# STUDY ON GPS RECEIVER ALGORITHMS FOR SUPPRESSION OF NARROWBAND INTERFERENCE

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## ABSTRACT

Despite the inherent resistance to narrowband signal interference afforded by GPS spread spectrum modulation, the low level of GPS signals makes them susceptible to narrowband interference. This paper discusses the application of a pre-correlation adaptive temporal filter for stationary and nonstationary narrowband interference suppression. Various adaptive algorithms are studied and implemented. Comparison of the convergence and tracking behavior of various algorithms is made.

## KEYWORDS

GPS Receiver, Narrowband Interference, Interference Suppression, Adaptive Temporal Filter

## I. INTRODUCTION

As GPS becomes an essential element of the civil infrastructure in the areas of aviation, ground transportation, communications, and power distribution, its vulnerability to interference must be addressed. Unintentional interference typically takes the form of a narrowband signal. Despite the inherent resistance to interference afforded by GPS spread spectrum modulation, the low level of GPS signals makes them susceptible to narrowband interference.

This paper discusses the application of a pre-correlation adaptive temporal filter for stationary and nonstationary narrowband interference suppression. Various adaptive algorithms are studied and implemented. Comparison of the convergence and tracking behavior of various algorithms is made.

## II. PREVIOUS WORK

To mitigate narrowband interference, several hardware and software function have been applied in GPS receiver designs. Figure 1 illustrates the generic digital GPS receiver block diagram with five numbered areas where the RFI mitigation techniques can be applied. The interference suppression techniques can be divided into pre-correlation and post-correlation techniques. The techniques associated with each of these numbered functions will be described below[1].

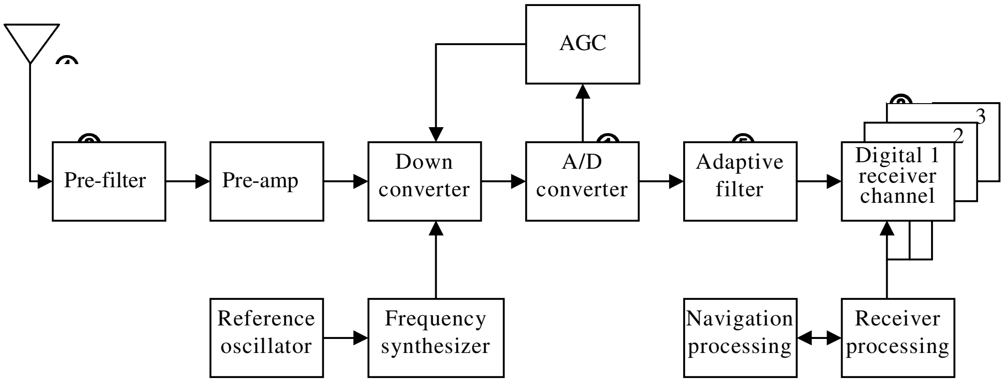

Figure 1 Generic digital GPS receiver with five anti-jam techniques points.

1. Adaptive A/D conversion technique

The first technique is adaptive A/D conversion. According to Amoroso the adaptive A/D converter moves the quantization levels towards the peak of the CW interference thereby preventing capture of the A/D converter by CW interference. This technique will improve the interference threshold by 6 dB[2], but it is still insufficient in hostile environments.

2. Front-End Filtering Techniques

The second technique is front-end filtering. Front-end filtering protects the GPS receiver from high-powered transmitters that are out of band with respect to the GPS L-band spectrum allocations. A sharp cut-off notch filter is often used when the interference is known and out of band. Performance penalties result from placing a passive filter between the antenna and the preamp, which will increase the noise figure and will not suppress the interference in pass band.

3. Code/Carrier Tracking Loop Techniques

The third technique is enhancement of the code and carrier tracking loops. This technique involves the use of internal aiding enhancements, external navigation aiding enhancements, closed carrier tracking loop aiding and open carrier tracking loop aiding.

