)

The main parameters of this filter are the notch bandwidth and its central frequency.

The filter presents a numerical zero on the unit circle at the rejected frequency as shown in Figure 2-2. The pole at the same frequency as the zero will adjust the width of the rejected band.

![Figure 2-2: Position of Zeros and Poles of \( H(z) \).](image)

2. THE NOTCH FILTER STRUCTURE & ALGORITHM

The following equation form of the Notch Filter has been considered in many papers [6]-[9]:

\[ H(z) = \prod_{k=1}^{n} \frac{1 - 2\cos \omega_k z^{-1} + z^{-2}}{1 - 2\alpha_k \cos \omega_k z^{-1} + \alpha_k^2 z^{-2}} \]  

(2-1)

where:

- \( n \) is the number of notch,
- \( \omega_k \) represents the notch frequencies,
- \( \alpha_k \) the corresponding pole contraction factor.

The \( \alpha_k \) determines the bandwidth of the notches which are proportional to \( 1 - \alpha_k \) (see below).
The Figure 2-3 is a zoom on the Magnitude of the Notch Filter being generated by a module of the COSSAP Software. Figure 2-4 represents the Phase of the Filter for the same simulation.

![Zoom on Phase of H(z)](image)

**Figure 2-4: Zoom on the Phase of Function H(z).**

Both figures show curves for 6 different values of the parameter $\alpha$. A smaller $\alpha$ gives a larger bandwidth and vice versa.

The poles of the filter in equation (2-2) are slightly displaced towards the origin by the contraction factor $\alpha$ which is close to, but less than unity.

As desired, the magnitude of the transfer function of this filter is approximately unity everywhere, except at the true sinewave frequencies where it is zero. The Bandwidth ($B_{3\text{dB}}$) in radians of the notch created by each pole-zero pair is approximately given by the following equation (2-3).

$$B_{3\text{dB}} = \frac{1 - \alpha}{\pi}$$

(2-3)

3. Model of The Generic COSSAP GPS RX

3.1 Brief Description of the COSSAP GPS RX

This section is a short description of the all-digital baseband GPS correlation processing which has been modelled mathematically and implemented in the software simulator [1]. Figure 3-1 shows the Generic GPS Receiver which has been implemented numerically on the COSSAP Software.

![Figure 3-1: Generic COSSAP GPS Receiver.](image)

The model includes the three main sections of a Communication System, the GPS Transmitter, the Channel Module and the Generic GPS Receiver. The Satellite Module is fully programmable to generate a specific GPS signal in the baseband modulated with a Navigation Message. The COSSAP GPS Model includes also a Double Dwell Search Strategy for Code and Carrier acquisition which activates the Tracking Module when GPS signal is synchronised to the local Pseudo-Noise C/A Code (see Figure 3-1).

The GPS Channel Module includes all GPS signal perturbations, such as the Doppler effect, thermal noise (SNR), effects of RF Filters, atmospheric degradations and external interferences. Figure 3-2 shows the block diagram of the Channel Module.

![Figure 3-2: Representation of the GPS Channel.](image)

The pseudorange time delay is measured by accurately tracking the PRN code phase of the input GPS signal using a digital energy detector in a fully programmable digital early-late Delay Lock Loop (DDLL, Figure 3-3).

![Figure 3-3: Digital Delay Lock Loop (DDLL).](image)
Code synchronisation and despreading are performed prior to carrier phase tracking since sufficient signal-to-noise ratio (SNR) is necessary for the DPLL to operate successfully. After the PRN code is removed, the SNR is increased by the despreading gain.

Figure 3-4 is a simplified functional block diagram of the Digital Baseband Processor DBP of the Generic COSSAP GPS Receiver.

![Block Diagram of the COSSAP GPSRx](image)

**Figure 3-4: Block Diagram of the COSSAP GPSRx.**

The advantages of this Receiver result from the inherent flexibility of its architecture. The COSSAP software model design make it easy to reconfigure and it is ideal for a variety of System Feasibility, Assessment and Application Validation.

The design philosophy was to provide a fully controlled structure to the user in order to provide fast signal acquisition and signal processing parameters to be adjusted. Table 3-1 shows some examples of the controlled command parameters. Some of them allow the receiver to select the satellite to be received and also to adjust the tracking bandwidth, the data rates and the sampling rates.

