An Improved Method for Fast Acquisition of Broadband and High-Speed Hopping Signals

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***Abstract* — The sliding correlation methods have been commonly applied in frequency hopping acquisition with synchronous-head. However, some limitations exist in acquisition time of serial sliding correlation and structure complexity of parallel sliding correlation for high-speed frequency hopping signals. Therefore, an improved fast acquisition method based on circular correlation and dual-judgment principle is proposed. The fast acquisition method is analyzed on the aspects of system complexity, anti-jamming performance and acquisition time. The simulation shows that the new method achieves good anti-jamming performance and has relatively simple operation structure for realizing fast acquisition of broadband and high-speed frequency hopping signals.**

Keywords - Acquisition; Frequency Hopping; Sliding Correlation; Circular Correlation

I. INTRODUCTION

FH (Frequency hopping) communication technology with good anti-jamming performance and LPI (low probability of interception) is widely used in satellite communication, remote control detection, modern radar, sonar system and other electronic systems. It can be divided into fast frequency hopping (FFH), medium frequency hopping (MFH) and slow frequency hopping (SFH). Along with the increasing of hopping rate, the anti-jamming performance of the system is enhanced. So the growth of hopping rate becomes the development trend of modern FH communication system. For the FH signal, it can be divided into direct FH signal and DS/FH signal. At this stage of military communication satellite system, DS/FH signals usually be used for presenting broadband and high-speed characteristics [1, 2], further enhancing its anti-jamming performance. To quickly and accurately realize the synchronization is a prerequisite for the normal work of the FH communication system. Commonly used synchronization methods include the independent channel method, the reference clock method, self-synchronizing method and synchronized-head method. Compared with other methods, synchronized-head method is widely used for fast searching, easy realization and reliable.

The synchronization process for broadband and high-speed FH signal is divided into synchronization acquisition and synchronization tracking. Synchronization acquisition completes the coarse synchronization in 1/2 chip width, while synchronization tracking completes the precise synchronization and lock the phase. The performance of synchronous acquisition largely determines the performance of the whole synchronization system. Broadband and high-speed FH signal requires shorter acquisition time in one FH gap to avoid leaking acquisition phenomenon. Commonly used sliding correlation acquisition method [3] has not completely met the requirements of broadband and high-speed FH signal. And the parallel acquisition method based on the matching filter and subspace analysis method, which has good acquisition performance, is difficult to be realized for its complicated algorithms.

In recent years, the researching on fast acquisition [4] focused on serial acquisition algorithm using FFT algorithm to calculate correlation value. Therefore, based on an in-depth study of commonly used acquisition method, this paper proposes an improved method for fast acquisition to realize the promotion of anti-jamming performance, the reducing of system complexity and the expected value of acquisition time.

II. 1 ACQUISITION METHODS FOR BROADBAND AND HIGH-SPEED FH SIGNAL

At present, FH communication system usually adopts serial sliding correlation acquisition method and parallel sliding correlation acquisition method [5~9].

In serial sliding correlation acquisition method, the local signal and receiving signal are processed by mixing and filtering. And the intermediate-frequency signal is output. Then the result of sliding correlation between intermediate-frequency signal and local code is used to judge the frequencies of sending and receiving ends the same or not. Finally, searching controller controls the acquisition system by the result of threshold decision. If the output exceeds the threshold value, acquisition is finished. And the tracking loop will be carried out. Otherwise the local sequences are phase shifted by searching commands, until acquisition successful. The principle of serial sliding correlation acquisition method is shown in figure 1.

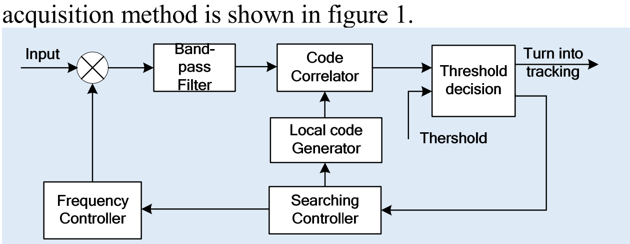

Figure1. Serial sliding correlation acquisition diagram

The principle of parallel sliding correlation acquisition method is shown in figure2. The receiving end consists of N band-pass filters for matching the number of frequency points. And their center frequencies are controlled by the local searching controller in real-time. The code-correlator output is used for threshold decision to determine he current frequency by correlation calculation of filter output and local code.

