

# Research on Noise FM Jamming Anti Frequency Domain Filtering to GPS M Code Signals

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**Abstract**—The new generation of GPS signal is added the M code which has a separated spectrum and wider bandwidth, so we use the noise FM jamming to interfere M code. Combined with the receiver frequency domain filtering anti-jamming technology, the effect of the frequency domain filtering of noise FM jamming is simulated and analyzed. The simulation results show that: the ability of noise FM jamming against the frequency domain filtering is better, and by adjusting the value of the frequency modulation slope, it can achieve the best effect. Meanwhile, the jamming bandwidth can cover the whole band of M code. The feasibility of implementation of jamming that noise FM against GPS M code signal is verified.

**Keywords**—BOC; noise FM jamming; the frequency modulation slope; frequency domain filtering

## I. INTRODUCTION

The successful practice of the precision strike weapon guided by GPS has fully demonstrated the value of the GPS in several regional wars[1]. Therefore, the jamming to GPS has been the focus of research all over the world. Russia has put forward 5 generations of GPS jammer theory including blanket jamming and deception jamming. By analyzing the current literature, we can find that the blanket jamming technology to C/A code and P code has been basically formed[2]. The new generation of GPS signal is added M code signal which adopt the BOC modulation, with separated spectrum and wider bandwidth. This makes traditional blanket jamming method aiming at the center frequency of L1 and L2 band ineffective.

Due to the limitation of the encryption technology and the forwarding delay[3], it is difficult to implement the deception jamming against the M code signal. Therefore, the research on blanket jamming against the M code is still significant. In reference [4], the code tracking error is used as the evaluation index of the jamming effect. It studied the influence of jamming frequency offset setting for single frequency continuous wave on the code loop tracking of satellite navigation signal, without considering suppression effect to the energy of single frequency continuous wave by frequency domain filtering. In reference [5], the code loop tracking error of GPS receiver under wideband Gauss noise jamming is derived and simulated. But it did not carry out a concrete analysis of the M code signal

In this paper, based on the analysis of the characteristics of the new generation of navigation signals, combined with the receiver frequency domain filtering anti-jamming technology,

the effect of the frequency domain filtering to noise FM jamming is simulated and analyzed. And the feasibility of implementation of jamming that noise FM against GPS M code signal is verified.

## II. CHARACTERISTIC ANALYSIS OF NAVIGATION SIGNALS

Before the modernization of GPS, the traditional GPS signals included the civilian C/A code on L1 band and the military P(Y) code on L1 and L2 band. Traditional GPS signals are modulated by BPSK-R, that is, data code and PN code (C/A code or P code) go through the DSSS system to spread the spectrum, and then the combination of them modulates the carrier wave. In BPSK-R(n) modulation, we can denote the rate of PN code as  $f_c = n f_0$  ( $f_0 = 1.023\text{MHz}$ ). The civilian C/A code on L1 band is modulated by BPSK-R(1), while the military P(Y) code is modulated by BPSK-R(10). The power spectrum can be expressed as:

$$G_{BPSK}(f_c) = f_c \frac{\sin^2\left(\frac{\pi f}{f_c}\right)}{(\pi f)^2} \quad (1)$$

In military aspect, one of the contents of the modernization of GPS is to add M code to L1 and L2 band. Different from the traditional C/A code and P code, M code adopts the binary-offset-carrier(BOC) modulation. First, the data code multiply by PN code to spread the spectrum. The spread spectrum sequence and square wave sub-carrier are modulated to get the BOC baseband signal. In the end, the BOC baseband signal is modulated to the carrier to form a BOC modulated signal. So, BOC baseband signal can be regarded as the product of BPSK signal and a square wave sub-carrier. Its spread symbol waveform can be expressed as:

$$s_{BOC}(t) = s_{BPSK}(t) \cdot \text{sgn}[\sin(2\pi f_s t + \varphi)] \quad (2)$$

where  $f_s$  is the rate of square wave sub-carrier;  $\varphi$  is the phase of sub-carrier, whose value is usually set as  $0^\circ$  or  $90^\circ$ , called sinusoidal BOC or cosine BOC.

