A new waveform design method of Military Anti-jamming Communication

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Abstract. The advantages and disadvantages of wireless communication systems are the key factors that determine victory or defeat in the war. The construction of military informatization has accelerated in various countries, and the struggle for electromagnetic space has become more intense. Therefore, the communication anti-jamming techniques received extensive concern. It is of great significance to explore a waveform that can communicate effectively under interference. In this paper, the complex electromagnetic environment, typical means of military communication jamming and anti-jamming are analyzed thoroughly. A double-sequence frequency hopping waveform design method based on pseudo-random chirp is proposed, which has some practical value in engineering.

1. Introduction
Many problems of communication systems are revealed in the Gulf War. After the war, military forces around the world are vigorously develop and improve their own command information system. High-performance military communication equipment has frequently entered the stage of electronic warfare. In September 2017, Russia and Belarus jointly held a "West-2017" military exercise. During the exercise, the communication interference signals released by the Russian army even affected Sweden, Latvia and other countries, disrupting telephone service for several hours[1]. In 2016, the US Army disbanded the original Electronic Warfare Division and established the Cyber Directorate to further enhance the US Army's electronic warfare capabilities. The US Army will deploy a comprehensive electronic warfare system with full combat capability by 202. This system can achieve a series of functions such as electromagnetic environment sensing, electronic support and attack. China started late in the field of electronic countermeasure, and is gradually transforming from a mechanized army to an informationized army[2].Therefore, the test of military anti-jamming communication is even more severe. Have a clear explicit understanding to the complex electromagnetic environment, jamming and anti-jamming methods in military communications, and actively explores new anti-jamming technologies, which is of great significance for the formation of communication road with Chinese characteristics[3].

2. Complex electromagnetic environment
The following four elements can be summarized by analyzing the current electromagnetic environment of military equipment[4]:

- Natural noise and some clutter received by the receiver during communication.
- Mutual interference between weapons and equipment.
- The electromagnetic environment formed by the external non-interfering equipment.
The electromagnetic environment formed by the external interfering equipment.

A complex electromagnetic environment is formed by the above four electromagnetic signals in a certain space. This will have an inestimable impact on the equipment and even on the entire military operation. How to solve the first three electromagnetic impact has a mature standard and theoretical basis, but the fourth belongs to intentional interference which has the characteristics of strong purpose and uncontrollable[5]. Therefore external jamming equipment is also the main concern of military communication anti-jamming. The technical means used in jamming equipment will be introduced in Section III.

3. Communication interference means
In general, commonly used means of interference can be divided into the following two categories[4]:

3.1 Blocking jamming
Blocking interference covers all or part of the frequency hopping communication band, so it can be subdivided into broadband, partial band and comb jamming. Broadband and partial band jamming can achieve better jamming effect without too much prior knowledge of communication signals, while comb jamming requires some prior knowledge. But the jamming power of comb jamming can be more concentrated and the jamming effect is better. At the same time, they all have the disadvantage of interfering with their own communication.

3.2 Aiming jamming
The aiming interference is aimed at the next hop frequency under the premise of successfully capturing the time-frequency characteristics of the enemy frequency hopping communication system. It can be divided into waveform tracking jamming, guided tracking jamming, and forwarding tracking jamming.

This kind of interference is the nemesis of the frequency hopping system. Once the implementation is successful, it can directly smash the enemy communication system, but the actual operation will be limited by the interference ellipse and the acquisition of the time-frequency characteristics.

Literature[6] makes simulation and performance analysis on noise amplitude modulation interference, frequency modulation interference and pseudo-random code stream modulation interference, which can give us a more intuitive impression on the interference signal. Literature[7] and literature[8] summarized the interference technology from the perspective of spectrum utilization of interference signals, and introduced the principles of tracking interference, blocking interference, direct spread communication correlated interference and non-correlated interference.

In the actual military communication countermeasure, the joint use of more than two kinds of jamming technology to further improve the jamming effect according to the specific situation.