With complexity of the structure, parallel acquisition method is comprised of N correlate branches, consisted by mixing, filtering, correlation and threshold decision, while the serial acquisition scheme requires only one related branch (Considering the implementation complexity, the parallel acquisition method requires N correlation branches, each consisting of mixer, filter, correlator and threshold device, while the serial acquisition scheme requires only one branch). In the anti-jamming performance of frequency hopping sequences, serial and parallel sliding correlation methods, applying the uniform threshold decision and same cycle length of frequency hopping sequence, have the same anti-jamming performance.

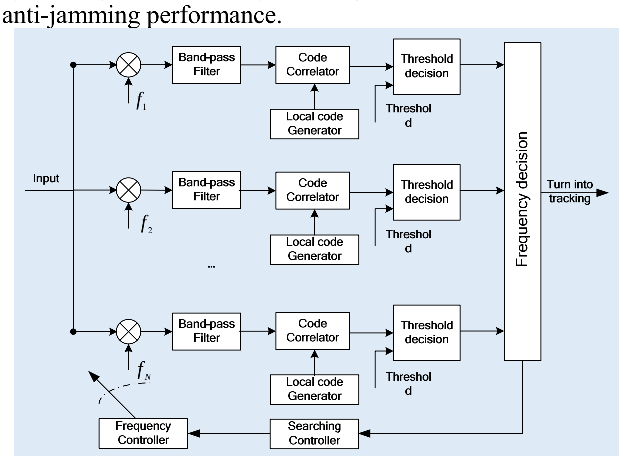

Figure2. Parallel sliding correlation acquisition diagram.

Hypothesis, the cycle length of FH sequence is N, and the time of frequency hopping gap is T. Then the correlate result is calculated for i ($i = N$) times. The expected values of acquisition time for serial and parallel sliding correlation method are calculated.

The expected time of parallel sliding correlation acquisition in the K frequency gap is given by

$$\vec{T} = \sum_{k=1}^{N} \{\rho(k)t\} = iT \quad (1)$$

While the expected time of serial sliding correlation acquisition is stated as

$$\vec{T} = \sum_{k=i}^{i+N-1} \{\rho(k)kT\} = \sum_{k=i}^{Ni} \frac{1}{N} kT = \frac{N+1}{2} iT \quad (2)$$

Thus, parallel correlation acquisition method is better then serial acquisition in expected time for the shorter acquisition time.

With the improvement requirements of modern FH communication system, the synchronized-head acquisition method can't meet the high-speed FH rate and transmission rate of FH signal. In synchronized head, the acquisition time determines the performance and stability of FH system. Therefore, based on the technology of circular correlation and dual-judgment theory, the improved fast acquisition method will be deeply researched.

III. THE IMPROVED FAST ACQUISITION METHOD

For broadband and high-speed frequency hopping signal, serial and parallel sliding correlation method are limited by acquisition timeliness and accuracy separately. Therefore, the fast acquisition mechanism is built. And the dual-judgment theory is introduced.

Circular correlation method [10~12]is a fast correlation method by improving correlation process. During the process of digital signal processing, circular correlation is actually a process of cyclic correlation for two sequences, which adopted a fast algorithm of FFT. Compared with linear correlation, the computational speed is improved greatly for achieving a fast acquisition.

The first process of circular correlation is to get the FFT outputs of N input sequence and local recurrence sequences, as follows.

$$X(n_1) = FFT[x(n)] \quad (3)$$

$$Y(n_1) = FFT[y(n)] \quad (4)$$

$x(n)$ and $y(n)$ represent the input sequence and local recurrence sequence respectively.

The product of $x(n)$ and $y(n)$ after FFT is expressed by as

$$Z(n_1) = X^*(n_1)Y(n_1) \quad (5)$$

And the results after IFFT operation can be written as

$$z(n) = IFFT[Z(n_1)] \quad (6)$$

The obtained $z(n)$ were compared with the acquisition threshold, so as to judge the process of acquisition successful or not.

The diagram of fast decision acquisition method which based on dual-judgment theory is presented in Figure 3.

