Novel Fast Acquisition Algorithm for DS/FH System

Weining Song, Yanzhong Zhang, Dingrong Shao, Shujian Li and Xiaojie Wen
School of Electronic and Information Engineering
Beihang University
Beijing, China
songweining1234@163.com

***Abstract*—Based on differential correlation technique, novel fast acquisition algorithm is developed for hybrid direct sequence and frequency hopping (DS/FH) system. Specifically, by using differential correlation for PN code phase and parallel searching for frequency, the fast acquisition is realized. Furthermore, in terms of acquisition time and hardware resources consumption, the proposed differential correlation acquisition method is compared with the conventional waiting self synchronization acquisition method and frequency parallel searching acquisition method. Analytical and simulation results reveal that the proposed algorithm can be used in DS/FH system.**

Keywords- DS/FH; acquisition; differential correlation

I. Introduction

Hybrid direct sequence/frequency hopping (DS/FH) spread spectrum system is widely used in civil and military for its excellent properties such as low probability of intercept (LPI) and low probability of jamming (LPJ) capabilities [1]-[4]. In order to increase the efficiency and avoid long set-up time, fast acquisition is required.

In DS/FH system, acquisition includes two parts: frequency domain acquisition and PN code acquisition. DMF (Digital Matched Filter) is widely used in PN code acquisition. There are usually two methods for frequency domain acquisition: waiting self synchronization acquisition and frequency parallel searching acquisition. In waiting self synchronization acquisition, receiver's frequency synthesizer is controlled to emit a certain frequency f_j, waiting for the corresponding signals. In frequency parallel searching acquisition, M (M is the total number of hopping frequencies) frequency synthesizers are controlled to emit M frequencies. For waiting self synchronization acquisition, one DMF is needed, and acquisition time will be one hop duration. For frequency parallel searching acquisition, acquisition time is one hop, but M DMFs are needed, which costs too much source for practical system.

In this paper, a novel acquisition method based on differential correlation is proposed. By employing differential correlation to avoid frequency effects, PN code acquisition is accomplished rapidly and then frequency acquisition is carried out.

This paper is organized as follows: the system model is proposed in section Ⅱ; in section Ⅲ, different acquisition algorithms are analyzed; in section Ⅳ, simulations and analyses results are given out to verify algorithms' performance.

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II. System Model

The received DS/FH spread spectrum signal (ignoring noise) can be expressed as

$$s(t) = Ac(t)d(t)\cos(2\pi f_i t + \theta_0) \tag{1}$$

- A is the signal amplitude.
- $c(t)$ is ±1 valued, N-chip-long PN codes with chip interval T_c seconds.
- $d(t)$ is data sequence valued ± 1.
- f_i is the frequency of hop i whose value is taken from the frequency set $\{f_1, f_2, \cdots, f_M\}$. M is the total number of hopping frequencies.
- θ_0 is phase of carrier.

For the whole acquisition time, the data signal $d(t)$ is assumed to be one, so that it can be ignored in (1).

III. Acquisition Algorithms

A. Waiting Self Synchronization Acquisition

Waiting self synchronization acquisition algorithm block diagram is shown in Figure 1.

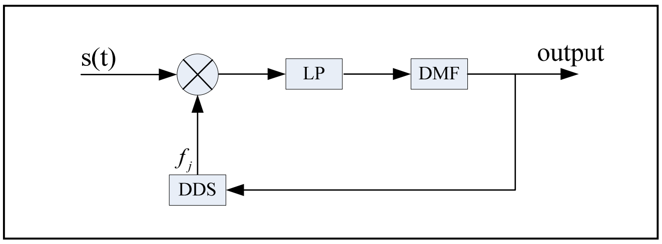

Figure 1.Waiting self synchronization acquisition circuit

As shown in Figure 1, the receiver waits at a certain frequency f_j ($j \in \{1, 2, \cdots M\}$), the received signal $s(t)$ is multiplied with $\cos(2\pi f_j t)$, the output will be:

$$\begin{aligned} s_{o1}(t) &= s(t)\cos(2\pi f_j t) \\ &= Ac(t)\cos(2\pi f_i t + \theta_0) \times \cos(2\pi f_j t) \\ &= \frac{Ac(t)}{2}\left\{\cos\left[2\pi(f_i + f_j)t + \theta_0\right] + \cos\left[2\pi(f_i - f_j)t + \theta_0\right]\right\} \end{aligned} \tag{2}$$