4. Communication anti-jamming technology
The mass production of high-speed signal processing chips poses a great challenge to the anti-interference ability of frequency hopping communication systems. In order to ensure the working efficiency communication systems, it is necessary to carry out related research[9].

4.1 Direct sequence spread spectrum DSSS
Direct spread spectrum technology is to spread the baseband spectrum to a wide bandwidth[10]. The theoretical basis is the Shannon formula. The spread spectrum communication schematic diagram is shown in figure 1[11]. At the sender, the baseband signal is spread-spectrum modulated by a high-rate pseudo-random code, and then intermediate frequency and radio frequency modulation are performed. Demodulation is performed first at the receiving end and then despread. It can be seen from the above analysis that the direct spread spectrum technology has strong anti-interference ability because it transmits signals with low power spectral density, and the receiving end reduces the power spectral density of the interference signal by despreading, thereby improving the signal-to-interference ratio of
4.2 Frequency hopping technology

The inspiration of frequency hopping (FH) technology comes from the beating notes of the piano. The transmitting and receiving parties perform RF frequency hopping according to the same hopping pattern algorithm under the premise of synchronization. Since the frequency hopping bandwidth is much larger than the original signal bandwidth, FH also achieves spectrum spreading, which is a kind of spread spectrum communication[13]. The schematic diagram is shown in Figure 2 [14]. FH through the frequency hopping to avoid jamming. Each user continuously changes the carrier frequency according to its frequency hopping pattern. When multiple users share the same frequency, the collision will lead to error code. Multi-dimensional modulation scheme is studied in[15], but the improvement of performance is still affected by collision interference. In reference [16] Message-driven FH is discussed. This is a kind of high efficiency spectrum spreading technique, which still has strong persistent ability under strong interference. In reference [17], clipper cascaded product-combining receiver is proposed. The results show that it can resist multi-tone interference and partial band interference in AWGN channel.

4.3 Differential frequency hopping technology

Differential frequency hopping (DFH) is another technique of frequency hopping spectrum spreading, and its typical application is CHESS radio. It adopts the asynchronous frequency hopping mode, and the next hop frequency is determined by the current frequency and the information to be transmitted. Correlation Pre-Windowing Filter (CPWF) on frequency domain is proposed in[18]. Compared with the product-combining and the linear receiver, the DFH signal received by this receiver can obtain higher hopping speed and data rate.

In addition to the three types of typical spread spectrum anti-jamming techniques described above, there is also an anti-jamming technology based on multi-sequence frequency hopping (MSFH).

4.4 Multi-sequence frequency hopping

Double-sequence frequency hopping (BSFH) is a typical example of MSFH. The schematic diagram is shown in Figure 3. BSFH uses two mutually orthogonal frequency hopping sequences to represent channel0 and channel1. These two channels are used to transmit information symbols 0 and 1 respectively. At the receiving end, there are also two hopping sequences corresponding to channel0
and channel1, and are consistent with the hopping pattern algorithm of the transmitting end. After the square law detection, the decision is made and the current data information is obtained. BSFH has better anti-jamming performance than conventional FH technology under the premise of synchronization.

![Multi-sequence frequency hopping schematic diagram](image)

Figure 3. Multi-sequence frequency hopping schematic diagram

When the BER is $10^{-5}$ under the worst-case partial band jamming, MSFH requires signal-to-jamming ratio (SJR) of 1.5 dB less than the conventional FH and 2.5 dB less than the DFH symbol-by-symbol (SBS) detector[19]. The MSFH has lower SER versus the conventional FH-2FSK under the same coding gain, and it also outperforms the DFH of a comparable decoding complexity[20]. In reference [21] and [22], shows that MSFH has better anti-jamming performance than conventional frequency hopping under multi-tone jamming and tracking jamming. Compared with DFH, MSFH has the following advantages[23]:

- Unconventional message representation: DFH has better anti-tracking jamming performance, but the next hop frequency is related to the current information. Therefore it is easy to cause error diffusion. MSFH uses hopping sequences to represent information. The hopping sequence is numerous and can also avoid error diffusion.
- Synchronal receiving: Compared with wideband reception of DFH, MSFH can achieve synchronous reception, which can reduce the probability of error diffusion.
- Excellent anti-broadband jamming performance: MSFH can achieve narrowband reception which can filter out some interference signals at the receiving end.