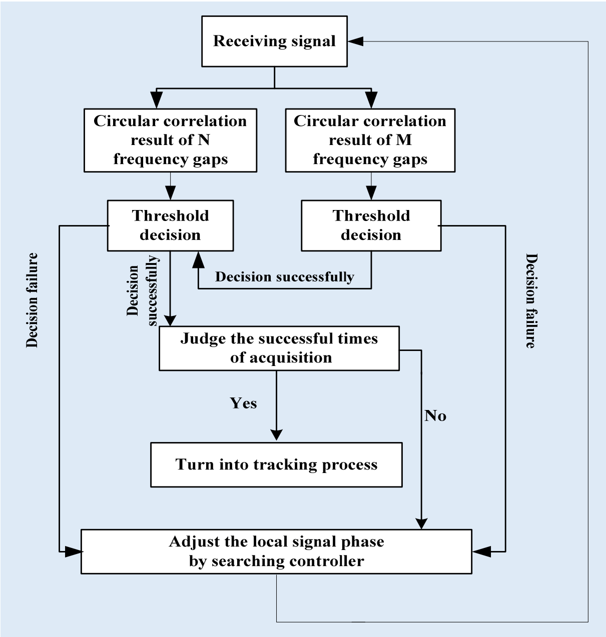

Figure3. Dual-judgment flow diagram.

In the threshold judgment, we set two threshold values, D_{suc-n} and D_{suc-m}.

D_{suc-n}, the threshold value of cumulative circular correlation of N frequency gaps when judgment successfully.

D_{suc-m}, the threshold value of cumulative circular correlation of M frequency gaps when judgment successfully.

Stage 1: the receiving signal and the local signal carry through circular correlation respectively in M and N frequency gaps. The results are $x(M)$ and $x(N)$, while $M < N$. Firstly, $x(M)$ is obtained and judged by threshold.

$$D_{in-m} = \sum_{M} x(M) \quad (7)$$

If $D_{in-m} > D_{suc-m}$, judgment successful and enter the second stage. Otherwise, adjust the local phase to restart.

Stage 2: judge the circular correlation results $x(N)$ of N frequency gaps by threshold.

$$D_{in-n} = \sum_{N} x(N) \quad (8)$$

If $D_{in-n} > D_{suc-n}$, acquisition successful and enter the tracking process. Otherwise, adjust the local phase to restart continually.

The fast decision acquisition mechanism is shown in Figure 4. The output of local carrier and receiving signal after mixing and filtering is correlated in M frequency gaps and N frequency gaps respectively. According to the threshold judgment, the current frequency of carrier is judged. If they are consistent, judgment successful, turn into tracking stage. Otherwise, the local signal phase is shift directly by the searching controller about 1/2 frequency gap, and then restarting signal acquisition continually.

When the frequency output of local frequency synthesizer is consistent with transmitting terminal in frequency hopping, the receiving signal and local signal are given as below:

$$s_f(t) = D(t)\sin(2\pi ft + \varphi_f) \quad (9)$$

$$s_{f+\Delta f}(t) = \sin(2\pi(f + \Delta f)t + \varphi_{\Delta f}) \quad (10)$$

Among them, the carrier frequency of receiving signal is f. Δf is the local intermediate frequency. φ_f and $\varphi_{\Delta f}$ are initial phases.

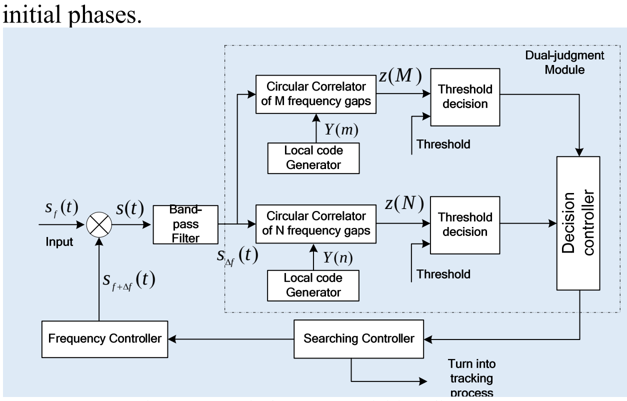

Figure4. Fast judgment acquisition diagram.