It can be got from (2) that, after low pass filter, if $f_i \neq f_j$, the input signal to DMF will be $\frac{Ac(t)}{2}\cos\left[2\pi(f_i - f_j)t+\theta_0\right]$, so that the correlation peak will be much smaller than threshold, then DDS will keep waiting f_j unless $f_i = f_j$, and then the frequency is changed according to frequency hopping pattern.

B. Frequency Parallel Searching Acquisition

Frequency parallel searching acquisition algorithm block diagram is shown in Figure 2.

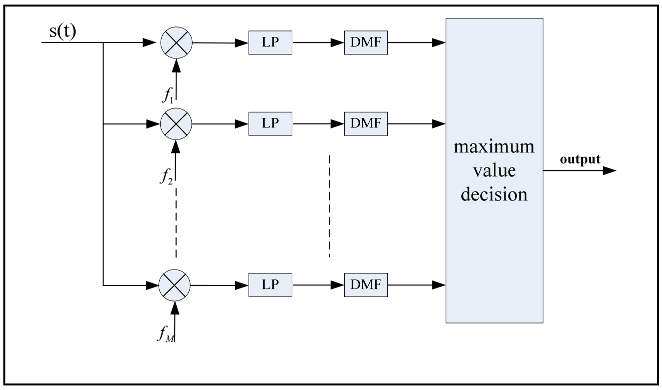

Figure 2.Frequency parallel searching acquisition circuit

As shown in Figure 2, there are M synthesizers. Take the *j-th* branch for example, the output will be:

$$\begin{aligned} s_{o2}(t) &= s(t)\cos(2\pi f_j t) \\ &= Ac(t)\cos(2\pi f_i t+\theta_0)\times\cos(2\pi f_j t) \qquad (3) \\ &= \frac{Ac(t)}{2}\left\{\cos\left[2\pi(f_i+f_j)t+\theta_0\right]+\cos\left[2\pi(f_i-f_j)t+\theta_0\right]\right\} \end{aligned}$$

It can be got from (3) that, after low pass filter, corresponding to current received signal's frequency f_i, output of the *i-th* branch's DMF will be much larger than the others, and acquisition process is accomplished.

C. Differential Correlation Acquisition

Differential correlation acquisition algorithm block diagram is shown in Figure 3.

The received signal $s(t)$ is multiplied with its delay $s(t-\tau)$ to find out PN code phase. Receiver waits at M hopping frequencies. Once the PN code phase is found out, M correlation results are obtained, and the maximum branch's frequency is current hopping frequency.

As shown in Figure 3, the received signal $s(t)$ is multiplied with its delay $s(t-\tau)$, the output will be:

$$\begin{aligned} s_{o3}(t) &= s(t)s(t-\tau) \\ &= A^2 q(t)\cos(2\pi f_i t+\theta_0)\times\cos\left[2\pi f_i(t-\tau)+\theta_0\right] \qquad (4) \\ &= \frac{A^2 q(t)}{2}\left\{\cos(4\pi f_i t+\psi)+\cos(2\pi f_i \tau)\right\} \end{aligned}$$

