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Research on Blanket Jamming to Beidou Navigation Signals Based on BOC Modulation

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Abstract

Aiming at the issue of influence of blanket jamming on performances of Beidou navigation signals, through studying Beidou signals based on the BOC modulation technology, establishing a blanket jamming mathematical model, and performing modeling and simulation on multiple jamming technologies, to attain the jamming curves of time domains and frequency domains of Beidou signals, and the correlation curve of the signal-to-jamming rate and the bit error rate under blanket jamming, and thus realizing evaluation on the jamming performance.

Keywords

Beidou Navigation Signals, Blanket Jamming, BOC

1. Modeling Analysis on Signals of Beidou Navigation System

The binary offset carrier (BOC) technology, as a research hotspot in the field of navigation, has been experimented in navigation signals of the American GPS system and the European Galileo system [1] [2]. Compared with the traditional way of spread spectrum modulation, the novel BOC modulation way has the advantages of improving the utilization rate of navigation frequency bands, restraining the multipath error of signals, reducing the coherence loss of signals, improving the pseudorange measurement accuracy, enhancing the anti-jamming performance of signals, etc.. The Beidou global navigation signal system will also adopt the BOC modulation technology [3]-[5].

1.1. BOC Basic Model

BOC modulation referred to auxiliary modulation on code signals generated by a satellite by taking a square wave as the subcarrier, then modulating to the main carrier, that is, multiplying the signal $S(t)$ and the subcarrier with the frequency being f_s, to split the frequency spectrum of signals into two parts, which are positioned on the right and left parts of the frequency of the main carrier [6].

That is:

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$$S_{BOC}(t) = A \bullet D(t)P(t)S_C(t)\cos(2\pi ft + \varphi) \tag{1}$$

In which, A refers to the signal amplitude; $D(t)$ refers to the message data; $P(t)$ refers to the PRN sequence; $S_C(t)$ refers to the subcarrier signal. The principle of BOC signals is shown in **Figure 1**, in which, f_c refers to the rate of the spread spectrum code, and f_s refers to the rate of the subcarrier. After the navigation data are modulated to the spread spectrum code, a rectangular subcarrier is then modulated to generate a BOC signal, and finally the BOC signal is modulated to the main carrier of the navigation signal frequency band to be transmitted.

BOC (14, 2) is taken as an example. **Figure 2** is the time domain waveform of PRN codes being subjected to BOC (14, 2) modulation, it is observed that the blue full line represents the extended code sequence (f_c), and the red dotted line represents the code sequence (f_s) after modulation. **Figure 3** is the power spectral density of the signal.

1.2. Power Spectrum and Autocorrelation Function of BOC Signals

In reference to promotion of the spectrum formula of BPSK modulation signals, the power spectral density of the normalization baseband of BOC (f_s, f_c) modulation can be attained as [6]:

$$G_{BOC}(f) = f_c \left(\frac{\sin\left(\frac{\pi f}{2 f_s}\right) \sin\left(\frac{\pi f}{f_c}\right)}{\pi f \cos\left(\frac{\pi f}{2 f_s}\right)} \right)^2 \tag{2}$$

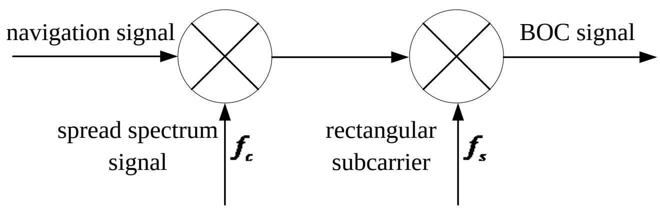

Figure 1. Schematic diagram of BOC signal modulation.