4. Adaptive antenna array

The forth technique is implemented at the antenna area, where adaptive antenna arrays can be used to mitigate narrowband and broadband interference. The antenna pattern is adapted in such a way so as to steer nulls in the direction of interfering sources, which is called a controlled reception pattern antenna (CRPA). The disadvantage is the high real estate and the complex RF electronics required to control the phase of the antenna array[3].

5. Adaptive temporal filter

The fifth technique is adaptive temporal filter, which is usually implemented as a tapped delay line whose weights are updated using an adaptive algorithm. The ATF is used as a linear predictor to predict the interference in the received GPS signal from its past samples. More about ATF will be discussed in section III.

## III. ADAPTIVE TEMPOTAL FILTERS

A lot of literature exists on the cancellation of narrowband interference in GPS receiver using adaptive temporal filters. The feature common among all the adaptive filter structure is filter weights that are adapted according to some cost function. In this work the cost function is the mean square error (MSE). The algorithm used to determine filter weights is known as an adaptation algorithm. Based on the adaptive filtering approach, the algorithm can be categorized as least mean squares (LMS) algorithm, transform domain based LMS (TDLMS) algorithm, gradient adaptive lattice (GAL) with joint process estimation and recursive least squares (RLS) algorithm.

1. Least mean squares (LMS) algorithm

In the LMS algorithm[4], an instantaneous estimate of the gradient of the cost function J is made and the weights are updated in the direction opposite to the direction of the gradient. The weight update equation is given as

$$w(k+1) = w(k) - \mu \hat{\nabla}(J(k)) \qquad (1)$$

where $\mu$ is the step size parameter which controls the rate of convergence and $\hat{\nabla}(J(k))$ is the instantaneous estimate of the gradient of the cost function. The gradient vector estimate is calculated from the estimated values of cross-correlation vector $\hat{p} = u(k)d(k)$ and input correlation matrix $\hat{R} = u(k)u^T(k)$. The gradient estimate is then given as

$$\hat{\nabla}(J(k)) = \hat{R}\, w(k) - \hat{p} = -u(k)[d(k) - u^T(k)w(k)] = -u(k)e(k). \qquad (2)$$

2. Transform domain based LMS (TDLMS) algorithm

This algorithm attempts to de-correlate the inputs by preprocessing them with a transformation that is independent of the input signal. As shown in figure 2 the algorithm is composed of three stages.

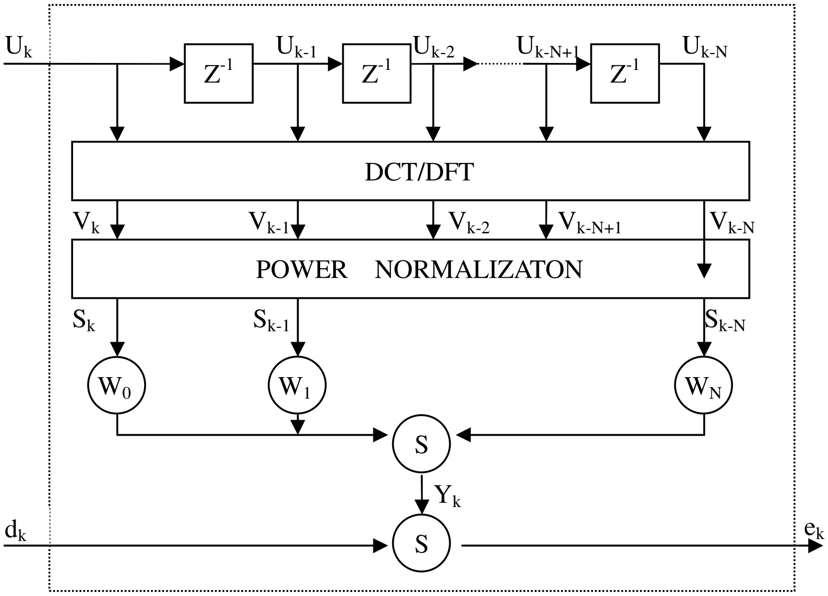

Figure 2 Transform domain LMS block diagram

First, the tapped delay inputs are preprocessed by DFT or DCT. The transformed signals are normalized by the square root of their power. The resulting signals are then input to an adaptive linear combiner whose weights are adjusted using the LMS algorithm.