M code is modulated by BOC(10,5) and its normalized power spectrum of the sine and cosine forms can be expressed as:

$$\begin{cases} G_{BOC\sin(10,5)}(f) = f_c \left[ \frac{\sin\left(\frac{\pi f}{f_c}\right) \sin\left(\frac{\pi f}{4f_c}\right)}{\pi f \cos\left(\frac{\pi f}{4f_c}\right)} \right]^2 \\ G_{BOC\cos(10,5)}(f) = f_c \left[ \frac{2 \sin\left(\frac{\pi f}{f_c}\right) \sin^2\left(\frac{\pi f}{4f_s}\right)}{\pi f \cos\left(\frac{\pi f}{2f_s}\right)} \right]^2 \end{cases} \quad (3)$$

where  $f_s = 10.23\text{MHz}$  is the rate of sub-carrier and  $f_c = 5.115\text{MHz}$  is the rate of PN code.

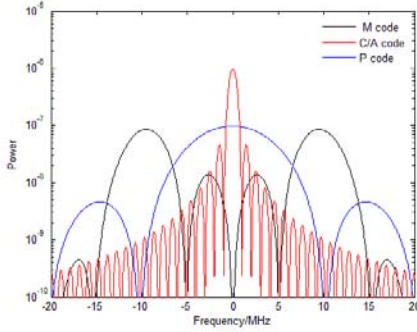


FIGURE I. POWER SPECTRUM OF NAVIGATION SIGNAL

The power spectrum of C/A code, P code and M code is as shown in Figure I. From the figure, we can see that, due to the adoption of the BOC modulation, M code has realized the separation of the spectrum. So, the original narrowband jamming (such as single tone jamming) which aims at the center frequency of L1 and L2 band is ineffective to M code. The bandwidth of C/A code and P code is about 2MHz and 20MHz, while the bandwidth of M code is about 30MHz. So, the original bandwidth of blanket jamming to C/A code and P code is not broad enough to cover the bandwidth of M code.

Therefore, the noise FM jamming with wider bandwidth can be regarded as an effective jamming pattern for M code.

### III. PRINCIPLE OF NOISE FM JAMMING

Noise FM signal is a kind of random signal which is formed by the carrier frequency modulation with the noise. The noise FM jamming signal entering the front end of the receiver can be expressed as:

$$J_{NF}(t) = U_j \cos\left(\omega_j t + 2\pi K_{FM} \int_0^t u_n(t') dt' + \varphi_n\right) \quad (4)$$

where modulation noise  $u_n(t)$  is a generalized stationary random process whose mean is zero and covariance is  $\sigma_n^2$ ;  $\varphi_n$  is a random variable obeying uniform distribution of  $[0, 2\pi]$  and independent to  $u_n(t)$ ;  $U_j$ ,  $\omega_j$  and  $K_{FM}$  are the amplitude, center angular frequency and frequency modulation slope of noise FM signal.