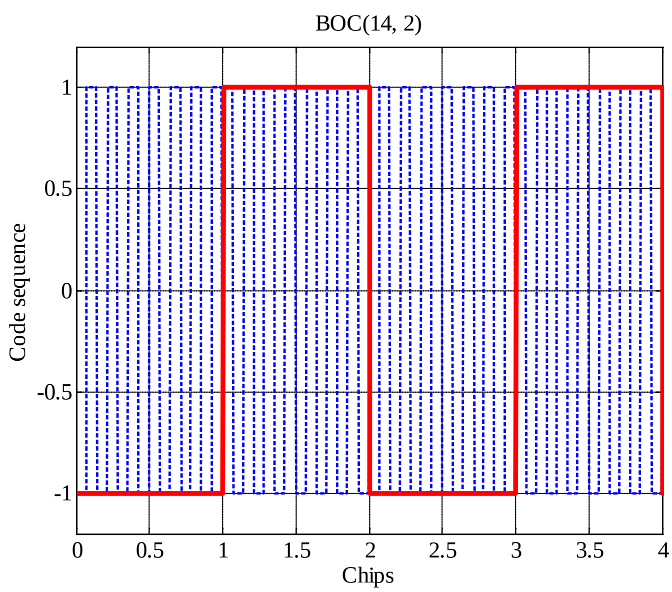

Figure 2. Waveform of BOC (14, 2) modulation signals.

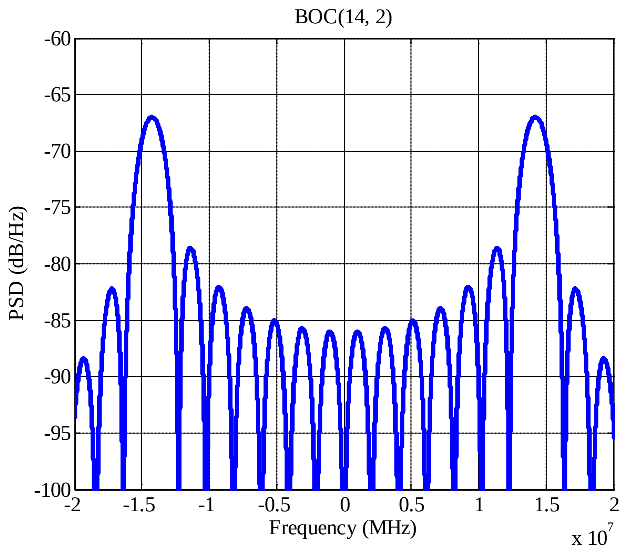

Figure 3. Power spectral density of BOC (14, 2) modulation signals.

When $n = \frac{2f_s}{f_c}$ is an even number,

$$G_{BOC}(f) = f_c \left(\frac{\sin\left(\frac{\pi f}{2 f_s}\right)\cos\left(\frac{\pi f}{f_c}\right)}{\pi f \cos\left(\frac{\pi f}{2 f_s}\right)} \right)^2 \tag{3}$$

When $n = \frac{2f_s}{f_c}$ is an odd number,

Generally, the autocorrelation function of BOC modulation cannot be easily explicitly expressed. Provided that signals take the complex bandwidth β_r as band limit ideally, the autocorrelation function can be defined as:

$$R(\tau) = \int_{-\beta_r/2}^{\beta_r/2} G_{BOC}(f) e^{j2\pi f \tau} df \tag{4}$$

The number of main lobes and side lobes between the main lobes on both sides on the BOC power spectrum is determined by two parameters, *i.e.* f_s, and f_c, and the specific corresponding relation is expressed as:

$$n = \frac{2f_s}{f_c} \tag{5}$$

In which, n represents the number of main lobes and side lobes between the main lobes on both sides, and also serves as the order of BOC modulation, f_s refers to the frequency of the subcarrier, and f_c refers to the code rate. Thus the number of main lobes and side lobes between the main lobes of BOC (14, 2) can be calculated to be 14, as shown in **Figure 3**.

2. Research on Jamming Technologies

Jamming on navigation signals mainly referred to jamming countermeasure to a user receiver, and classified into blanket jamming and deception jamming in technology.

2.1. Blanket Jamming

By launching certain types of jamming signals, masking the frequency spectrum of signals launched by the adverse party in a certain way, and blanketing satellite signals reaching the antenna terminal of a receiver, to cause a result that the adverse party cannot correctly receive satellite signals to carry out positioning, and thus the capability of the adverse party to conduct normal operation is degraded or completely destroyed [7].