The algorithms steps are given below[4]:

a. Transformation of input signal vector

$$v(k) = Tu(k) \qquad (3)$$

where transform T is the DFT or DCT.

b. Power normalization

$$s_i(k) = v_i(k) / \sqrt{P_i(k) + \varepsilon} \quad i = 0 \text{ to } N-1 \qquad (4)$$

$$P_i(k) = \alpha P_i(k-1) + (1-\alpha) s_i^{\,2}(k) \quad i = 0 \text{ to } N-1 \qquad (5)$$

c. LMS filtering

$$e(k) = d(k) - s(k)w(k) \qquad (6)$$

$$w(k+1) = w(k) + \mu e(k)s(k) \qquad (7)$$

3. Gradient adaptive lattice (GAL) with joint process estimation

As shown in figure 3, a multistage lattice filter consists of M-1 stages which is referred to as the predictor order. Each stage has the appearance of a lattice, hence the name lattice as the structural descriptor. Because the backward prediction errors are uncorrelated, the use of backward prediction errors for the joint estimation of the desired process results in faster convergence compared to the transversal structure[4].

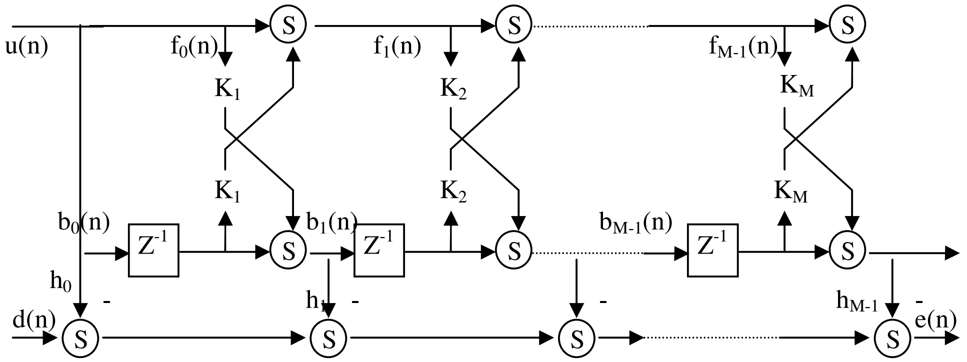

Figure 3 Multistage lattice filter

The m$^{th}$ stage of the lattice predictor is described by a pair of input-output relations:

$$f_m(n) = f_{m-1}(n) + k_m b_{m-1}(n-1) \quad (8)$$

$$b_m(n) = b_{m-1}(n-1) + k_m f_{m-1}(n) \quad (9)$$

4. Recursive least squares (RLS) algorithm

This algorithm implements recursively an exact least square solution. The wiener solution is given by $W = R^{-1}P$ where R is the input signal correlation matrix and P is the cross-correlation between desired signal and the input signal. At each time step RLS estimates R and P based on all past data and updates the weight vector using the matrix inversion lemma[4].

While the RLS algorithm has the advantage of a fast convergence rate and low sensitivity to input eigenvalue spread, it has the disadvantage of being computationally tintensive. The numerical robustness of the RLS algorithm can be improved by using QR based decomposition of the inverse correlation matrix. Lattice based RLS have better numerical robustness and less computational complexity than the standard RLS.

## IV. Application of ATF for narrowband mitigation in GPS receiver

As shown in figure 4, ATF is implemented as a linear predictor to cancel narrowband interfering signal from the down-converted and sampled received GPS signal, which can be modeled as:

$$R(k) = S(k) + N(k) + I(K) \tag{10}$$

where $S(k)$ is the GPS signal, $N(k)$ is the receiver thermal noise, and $I(k)$ is the narrowband interference at the output of the A/D converter in GPS receiver.