After the above analysis, it can be known that MSFH is a good FH technology, but it has a fatal disadvantage that when the dual sequence is interfered by the enemy, its BER will become very high. Therefore, MSFH based on pseudo-random chirping is proposed[24].

5. **MSFH based on pseudo-random linear frequency modulation (MSFH_PRLFM)**

The schematic diagram is shown in Figure 4.

![MSFH_PRLFM schematic diagram](image)

Figure 4. MSFH_PRLFM schematic diagram

The channel spacing of the tactical VHF station is 25KH provided by GJB 2928-1997[3]. This instantaneous narrowband bandwidth is a little bit wider than the original signal bandwidth, with some free bandwidth in addition to the protection interval bandwidth. Therefore, PRLFM is used to extend the baseband signal bandwidth to a certain extent, but less than 25KH. After BSFH modulation, finally sent out by RF. The two parallel channels at the receiving end respectively generate the hopping
sequence 0 and the hopping sequence 1. After the de-hopping, the matched filter is used to demodulation. Finally, the current hop user information is obtained through comparison judgment.

It can be seen from the above analysis that BSFH_PRLFM has better anti-jamming performance than DFH, and has the following advantages compared with conventional FH:

- Low probability of being disturbed: In the case of synchronization, the probability that the interference signal matches the matched filter at the receiver is very low, thus improving the detection probability
- Double insurance mechanism: We already know that when it interferes with the current transmission frequency, the detection probability will be increased. When the dual frequency is disturbed, the probability of error is also very low because the information has the characteristics of PRLFM.

6. Simulation results and analysis
The above communication system was built using MATLAB/Simulink for simulation. In the experiment, it is assumed that it is fully synchronized. The schematic diagram of the Simulink model is shown in Figure 5.

![Figure 5. Schematic diagram of MSFH_PRLFM simulation module](image)

In the experiment, the data rate is 100b/s, the sampling rate is 1MHz, the frequency hopping rate is 200 hops/s, the frequency hopping point is 7, the frequency hopping interval is 25KHz, and the center frequency is 100KHz. The PRLFM slope is 256, and the slope conversion time is 0.5ms. The BSFH signal generating module and the PRLFM signal generating module are shown in Figs 6.

![Figure 6. Schematic diagram of BSFH and PRLFM simulation module](image)

When performing the simulation, the signal-to-noise ratio is set to 16 dB, and a single-tone
interference signal is set at the dual frequency of each hop. When the PRLFM module is removed, the BER curve of BSFH is obtained by changing signal-to-interference ratio. The PRLFM is added to obtain the BER curve of the BSFH_PRLFM system. The simulation results are shown in Figure 7.

![BER comparison of BSFH and BSFH_PRLFM.](image)

It can be seen from figure 10 that the BSFH system has a BER greater than 10^{-1} when the signal-to-interference ratio is less than 4dB, but the BER of BSFH_PRLFM still be guaranteed to be in the order of 10^{-3} when the signal-to-interference ratio is -3dB. It can be proved that the scheme proposed in this paper improves BSFH system and has good anti-jamming performance.

7. Conclusion

Military communications play an more and more important role in modern military operations which determines the outcome of a war. In this paper, the development of foreign communication technology is analyzed, and some typical jamming and anti-jamming methods are summed up. Finally, the MSFH_PRLFM is introduced in detail. According to theoretical analysis and simulation verification, this technology has good anti-jamming performance and engineering practicability.

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