Blanket jamming includes spot jamming, blocking jamming and correlation jamming. Spot jamming is conducted in a manner of mainly performing jamming to satellite signals in specific code types, to cause the signals to fail at a certain area by adopting the frequency spot technology, through perfectly aligning the jamming carrier frequency to the signal carrier frequency [8]. Blocking jamming is conducted in a manner of blanketing satellite signals reaching the antenna terminal of a receiver through launching jamming signals, to attain the purpose of jamming. Blocking jamming has multiple jamming systems, including single-tone jamming, multi-tone jamming, etc. Generally, spot jamming is regarded a special case of blocking jamming; noise jamming guarantees that uniform-bandwidth jamming spectrums can be generated in blocking jamming. Correlation jamming has a jamming system modulated with pseudo codes, that is, jamming is carried out by using the characteristic that the pseudo code sequence of jamming signals and the pseudo code sequence of navigation signals are greatly correlated. Compared with uncorrelated jamming, more energy can pass the narrow-band filter of a receiver, and therefore effective jamming realized in other way can be realized with smaller power.

2.2. Deception Jamming

Referred to launching ghost signals having the same parameters (only with different information codes) with real satellite signals to jam a receiver, to cause the receiver to generate error location information, and functioning as a pseudo satellite.

Deception jamming to navigation signals can be conducted in two ways: providing false navigation information or increasing the signal propagation time delay, which correspond to two jamming systems, *i.e*. the "production" jamming system and "forwarding" jamming system [9]. Production jamming means launching radio signals same with satellite signals by a jamming source to deceive a receiver, to cause error decoding. Forwarding jamming means re-broadcasting the received satellite signal to constitute a false satellite signal, to lead to error decoding by the receiver and cause ranging error, and thus error positioning is caused.

2.3. Single-Tone Jamming

Single-tone jamming referred to launching signals at one frequency, and therefore jamming signal is a single frequency continuous wave voice frequency. Single-tone jamming is also called dot frequency jamming [10].

2.4. Multi-Tone Jamming

A jammer can launch L (being greater than 1) audios, which can be randomly distributed, or positioned on specific frequency bands. Under the circumstances that a specific target anti-jamming communication system is very vulnerable to jamming by specific audios and the jammer recognizes the situation, audios should be used more cautiously at the specific frequencies, and should not be randomly distributed [11].

When the audios are at adjacent channels, independent multi-tone jamming is formed, that is comb jamming. Therefore, the following assumption is adopted in default no matter which audio jamming countermeasure is discussed, that is the audio is positioned at one frequency of a frequency spectrum accurately, thus the jamming audio can pass the filter of a receiver, and distortion or attenuation is not generated. Independent multi-tone jamming is formed in a manner of superposing n independent sine wave signals, A refers to the amplitude, Δf refers to the stepping frequency width, and the time-domain expression is as follows:

$$x(t) = A\sum_{n=1}^{N}\sin\left[2\pi\left(f_0 + n\Delta f\right)t\right] \tag{6}$$

2.5. Noise Jamming

The generalized stationary random process:

$$J(t) = U_j\cos\left[2\pi K_{FM}\int_0^t u\left(t'\right)dt' + w_j t + \varphi\right] \tag{7}$$

Called noise frequency modulation jamming, in which modulation noise $u(t)$ is the zero-mean generalized stationary random process, φ is a random variable mutually independent to $u(t)$ and uniformly distributed between $[0,2\pi]$, U_j refers to the amplitude of noise frequency modulation signals, w_j refers to the center frequency of noise frequency modulation signals, and K_{FM} refers to the slope of frequency modulation.

Gaussian noise and sinusoidal signals are used for noise frequency modulation, and jamming signals are formed after filtering and power amplification. The effective bandwidth of signals subjected to noise frequency modulation is only correlated to the amplitude effective value of modulation noise, and the frequency modulation coefficient, and barely correlated to the bandwidth of modulation noise.