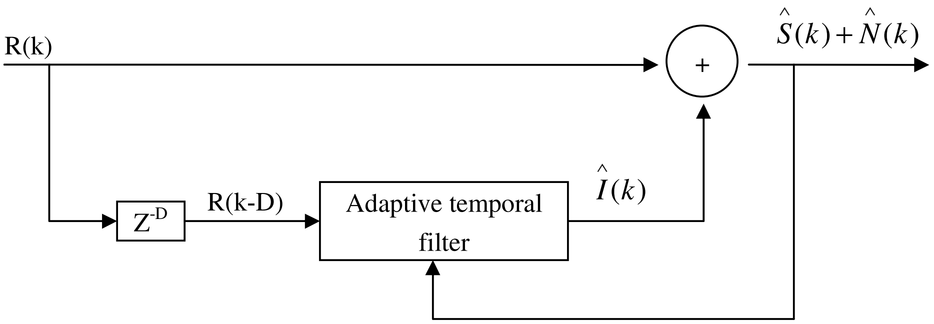

Figure 4 ATF used in GPS

In adaptive filtering nomenclature, $R(k-D)$ is the input signal, $\hat{I}(k)$ is the output signal, and $R(k)$ is the desired signal. The delay $D$ is the de-correlation parameter. This delay should be just enough to de-correlate the GPS signal, while still maintaining a high correlation between the interference samples, so that interference can be accurately predicted and canceled.

The effectiveness of the various algorithms in removing the interference can be measured by the improvement in the post-correlation SNR. Three stationary CW interferences at 1MHz, 2MHz, and 0.123MHz were present with their power levels varied from 0 dB above thermal noise level to 20 dB above thermal noise level. The GPS signal is 18 dB below thermal noise level. The filter order was 10. Ideally a filter order 6 would be sufficient to remove three tone interferences. A higher filer order was used to make the notches in the frequency domain narrower for better interference cancellation and at the same time removing only a small portion of the GPS signal.

The performance of the orthogonalizing algorithms is approximately 0.5-2dB better than the LMS algorithm for stationary multi-tone CW interference cancellation, with the lattice based RLS performing the best. The interference to signal power ration of 18 dB corresponds to interference to thermal noise power ration of 0 dB since the signal is 18 dB below the thermal noise power. At this low level of INR, the prediction of the interference is not accurate enough for the LMS and TDLMS algorithms, thereby resulting in inaccurate interference cancellation. But the GAL and lattice based RLS provide an improvement in SNR. The lattice based RLS combines the fast convergence advantage of an RLS algorithm thereby giving improved performance. As the interference power increase, the prediction improves resulting in better interference cancellation and increase in SNR.

As the interference power increase, the conditioning of the input correlation matrix deteriorates and the eigen-spread increases. In this case the LMS algorithm converges very slowly and hence does not remove the interference, resulting in degraded post correlation SNR at higher interference power levels. On the other hand the orthogonalizing algorithms are insensitive to eigen-spread, hence their post-correlation SNR shows an improvement with increasing interference level.

Except for the post-correlation SNR improvement, significant tracking improvement is achieved by implementing an adaptive temporal filter for notching out narrowband interference. This is especially true at high level of interference. The lattice based algorithms perform best.

## V . Summary

This paper has discussed the implementation of various adaptive algorithms for narrowband interference cancellation. The use of orthogonalizing algorithms, i.e. the transform domain based LMS, gradient adaptive lattice (GAL), and lattice based least squares provided significant improvement in post-correlation SNR as compared to the LMS algorithm. The transform domain based LMS and gradient lattice based algorithms perform almost as well as standard RLS and do not have robustness problems. The lattice based RLS showed the best performance in a narrowband interference environment in terms of convergence speed and tracking. The computational complexity of the lattice based RLS is order of magnitude greater than the transform domain based LMS and GAL. With the tremendous leap in the processing power of the VLSI chips, it is feasible to implement the lattice RLS algorithms in real time. The GPS receiver performance would be greatly enhanced in a complex interference environment.

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