The output after mixing process is showed as below:

$$\begin{aligned} s(t) &= s_f(t)s_{f+\Delta f}(t) \\ &= D(n)\sin(2\pi ft + \varphi_f)\sin(2\pi(f+\Delta f)t + \varphi_{\Delta f}) \\ &= \frac{1}{2}D(n)\cos(2\pi(\Delta f)t + \varphi_{\Delta f}) \\ &\quad -\frac{1}{2}D(n)\cos(2\pi(2f+\Delta f)t + \varphi_{2f+\Delta f}) \end{aligned} \quad (11)$$

The intermediate frequency signal through band-pass filtered can be stated as:

$$s_{\Delta f}(t) = \frac{D(n)}{2}\cos(2\pi\Delta ft + \varphi_{\Delta f}) \quad (12)$$

The intermediate frequency signal and local signal are calculated by circular correlation in M frequency gaps and N frequency gaps. The outputs are shown as follows

$$\begin{aligned} z(M) &= \sum_{M} IFFT[Z(m)] \\ &= \sum_{M} IFFT[FFT^{*}[s_{\Delta f}(t)]FFT[Y(m)]] \end{aligned} \quad (13)$$

$$\begin{aligned} z(N) &= \sum_{N} IFFT[Z(n)] \\ &= \sum_{N} IFFT[FFT^{*}[s_{\Delta f}(t)]FFT[Y(n)]] \end{aligned} \quad (14)$$

While $Y(m)$ and $Y(n)$ are the native code generator outputs, as follows.

$$Y(m) = D(m)\cos(2\pi\Delta ft + \varphi_{\Delta f}) \quad (15)$$

$$Y(n) = D(n)\cos(2\pi\Delta ft + \varphi_{\Delta f}) \quad (16)$$

$z(M)$ and $z(N)$ are judged by the threshold arbiter. When circular cumulative output of M frequency gaps and N frequency gaps, $z(M)$ and $z(N)$ exceed the thresholds, acquisition successful and turn into tracking process.

Otherwise, the local signal phase is shift directly by the searching controller about 1/2 frequency gap, and then restarting signal acquisition continually.

IV. SIMULATION ANALYSIS

A. *Structure complexity*

Contrast to the serial sliding correlation acquisition method, the structural complexity of fast decision acquisition method increases slightly. The fast decision acquisition method, as shown in principle diagram, with a dual-judgment module improves the acquisition efficiency, decreases the acquisition time and provides synchronization stability process for broadband and high-speed FH signal. In term of the structural complexity, the computing and storage resources of FH system are not occupied obviously. Therefore, it is worth to increase relative resources properly for the acquisition time of high-speed frequency hopping signal. The improved acquisition method has greatly improved the consumption of resources than parallel sliding acquisition method. For broadband and high-speed FH signal, it is clearly inapplicable for increasing the acquisition branch of parallel acquisition method extremely to meet the fast acquisition performance. The improved acquisition method with dual-judgment module can provide similar acquisition expected time to the parallel acquisition method. Therefore, based on the system structure complexity, the improved acquisition method is more suited to meet the acquisition requirements of broadband and high-speed FH signal.

B. *Anti-jamming performance*

The fast decision acquisition method based on circular correlation derived from the FFT theory. Correlation accumulated result of a FH cycle is used for acquisition judgment. Therefore, the same cycle length of FH sequence, the same anti-jamming performance of improved correlation method and sliding correlation method with a uniform threshold. Because the synchronized-head is pseudo random code with good autocorrelation and cross-correlation features, the acquisition method based on FFT algorithm has better anti-jamming performance.

Taking the simulation source of synchronization-head, which based on pseudo random code, for example, the FH communication system is simulated. The system parameters are set as follows. They are hopping speed of 16000Hops, code rate of 4.8Mbps, sampling in the frequency of 12GHz, hoppingbandwidthinthefrequencyof1GHz~3GHz, frequency band width of 100MHz and BPSK modulation manner. The center frequency of broadband and high-speed FH signal is set in 1.3GHz. The improved acquisition method has been compared with the common method in the environment of Gauss white noise of200MHzbandwidth.

Successful acquisition results map of two kinds of acquisition methods without interference signal are shown as follows.