The generalized stationary random process:

$$J(t)=\left[U_0+U_n(t)\right]\cos\left[w_j t+\varphi\right] \tag{8}$$

Called noise amplitude modulation jamming, in which $U_n(t)$ refers to generalized stationary random noise, of which modulation noise is a zero mean, and the variance being σ_n^2, and being distributed between $\left[-U_0,\infty\right]$, φ refers to a random variable which is uniformly distributed between $[0,2\pi]$, and mutually independent to $U_n(t)$, and U_0 and w_j are constants.

From the expression of noise amplitude modulation, it is observed that noise amplitude modulation jamming is generated due to generation of band-limited noise fundamentally. Firstly, a set of mutually-independent Gaussian white noise is generated, and then the Gaussian white noise passes a band-limited filter to produce required band-limited noise [12]. The noise amplitude modulation signal and the corresponding power spectrum can be attained through amplitude modulation by means of band-limited Gaussian noise.

Noise amplitude modulation jamming can be defined as narrow-band jamming, as the frequency spectrum width thereof is only twice that of modulation noise. Requirement on a modulator is high with increase of the spectrum width of modulation noise, thereby leading to a too complicated circuit which is difficult to realize. In addition, the frequency spectrum width of noise amplitude modulation is also limited by the limited bandwidth of an oscillating tube.

The generalized stationary random process:

$$J(t)=U_j\cos\left[w_j t+K_{FM}U(t)+\varphi\right] \tag{9}$$

Called noise phase modulation jamming, in which modulation noise $U_n(t)$ is the zero-mean generalized stationary random process, φ is a random variable uniformly distributed between $[0,2\pi]$, and mutually independent to $U_n(t)$, and U_j, w_j and K_{FM} are constants.

The total power of phase modulation waves is equal to the carrier power. When the effective phase shift D is very small, the power spectrums form a bump function at the center frequency, and are distributed uniformly within the bandwidth $2\Delta F$ around the center frequency, and energy is concentrated at the center frequency; when the effective phase shift is increased, the energy at the center frequency is converted into side frequency energy, however, the bandwidth is unchanged; when the effective phase shift D is greater than 1, energy is mainly distributed in side frequencies, the spectrum width is broadened, and the power spectrum is low. The effective frequency bandwidth of noise phase modulation signals is correlated to the frequency bandwidth of modulation signals, the amplitude of modulation signals, and the phase modulation coefficient [13] [14].

3. Jamming Simulation of Beidou Navigation System

The jamming analysis program is mainly conducted in a manner that a Beidou navigation signal generating module and a jamming signal generating module are integrated through a human-computer interaction interface, the parameters of different jamming modules can be adjusted according to requirements, the waveform characteristics of time domains and frequency domains of Beidou navigation signals generated by the Beidou navigation signal generating module, and the chosen jamming signals can be observed in real time, the two can be simulated into a signal reaching the receiver terminal through jamming analysis software in an integrating way, and the time domains and frequency domains of the signal are displayed. By integrating the Beidou navigation signal source with the jamming modules, bit error rates under different jamming conditions are attained through further simulation and the jamming effect is analyzed.

Blanket jamming has great jamming power, so the pseudorange measurement precision of a receiver can not only be reduced, even error decoding can be caused directly, thereby leading to incapability of positioning by the receiver. Multiple blanket jamming effects are analyzed and simulated mainly in the aspects of time domain and frequency domain simulation and bit error rate simulation.

Setting the information code rate to be 0.1 MHz, the BOC modulation subcarrier frequency to be 14 MHz, the spread spectrum code rate to be 2 MHz, the intermediate frequency carrier to be 100 MHz, the sampling frequency to be 1440 MHz, the signal-to-jamming rate to be 10 db, and the transmit information bit to be 100,000. When being free from jamming, time domain and frequency domain simulation of signals received by a receiver as shown in **Figure 4** and **Figure 5**.

Setting the Gaussian noise variance $\sigma^2 = 1$, the jamming power to be 4 W, and the jamming frequency to be 40 MHz, jamming signals with different signal-to-jamming rates are applied respectively, Monte Carlo statistical experiments are conducted, and independent statistics are performed for 100 times to obtain the simulation result as shown in **Figures 6-11**.