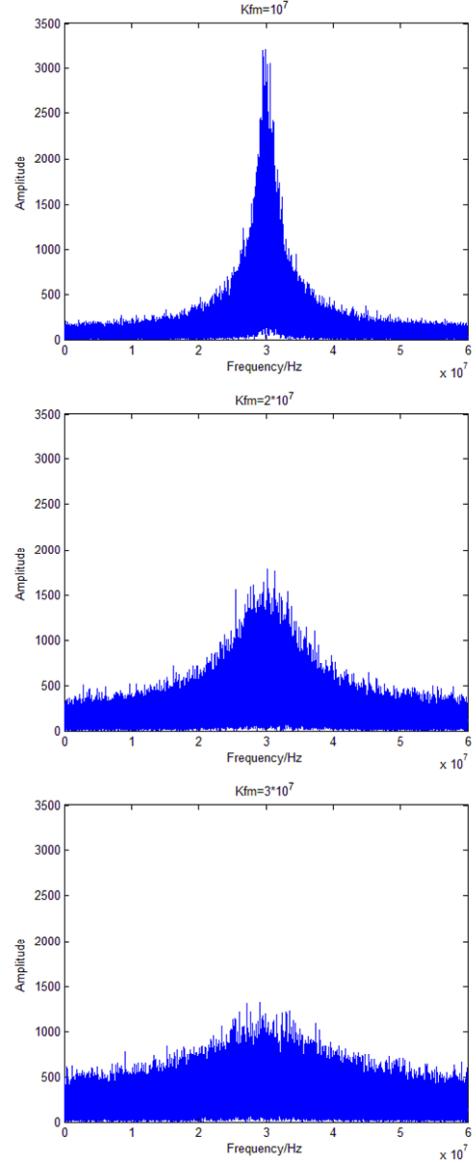


FIGURE II. POWER SPECTRUM OF NOISE FM SIGNAL WITH DIFFERENT  $K_{FM}$

Effective frequency modulation bandwidth is  $f_{de} = K_{FM} \sigma_n$ , and effective frequency modulation index is  $m_{fe} = \frac{K_{FM} \sigma_n}{\Delta F_n}$ ,

where  $\Delta F_n$  is the equivalent bandwidth of modulation noise. When  $m_{fe} \geq 1$ , it appears as wideband noise FM signal. The power spectrum of the noise FM jamming signal can be expressed as:

$$G_{J_{NF}}(f) = \frac{U_j^2}{2} \frac{1}{\sqrt{2\pi} f_{de}} e^{-\frac{(f-f_j)^2}{2f_{de}^2}} \quad (5)$$

where  $f_j$  is the center frequency of noise FM jamming.

The total power of the noise frequency modulated wave is the same as the total power of the carrier, which is independent of the modulation noise power. It can be expressed as:

$$P_{J_{NF}} = \int_{-\infty}^{\infty} G_{J_{NF}}(f) df = \frac{U_j^2}{2} \quad (6)$$

The half power bandwidth of noise FM jamming is:

$$\Delta f_j = 2\sqrt{2\ln 2} f_{de} = 2\sqrt{2\ln 2} K_{FM} \sigma_n \quad (7)$$

From the formula above, we can see that, the bandwidth of the noise FM interference is independent of the bandwidth of the baseband noise  $\Delta F_n$ , but depending on the power of the baseband modulation noise  $\sigma_n^2$  and the frequency modulation slope  $K_{FM}$ .

Referring to the existing hardware conditions, we simulate the noise FM jamming with different frequency modulation slope. Simulation condition: the power of baseband modulation noise is 0dBW, the bandwidth is  $\Delta F_n = 3\text{MHz}$ , the center frequency of jamming is  $f_j = 50\text{MHz}$ . The simulation results is shown in Figure II.

From the simulation analysis, we can see that, in the circumstances that the power of the base band modulation noise is certain, the frequency modulation slope larger, the spectrum of the noise FM signal is more similar to the noise, and the bandwidth is wider.

#### IV. SIMULATION ANALYSIS OF ANTI FREQUENCY DOMAIN FILTERING

Frequency domain filtering processing method is commonly used in GPS receiver anti-jamming technology. Through the FFT transform, the mixed signal composed by the navigation signals, the environmental noise and interference is mapping to frequency domain. Then, through interference detection, find the interference spectrum position and suppress the jamming signal. Finally, do the IFFT to the frequency domain signal after suppression to change it back to the time domain and send the anti-interference signal to the receiver.

Interference suppression is carried out after the transformation. The frequency domain interference suppression algorithm includes threshold detection method, K spectral line algorithm, median filtering method, etc.. In all kinds of interference detection, threshold detection method is the most widely used method at present. The principle of the method is similar to the capture detection, that if the value of signal energy exceeds a preset interference threshold, we can think that there are interferences in the received signal, and those spectral lines which exceed the threshold are judged as interference spectral lines. There are three methods to deal

with the interference spectrum, which are zero, linear weakness, and clamp to the threshold value.

In the interference suppression algorithm based on threshold detection, the design of the interference detection threshold is the key problem in the algorithm implementation. The common threshold selection method includes: N-sigma algorithm,  $\sigma^2$  maximum likelihood estimation method, etc..