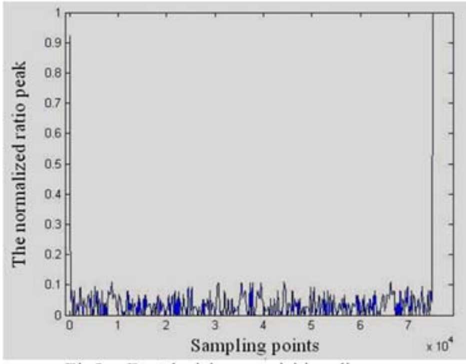

Fig5.a. Fast decision acquisition diagram.

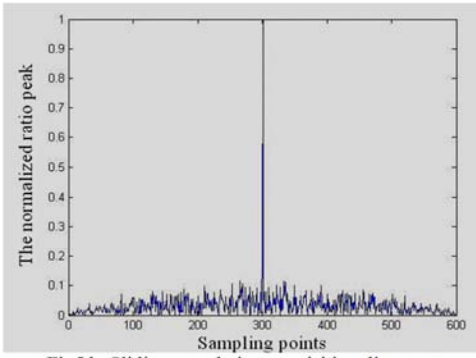

Fig5.b. Sliding correlation acquisition diagram.

The acquisition diagrams with bandwidth interference signal at 26.922dB JSR are shown as follows.

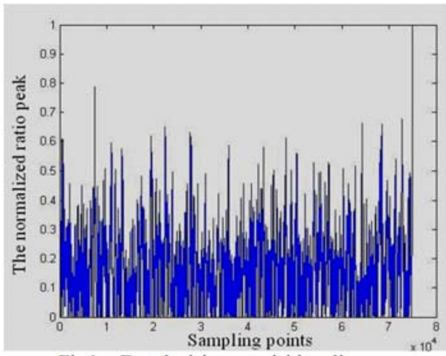

Fig6.a. Fast decision acquisition diagram

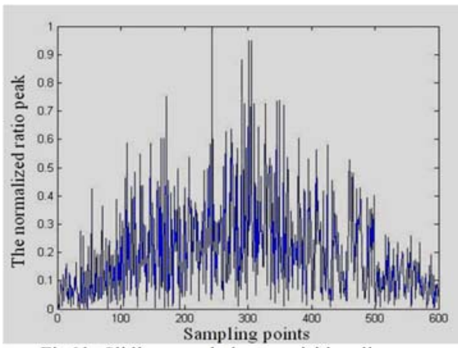

Fig6.b. Sliding correlation acquisition diagram

Along with the increasing of JSR, the acquisition ratio peak diagrams are shown in figure 3.

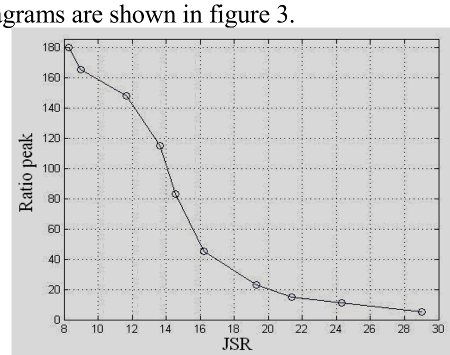

Fig7.a. JSR change map of fast decision method.

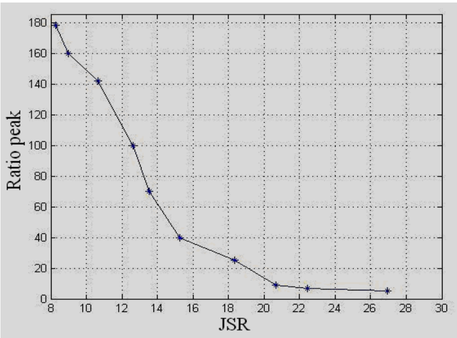

Fig7.b. JSR change map of sliding correlation method.

According to the analysis of simulation results, improved fast decision acquisition method and sliding correlation acquisition method complete the acquisition of broadband and high-speed frequency hopping signal without jamming. Under jamming, the two methods express different acquisition performance. In the sliding correlation acquisition diagram, multiple acquisition peaks appear, which means the interference signal successfully interfere the synchronization information and destroy the synchronization process. In the fast decision acquisition graph, Acquisition peak is still clearly visible that the interference signal did not cause destructive impact on the synchronization process. In the JSR variation diagram, two kinds of acquisition ratio peak have gradually become smaller along with the increase of JSR. When the JSR is 26.97dB, sliding correlation acquisition ratio peak is lower than the acquisition threshold, failure to acquisition. Keeping on increasing the JSR to 29.002dB, the improved fast decision acquisition ratio peak is lower than the acquisition threshold, failure to acquisition. The simulation results show that the anti-jamming performance of improved fast decision acquisition is better than the commonly used methods.