Figures 6-11 are time domain and frequency domain graphs of signals received by the input terminal of a receiver under the effect of three types of noise, and the jamming effects of jamming signals on time domains and frequency domains can be observed visually. **Figures 12-14** is a curve, of which bit error rates of three types of

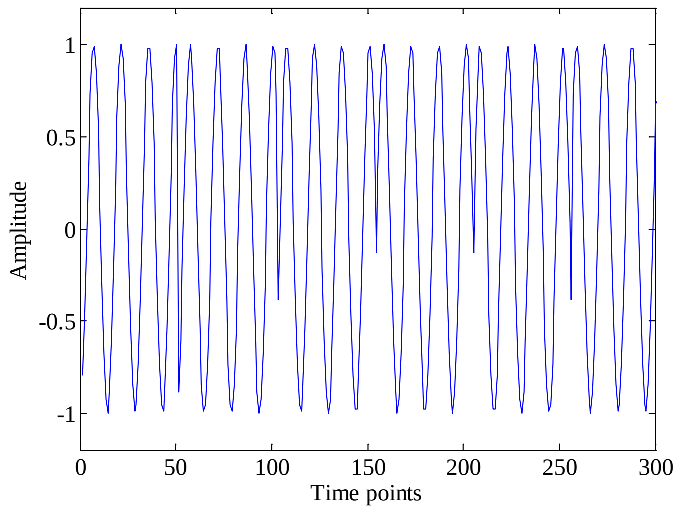

Figure 4. Time domain graph of jamming-free BOC modulation signals.

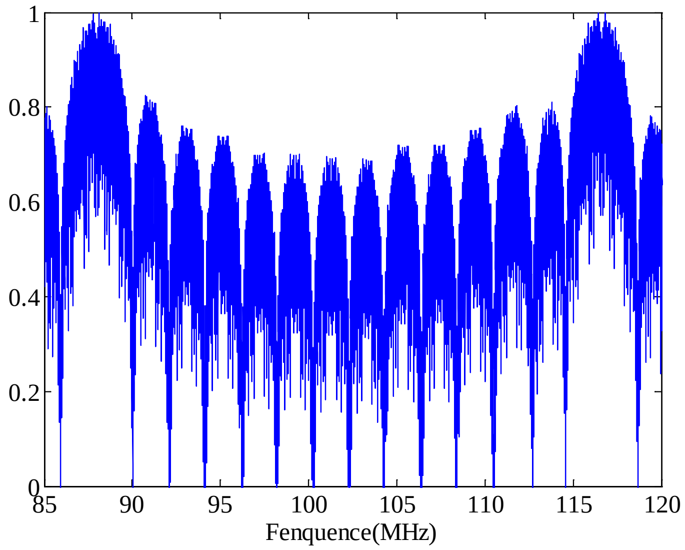

Figure 5. Frequency domain graph of jamming-free BOC modulation signals.

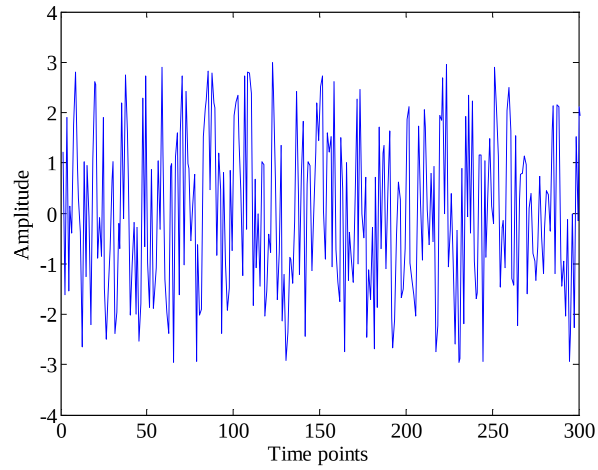

Figure 6. Time domain graph of noise frequency modulation jamming BOC modulation signals.

