Digital Signal Processing **12**, 175–192 (2002)
doi:10.1006/dspr.2002.0447

# GPS Antijam via Subspace Projection: A Performance Analysis for FM Interference in the C/A Code

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Zhao, L., Amin, M. G., and Lindsey, A. R., GPS Antijam via Subspace Projection: A Performance Analysis for FM Interference in the C/A Code, *Digital Signal Processing* **12** (2002) 175–192.

This paper is concerned with frequency modulated (FM) interference cancelation in GPS receivers. FM signals are instantaneously narrowband and have clear time–frequency signatures that are distinct from the GPS C/A spreading codes. Interference cancelation is performed by first constructing the interference subspace and then projecting the data onto the orthogonal subspace. Interference subspace estimation can be provided by the time–frequency distribution (TFD) or any other instantaneous frequency (IF) estimator. The GPS receiver signal-to-interference and noise ratio in the presence of IF or phase estimation errors is derived. The errors are assumed Gaussian and independent. From both analysis and simulations, it is shown that phase estimation errors can substantially impede interference rejection in GPS using subspace projection techniques.


## 1. INTRODUCTION

The Global Positioning System (GPS) is a satellite-based, worldwide, all-weather navigation and timing system [1, 2]. It was initiated by the Department of Defense primarily for the U.S. military to provide precise estimates of position, velocity, and time. However, the civilian applications of GPS are growing at an astonishing rate, a phenomenon not completely understood during the design phase of the system. GPS has found applications in land transportation, civil aviation, maritime commerce, surveying and mapping, construction, mining, agriculture, earth sciences, electric power systems, telecommunications, and outdoor recreational activities [3].

The GPS is a direct sequence spread spectrum (DSSS) system that inhibits a certain degree of protection against jammers. A typical GPS coarse acquisition



1051-2004/02 $35.00

(C/A) code receiver can tolerate a narrowband intereferer with a jammer-to-signal ratio (JSR) of approximately 40 dB. Nonetheless, the jammer may be much stronger than 40-dB JSR due to the fact that the received GPS signal is very weak with a power of approximately −160 dB W. The ever-increasing reliance on GPS for navigation and guidance has created a growing awareness of the need for adequate protection against both intentional jamming and unintentional interference. In general terms, a jammer is traditionally a high power signal that occupies the same frequency as the desired signal, making reception by the intended receiver difficult or impossible. As antijamming techniques become increasingly effective, jammers themselves have become smarter and more sophisticated, and generate signals that are difficult to combat. These smart jammers typically incorporate temporal nonstationarities or spatial diversity which complicate the identification and subsequent excision process.

Techniques based on time–frequency distributions have been employed for suppression of nonstationary FM interference in broadband communication platforms [4–8]. Most recently, subspace projection techniques based on time–frequency have been applied to GPS with single and multisensor receivers [9, 10]. These techniques assume clear jammer time–frequency signatures and rely on the distinct differences in the localization properties between the interference FM waveforms and the C/A Gold codes of the GPS signals. The FM jammer instantaneous frequency (IF), whether provided by the time–frequency distributions (TFDs) or any other IF estimator [11–13], is used to define the temporal signature of the interference, which is in turn used to construct the interference subspace. The respective projection matrix is applied to excise the jammer power in the incoming signal prior to correlation with the receiver C/A codes. The result is improved receiver signal-to-interference and noise ratio (SINR).

As the jammer subspace is solely determined by the jammer IF, the estimation of the IF plays an important role in the FM interference mitigation. Errors in IF may occur in many situations, where it becomes difficult to determine the IF due to a drop in jammer power, the presence of amplitude modulations, or high levels of cross-terms in the time–frequency domain. With perturbations in IF, the GPS receiver antijamming performance is degraded, lowering the receiver SINR. This paper analyzes the GPS receiver performance in the presence of phase estimation errors. As the error patterns of phase estimates are signal dependent and difficult to ascertain, the IF and phase errors are modeled as zero-mean Gaussian white noise process. This model implies that the phase errors are both unbiased and independent.

The Gaussian assumption is motivated by the fact that phase errors, directly obtained from the analytic signal of FM in complex Gaussian additive noise, have wrapped normal distributions [14]. For high jammer power, the distribution variance becomes very small and the phase errors assume a Gaussian distribution. It was also shown in [14] that the phase errors are independent, provided they belong to data samples separated by even-indexed numbers. Accordingly, the independent phase error assumption can be