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>FUNCTIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>$f_s$</td>
<td>Sampling Rate</td>
</tr>
<tr>
<td>Num Sat</td>
<td>Satellite Selection</td>
</tr>
<tr>
<td>$R_D$</td>
<td>Navigation Data Rate</td>
</tr>
<tr>
<td>Data On Off</td>
<td>BPSK Modulation</td>
</tr>
<tr>
<td>$T_{int_DPLL}$</td>
<td>Integration Time of DPLL</td>
</tr>
<tr>
<td>$T_{int_DDLL}$</td>
<td>Integration Time of DDLL</td>
</tr>
<tr>
<td>Coeff[$\alpha$]</td>
<td>Filter Loop Coefficient</td>
</tr>
<tr>
<td>GD and GP</td>
<td>DDLL and DPLL Loop Gains</td>
</tr>
<tr>
<td>SNR</td>
<td>Signal to Noise Ratio</td>
</tr>
<tr>
<td>J/N</td>
<td>Jammer to Noise Ratio</td>
</tr>
</tbody>
</table>

*Table 3-1: Some Parameters of the COSSAP GPSRx.*

The fully programmable characteristics also include predetection bandwidth, loop filter order and bandwidth, AGC characteristics, C/N$_0$ measurement, etc.

The features of this highly generic new digital mechanisation are its potential:
1. to evaluate anti-jamming technique on a GPS receiver,
2. to improve the quality of the signal reception,
3. to evaluate different loop discriminators and architecture,
4. to test many scenarios on specific Application Systems.

![Code Phase Discriminator](image)

**Figure 3-5: DDLL Code Phase Discriminator.**

Figure 3-5 shows an example of the DDLL Code Phase recovery which is one of the most important measurements of the receiver.

![DDLL Transient Responses](image)

**Figure 3-6: DDLL Transient Response.**

Figure 3-6 shows the Transient DDLL Response analysis which can be observed during the acquisition mode. The overall designed structure will help us in several stages of the Mitigation Technique Elaboration.

### 3.2 Impact of the CWI on the COSSAP Model

For this first experiment, a fixed CWI is introduced inside the Channel Module of COSSAP as shown in Figure 3-7. Figure 3-8 shows the phase variance error of the Code Loop as a function of the Interference to Signal power ratio with and without the Notch Filter. In this first configuration, the CWI is at 1.023MHz of
the sampled GPS signal of \( f_s = 4.092 \text{Msamples/sec} \). The CWI is located between the main lobe and the first sidelobe of the useful GPS signal.

**C/A Baseband Signal**

![Diagram](image)

**Figure 3-7: Fixed CWI in a GPS Signal.**

The Notch Filter processes the first few input samples to converge rapidly on the central frequency of the interference. Even during the rejection process, the algorithm will refresh its filter coefficients in real time to track the interference.

For all the simulations, the GPS Signal to Thermal Noise Power ratio was -20dB.

![Table](image)

**Figure 3-8: Process with CWI at \( f_s = 1.023 \text{MHz} \).**

Figure 3-9 represents the same scenario with the interference placed at 401.9KHz.

![Table](image)

**Figure 3-9: Process with CWI at \( f_s = 401.9 \text{KHz} \).**

The results are interesting. In Figure 3-9, the CWI is at the frequency 401.9KHz which is directly inside the main lobe of the GPS signal. It should be remembered that nearly 95% of the useful GPS signal energy is contained within the main lobe [4].

### 3.3 Impact of the Chirp CWI on the Model

![Diagram](image)

**Figure 3-10: GPS Signal with a Chirp CWI.**

In this last configuration, a chirp CWI is introduced inside the Channel Module of COSSAP as shown in Figure 3-10. The CWI is swept from the Shannon Frequency (0.5) down to zero. The CWI power was fixed to 20dB above the thermal noise power.

![Table](image)

**Figure 3-11: Results Obtained using a Notch in Presence of a Chirp CWI.**

Figure 3-11 shows the phase variance error of the Code Loop in function of the CWI position in the GPS Spectrum.

The results are conclusive; for all tested situations, the Notch Filter Mitigation Technique gives an excellent improvement on the GPS signal reception. The limit of the Notch Filter Processing is only a function of the type of interference. For CWI, Chirp CWI and Narrowband Interferences, Notch Filter performs also very well on many other MonteCarlo Simulations [1].
4. GPS SIGNAL DEGRADATION USING NOTCH FILTER

To evaluate the degradation introduced on a GPS Signal, measurements of the correlation loss between an ideal GPS signal and one filtered with a notch filter are simulated. Our objective is to introduce a maximum correlation loss as low as 1 dB in the absence of interference. The simulation has been done with the COSSAP Software using the integrated Generic GPS Receiver Software Modules.

We give here the results obtained for a GPS Signal centered in the baseband and sampled at 4.092M samples/sec, which means that only the principal GPS lobe and the first sidelobe are used.