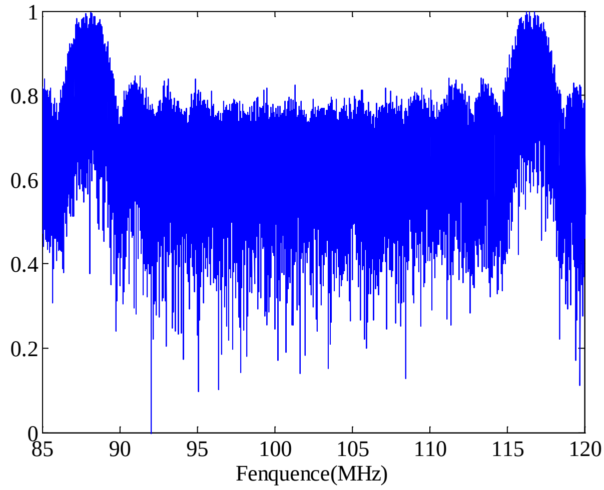

Figure 7. Frequency domain graph of noise frequency modulation jamming BOC modulation signals.

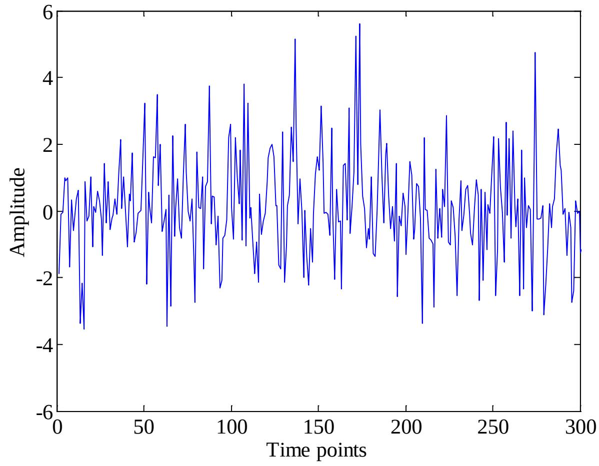

Figure 8. Time domain graph of noise amplitude modulation jamming BOC modulation signals.

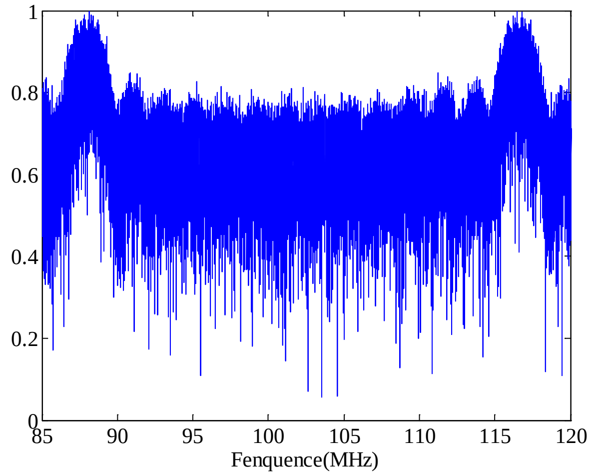

Figure 9. Frequency domain graph of noise amplitude modulation jamming BOC modulation signals.

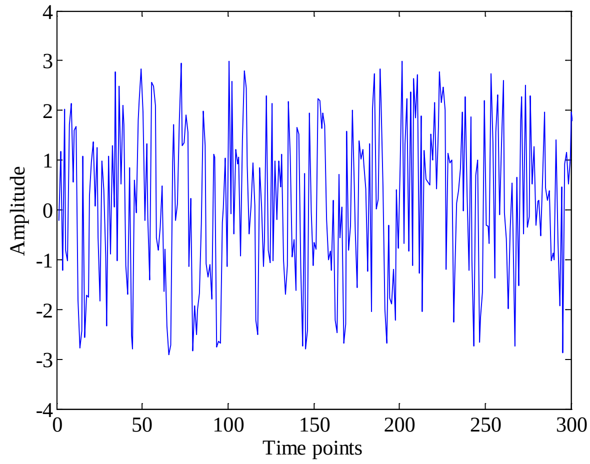

Figure 10. Time domain graph of noise phase modulation jamming BOC modulation signals.