The single GPS anti-jamming chip designed by MITRE uses the N-sigma algorithm to determine the interference detection threshold. The design principle of N-sigma algorithm is given in Figure III, in which the threshold value is selected to remove the interference signal with the overall average value of the signal. N-sigma suppression algorithm calculates the energy of each component of the composition (in dB), the standard deviation  $\sigma_{calc}$  and the average value  $\mu_{calc}$ . The threshold value can be taken as:

$$Th = \mu_{calc} + N \cdot \sigma_{calc} \quad (8)$$

$$\mu_{calc} = \sum_{k=0}^{N_p-1} \frac{10\log(|X(k)|)}{N_p} \quad (9)$$

$$\sigma_{calc} = \frac{1}{N_p} \left[ \sum_{k=0}^{N_p-1} (10\log(|X(k)|))^2 - \frac{1}{N_p} \left( \sum_{k=0}^{N_p-1} 10\log(|X(k)|) \right)^2 \right] \quad (10)$$

N is an adjustment factor and it is positive and real, which can maintain the threshold value above the noise energy. If the value of N is too large, the estimated threshold is too high and the interference leakage is serious; on the contrary, if the value of N is too small, the estimated threshold is too low and the filter process will produce a large distortion of the desired signal. Considering from the jamming aspect, the higher threshold is more conducive to interference signal to go into the receiver.

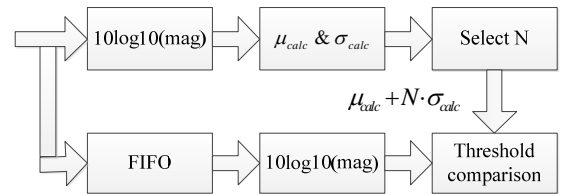


FIGURE III. DESIGN PRINCIPLE OF N-SIGMA ALGORITHM

The suppression effect of different threshold of frequency domain filtering and different frequency slope of noise FM jamming is shown in Figure IV. Simulation experiment is done in Matlab R2014a and the JSR entering the receiver is the criterion. The value of N is given in reference [6]. Simulation condition: the navigation signal selects the M code signal; the JSR is 45dB; the front-end bandwidth of receiver is 40MHz.

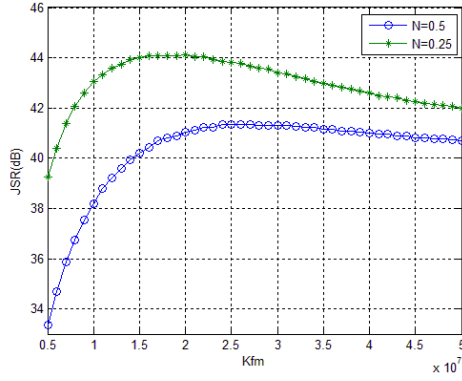


FIGURE IV. JSR ENTERING RECEIVER WITH DIFFERENT  $K_{FM}$

From the simulation results, we can see that, when  $N=0.5$  and the frequency modulation slope  $K_{FM} = 2 \times 10^7$ , the JSR has the minimum loss and the half power bandwidth of noise FM jamming is  $\Delta f_j \approx 47 \text{ MHz}$ ; when  $N=0.25$  and the frequency modulation slope  $K_{FM} = 2.5 \times 10^7$ , the JSR has the minimum loss and the half power bandwidth of noise FM jamming is  $\Delta f_j \approx 58 \text{ MHz}$ . Therefore, we can adjust the value of  $K_{FM}$  to make it better to against the frequency domain filtering. At the same time, the bandwidth of jamming signal can just cover M code of 30 MHz, without causing the jamming energy waste.

## V. CONCLUSION

In this paper, based on the analysis of the characteristics of the new generation of navigation signals, combined with the receiver frequency domain filtering anti-jamming technology, the effect of the frequency domain filtering to noise FM jamming is simulated and analyzed. The results show that the noise FM jamming is good at anti frequency domain filtering and by adjusting the value of the frequency modulation slope, it can achieve the best effect. Meanwhile, the jamming bandwidth can cover the whole band of M code. The feasibility of implementation of jamming that noise FM jamming to GPS M code signal is verified. The next step is to analyse the interference performance of the noise FM jamming to M code and research on the effectiveness of the implementation of jamming to M code.

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