We consider a notch with variable bandwidth (a between 0.9 and 0.999) sweeping the GPS Spectrum Signal. The block diagram of the simulated model is shown in Figure 4-1.

![Ideal GPS Signal → H(f) → Correlation → Notch Filter](image)

Figure 4-1: Estimated Correlation Loss Procedure.

Our correlation process is normalised in such a way that when using the Notch Filter, the correlation gives directly a good estimation of the GPS Correlation Loss.

![GPS CORRELATION LOSS](image)

Figure 4-2: Estimated GPS Correlation Loss for a Notch of 0.9<α<0.98.

Figure 4-2 shows the results of the GPS Correlation Loss for the parameter α between 0.9 and 0.98. On the x-axis, one can see the central frequency of the notch and its estimated correlation loss on the y-axis. Each curve contains 200 points, i.e. 200 correlations over 1 msec. We remind one GPS characterisation, let’s say the line spectrum spacing of 1 KHz. The figure demonstrates that the correlation loss depend strongly on the central frequency of the notch, and furthermore this degradation will increase with the GPS spectrum energy. Moreover, in Figure 4-2, we can see that this degradation increased rapidly with the 3 dB bandwidth of the notch due to the fact that the same notch with larger bandwidth will reduce the spectral energy of a larger number of GPS spectral lines and at the same time, the notch will introduce a larger out-of-band phase distortion.

While reducing the notch bandwidth, we reduce the GPS degradation and it turns out that this degradation due to one spectral lines elimination can be observed.

Figure 4-3 shows the correlation results for values of α from 0.99 and 0.998. These values are found to be suitable and completely acceptable for a single notch.

![GPS CORRELATION LOSS](image)

Figure 4-3: Estimated GPS Correlation Loss for a Notch of 0.99 < α < 0.998.

![GPS CORRELATION LOSS](image)

Figure 4-4: Estimated GPS Correlation Loss for a Notch of 0.995 < α < 0.999.
In Figure 4-4, a frequency zoom on the region where is concentrated the major part of the GPS signal energy (main lobe of the GPS Signal) is represented. The results were obtained for values of $\alpha$ very near to unity (from 0.995 to 0.999) corresponding to a denormalised bandwidth at 3 dB of 6.4 KHertz and 1.2 KHz using a sampling rate of 4.092 Msamples/sec. The normalised frequency step for this simulation is 0.0001, corresponding to 400Hz. This means that the position of the notch was moved 400Hz between each simulation. With a notch bandwidth of the order of 1KHz we eliminate, from the spectrum, only one line each time during the sweep and the out-of-band phase distortion is practically negligible. This is probably the optimum that one can do to observe the line spectrum influence.

It is found that we need a value of $\alpha$ large enough to obtain acceptable GPS degradation but small enough to obtain an efficient rejection process. To define with precision this range for the filter parameter $\alpha$, more simulations were performed.

![CWI ATTENUATION](image)

Figure 4-5: Measurement Rejection on a CWI using a Quantified Notch Filter.

The quantization effect of the filter has been observed by measuring the obtained attenuation of a CWI fixed at the central frequency of the Quantized Notch Filter.

To resolve the numerical problem during simulations, we have added a sinusoid to a very small White Noise Signal (SNR = 80dB). The results are represented for the two extremities of the parameter $\alpha$ (0.9 and 0.995).

One can notice that the definition of the number of bits used for the filter coefficients is critical. To obtain a very narrow notch, it is necessary to increase the number of bits of the filter coefficients. This was another factor to take into account during the design process because of the complexity of building the filter inside a limited physical space (FPGA, XILINX).

5. HARDWARE EXPERIMENT USING NOTCH FILTER

Figure 5-1 shows the modifications to the GEC Plessey GPS Receiver in order to connect the filter. The goal is to access the amplitude and the sign inputs of the GP2021 IC (the 12 Channels Correlator of GEC Plessey, ([5] for more details) and to get the sampling clock out of the receiver which can be found between the GP2010 (the Receiver Front End) and the Digital Correlators. These inputs are TTL compatible signals and can be accessed simply by raising 2 chip resistors.

On the same figure, one can see the short-circuit connector for the normal operation and the analogue IF GPS signal output ready for filtering.

![Figure 5-1: Small Modifications to the GEC Plessey GPS Receiver for the Notch Filter Integration.](image)

Figure 5-1: Small Modifications to the GEC Plessey GPS Receiver for the Notch Filter Integration.

![Figure 5-2: Structure of the Notch Filter.](image)

Figure 5-2: Structure of the Notch Filter.