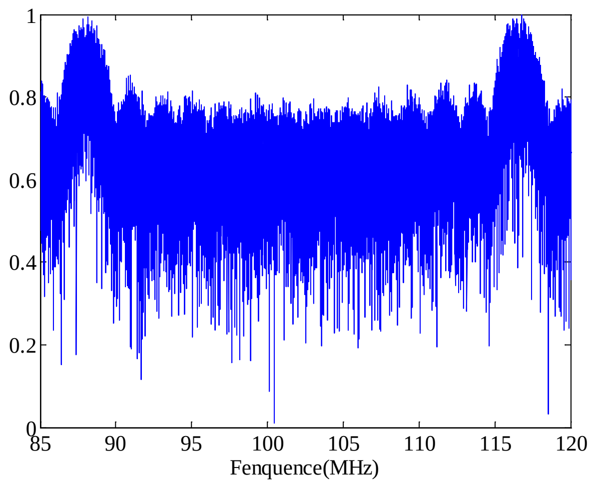

Figure 11. Frequency domain graph of noise phase modulation jamming BOC modulation signals.

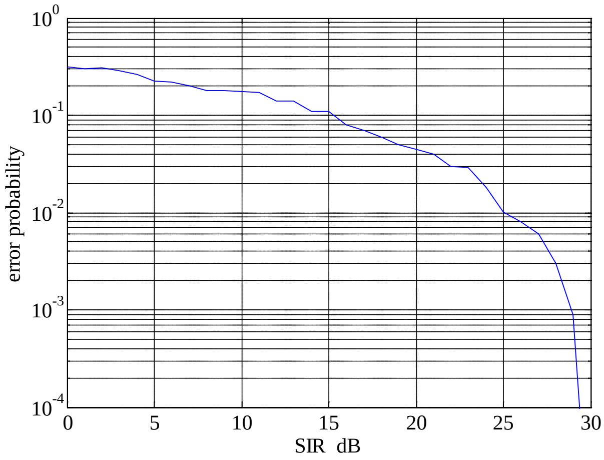

Figure 12. Error probability performance against SIR of noise frequency modulation.

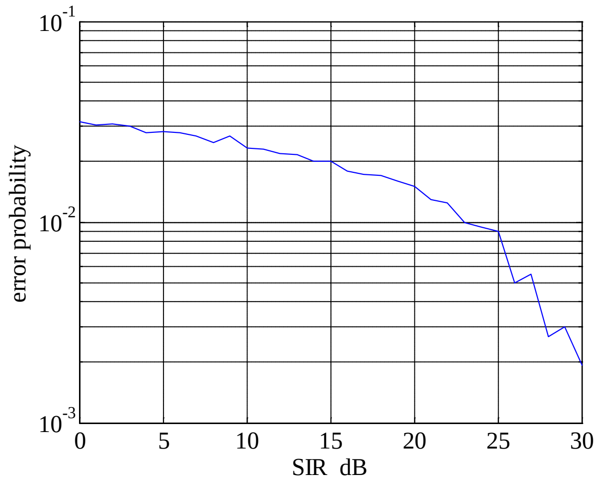

Figure 13. Error probability performance against SIR of noise amplitude modulation.

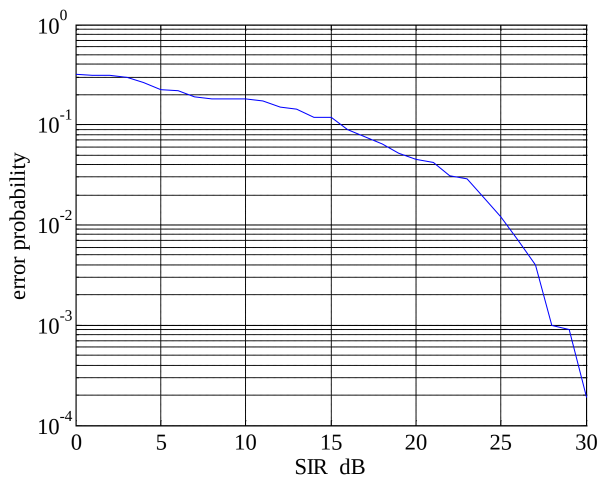

Figure 14. Error probability performance against SIR of noise phase modulation.