C. *The value of acquisition time*

Without jamming, the cycle length of frequency hopping sequence is set at N and the judgment is executed under accumulating I (I=N) gaps. There are L codes, carried in one frequency hopping, while the acquisition time of frequency hopping gap is T_1 ($T_1 < T$). Then the probability of successful acquisition for fast decision acquisition method in the gap k is given as below:

$$\rho(k) = \begin{cases} 1/N, & k = 0,1,2,\cdots,N-1; \\ 0, & else. \end{cases} \quad (17)$$

The first level judgment of dual-judgment mechanism judges the circular correlation accumulation result of M frequency gap. When the circular correlation result does not exceed the decision threshold, the circular correlation result of N gap is not necessary to be judged. Thus the judgment time of unsuccessful is MT_1.

The successful acquisition time of k frequency gap is set as follows:

$$t = \begin{cases} iT_1 + kMT_1, & k = 0,1,2,\cdots,N-1; \\ 0, & else. \end{cases} \quad (18)$$

The expectation of acquisition time is given by

$$\vec{T}_1 = \sum_{k=i}^{i+N-1}\{\rho(k)t\} = \sum_{k=0}^{N-1}\frac{iT_1 + kMT_1}{N} = iT_1 + (\frac{N-1}{2})MT_1 \quad (19)$$

As you can see in the above formulas, the acquisition time of a frequency gap is T_1, which is smaller than T. The frequency gap number M is smaller than i. Therefore, the performance of fast decision acquisition method is better than serial sliding correlation method, while the expectation of serial sliding correlation method is $(N+1)/2*iT = iT + (N-1)/2*iT$. The smaller M, the better acquisition performance of fast decision acquisition method. When M is 1, the fast decision acquisition is closely in time expectation with the parallel sliding acquisition, meet the requirement of smaller expectation time. But M can not become small blindly, or the information leak rate will increase and the anti-jamming performance gets worse. Therefore, we need to determine the value of M according to the actual situation.

Under the same simulation conditions, the acquisition time of sliding correlation acquisition method and fast decision acquisition method are compared. And the processing time are shown in Table 1.

Chart1. The comparison of Acquisition time

	Processing time of signal acquisition at 1.3GHz	Processing time of signal acquisition at 1.5GHz
Sliding Correlation Acquisition Method	5.3261s	5.3416s
Fast Decision Acquisition Method	4.8803s	4.8629s

Due to chart 1, the time needed of fast decision acquisition method to handle one FH signal is shorter than sliding correlation acquisition method about 0.4 second. The structures of two systems are all identical completely except correlation and judgment method. Therefore, the performance of fast acquisition method overmatches the serial sliding correlation method.

In conclusion, the improved acquisition method is superior to traditional serial sliding method, and the expected value is close to the expected value of parallel sliding correlation method. Therefore, fast acquisition method is fit for synchronization demands of broadband and high-speed frequency hopping.

V. CONCLUSIONS

In the study of broadband and high-speed frequency hopping signal acquisition, this paper introduces the correlation method of serial sliding and parallel. Serial sliding acquisition mechanism is simple but the acquisition time needed is so long. Parallel sliding correlation acquisition time is short though structure is too complex to complete. Modern acquisition method needs quickly acquisition speed, and system structure is incapable of over complex. Therefore, this paper comes up with an improved acquisition method, which is fast acquisition method. The fast acquisition method improves the related algorithm and judgment method, which could shorten time of correlation operation and judgment. This method is apt to realize that it has good anti-jamming performance, fast acquisition property and shorter acquisition time than serial sliding correlation method with relatively simple structure. Therefore, based on the comprehensive consideration of the parameters of broadband high-speed frequency hopping signal, the requirement of acquisition time and system structure complexity, circular correlation acquisition method for fast judgment is suitable for the acquisition requirements of broadband and high-speed frequency hopping signal.

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