Figure 5-2 represents a simplified block diagram of the designed Notch Filter. The Analogue IF Signal will first encounter a 12 bit ADC (up to 41MBPS) after where the sampled data is stored into a FIFO memory (First In First Out) to allow the required time to the DSP for algorithm convergence. At the same time, the digital GPS signal is filtered on a real time basis by the notch filter applying the coefficients calculated by the DSP (a TMS320C31). Figure 5-3 shows the complete
filter ready for interference rejection and is simple to insert into any digital receiver.

The useful IF signal is of 1.9MHz bandwidth centered at 4.309MHz. Figure 5-6 shows the useful IF spectrum.

The first experiment was concerned with the intentional jamming of the GEC Plessey GPS Receiver.

The SNR Measurements have been recorded and they are presented in Figure 5-7 while sweeping during 200sec a CWI of power -80dBm from [L1 + 2MHz] to [L1 - 2MHz] (as shown in the Figure 3-10). This result is quite bad and it must be interpreted together with other pseudo-measurements.

Even if the SNR Ratio seems to increase during the presence of the CWI in the central L1 band (95% of the
useful GPS signal), the pseudo-distance (Figure 5-8) and the pseudo-speed (Figure 5-9) are completely useless information and it was possible to observe the GPS Receiver completely lost and unreliable.

![Observed Pseudo-Range Rate](image)

**Figure 5-9: Observed Pseudo-Range Rate.**

One step further on the analysis was to introduce the notch. Figure 5-10 shows the frequency spectrum of the IF signal when a notch using a parameter \( \alpha = 0.953 \) is inserted to the signal.

![Notch spectrum](image)

**Figure 5-10: Notch using \( \alpha = 0.953 \) at 1.403 MHz.**

Figure 5-11 shows the extreme scenario where a -55dBm CWI is presented at the L1 Band and when a notch filter of \( \alpha = 0.953 \) is activated. The attenuation of the CWI was measured to be 48dB and the GEC Plessey receiver still continued to navigate properly.

![Attenuated CWI spectrum](image)

**Figure 5-11: Spectrum of a 48dB Attenuated CWI (Input power of -55dBm using \( \alpha =0.953 \)).**

The results of Figure 5-12 illustrate a scenario where a CWI mixed in with the RF have an increasing power of 5dB every 30 seconds. The measurements show that with a CWI of -80dBm, the GEC Plessey Receiver is completely unreliable (even with -90dBm !). When applying the Notch Filter to the signal, the power of the CWI can go up to -75dBm without any perturbation of the SNR measures. The reaction of the GPS Receiver was as if there were no interference at L1. The limitation of the filter seems to be reach at the power of -65dBm which corresponds to a very strong narrowband interference.

![SNR Variation Function of CWI Power](image)

**Figure 5-12: Observed SNR with and without Notch Rejection.**

Finally, Figure 5-13 is the measured attenuation of a -80dBm CWI on the complete Shannon Frequency Band. The attenuation is between -30 and -50dBm.

![Measured Attenuation](image)

**Figure 5-13: Measured Attenuation Achieved by the Notch on a -80dBm CWI.**

The result of the simulations showed in Figure 4-5 is near reality and seems to confirm the accuracy of our model.

**GENERAL CONCLUSION**

In this paper, an interference suppressing method which employs a Notch Filter was presented. The proposed Narrow Band Interference Suppressor comprises entirely digital signal processing, so it is suitable for LSI
implementation which ensures low cost and high stability.

The Notch Filter Method minimises the signal energy by adjusting a notch at the best position around the interference. Contrary to the conventional FFT based processing method removing almost totally the spectral energy around the interference, the notch filter can adjust the bandwidth to the best fit of the interference shape and achieve a minimum phase distortion. Simulations on the COSSAP Generic GPS Receiver show clearly the good efficiency of Notch Filter when applied to a Spread Spectrum Signal.

The paper intends to present a solution to improve the performance of the receiver in the presence of interferences. Simulation results show that the interference cancellation technique using a Notch Filter is efficient against major kinds of Narrow Band Interferences. A filter has been designed in hardware and integrated to a GPS Receiver to show the improvement on SNR and Pseudo-measurements.

Or course, the limitations of the filter concern the wideband interference which were not taken into account in this paper. Other techniques such the ones summarised in Section 1.1 can be used for these particular interferences.

Once again, for those of us who believe in the field of Digital Signal Processing are prone to believe that Telecommunication and Electronic Systems are just becoming an application of DSP.

ACKNOWLEDGEMENTS

The author would express grateful thank to the STNA for the financial support of this program. Thanks also extend to M.Vincent Caillettes, Dr. Alain Ducasse and Prof. Michel Bousquet for all their support during the phase of the simulation and realisation.

REFERENCES