jamming change along with signal-to-jamming rates. It is observed that jamming with uniform power density is formed in the passband of a filter after the receiver is jammed by noise, due to spread spectrum gain, and the receiver extends the jamming power while amplifying the signal power. The spread spectrum gain of Beidou system is great, and great power is required to complete jamming. No significant difference exists among the jamming effects, by contrast, the noise amplitude modulation is low in bit error rate when the signal-to-jamming rate is lower than 25 dB, and the bit error rate is high when the signal-to-jamming rate is greater than 25 dB. The effect of blanket jamming can be illustrated more obviously by noise modulation jamming, a jamming function is fulfilled, and however, great power is required to achieve certain jamming effects.

4. Conclusion

The paper mainly focuses on detailed description and simulation on how to jam the Beidou system (BOC modulation). The research keystone lies in the definition, characteristics and superiority in terms of anti-jamming of the BOC modulation method; signal source modeling, jamming modeling and BOC modulation jamming modeling are completed; multiple jamming methods are simulated and the jamming results are analyzed, and accordingly the validity of the jamming methods is demonstrated.

References

[1] Tan, X.Y. (2000) Research of Anti-Interference and Countermeasures of GPS Used in Military Navigation. *Electronics Optics & Control*, No. 4, 23-28.

[2] Gao, J., Li, Z.J. and Dai, G.X. (2000) Jamming to GPS Signal. *Aerospace Electronic Warfare*, No. 2, 43-45.

[3] Sun, H.T., Wang, C.Q. and Feng, J.D. (2004) Current Situation and Development of Anti-Jamming Technology of GPS System in USA. *Electro-Optic Technology Applicatio*n, **19**, 57-63.

[4] Chu, H.L. and Li, C.X. (2010) Research on Key Technologies of BOC Modulation Navigation Signal. *Radio Engineering*, **40**, 34-37.

[5] Li, X.H. and Bian, Y.J. (2003) Analysis of AM Phenomenon in BPSK Signal. *Journal of Time and Frequency*, **26**, 111-119.

[6] Wang, L., Liu, C.H. and He, S.B. (2009) Interference Effects on BOC Signals. *Chinese Space Science and Technology*, **4**, 69-76.

[7] Yang, L., Bo, Y.M. and Tian, M.H. (2008) Research of Anti-Jamming Characteristic for BOC Signal. *Computer Science*, **35**, 33-35.

[8] Bai, Y., Lu, X.C., Wang, J. and Han, T. (2015) Interference Suppression Method Based on NEW-MDCFT in Satellite Navigation System. *Journal of Navigation and Position*, **3**, 61-65.

[9] Yu, H.J. and Pan, C.S. (2006) The Research and Implementation of the Blocking-Suppressing Jamming Technique in GPS. *Transactions of Shenyang Ligong University*, **25**, 65-67.

[10] Xiao, J.Q. and Ji, Q. (2007) A Robust Content-Based Digital Image Watermarking Scheme. *Signal Processing*, **87**, 1264-1280. http://dx.doi.org/10.1016/j.sigpro.2006.11.002

[11] Wei, X.G. (2011) Study of Jamming to GPS Signal Modulated by BOC. *Electronic Design Engineering*, **19**, 139-144.

[12] Wo, Y., Han, G.Q. and Zhang, B. (2005) A New Feature-Based Image Content Authentication Algorithm. *Chinese Journal of Computers*, **28**, 105-112.

[13] Xiang, D.S., Xiong, Y.S. and Zhu, G.M. (2006) An Image Adaptive Gray-Scale Watermark Embedding and Extraction Algorithm Based on Visual System. *Journal of Image and Graphics*, **11**, 1026-1035.

[14] Zang, P. and Fan, Y.B. (2006) Study and Comparison of Image Watermark Based on Wavelet Packet and Multi-Wavelet. *Computer Engineering*, **32**, 162-164.