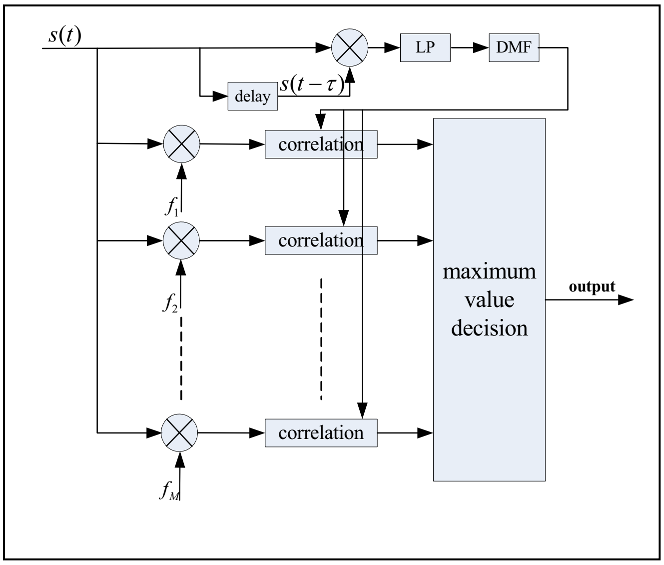

Figure 3. Model of differential correlation acquisition circuit

In which,

$q(t) = c(t)c(t-\tau)$, $\psi = -2\pi f_i \tau + 2\theta_0$.

Equation 4 contains two components: a low frequency term $\cos(2\pi f_i \tau)$ and a high frequency term. The low frequency term can be used to find PN code phase [5].

Strictly speaking, it is difficult to use this to approach for acquisition. In order to make this approach function properly, one must make $\cos(2\pi f_i \tau)$ close to ± 1. Because the input frequency is variable, τ should be cautiously chosen to make sure that for all f_i ($i = 1,2\cdots M$), $\cos(2\pi f_i \tau)$ is closed to ± 1. For example, in a certain system, $M = 1\cdots 10$,

$f_1 = 10MHz, f_2 = 20MHz \cdots f_{10} = 100MHz$, then τ can be chosen as $0.5us$, so that for f_i:

$$\cos(2\pi f_i \tau) = \cos(2\pi f_i \times 0.5us) = 1 \qquad (5)$$

It should be noticed that, during frequency changing period, (5) is not tenable. For DS/FH system, frequency stable time is much larger than changing time so differential correlation can be used in most time.

IV. Performances Analysis

A. Displacement Sequence Self-correlation

In differential correlation acquisition algorithm, a new PN code is formed by $c(t)c(t-\tau)$. As a certain example in (3.3), $c(t)$ is chosen as 63-chip-long m sequence, and τ is one chip time ($0.5us$). According to displacement additivity of m sequence, the new code is the displacement sequence of original m sequence, and its self-correlation is shown as figure 4.

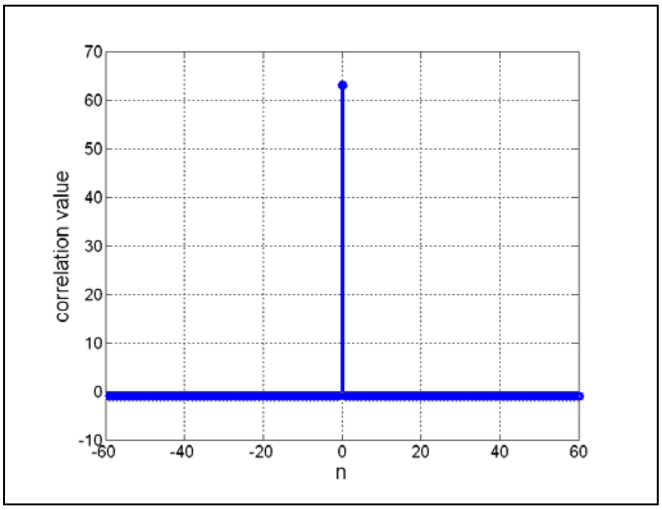

Figure 4. Displacement sequence self-correlation

B. *Acquisition Performance Comparison*

To analyze the acquisition performance, assuming that there is one PN code in one hop, besides, the number of hopping frequencies is M and PN code length is N . For ROM source is adequate relatively, hardware consumption analysis focuses on adder source.

If DMF is used for PN code acquisition in these three algorithms, it can be got that:

For waiting self synchronization acquisition, acquisition time is MT_h (T_h is one hop time) and the number of adders needed is N . For frequency parallel searching acquisition, acquisition time is T_h and the number of adders needed is NM .

For differential correlation acquisition, acquisition time is DMF's acquisition time (T_h) adding correlation time (T_h), that is, $2T_h$, and the number of adders needed is $N+M$ .As shown in Table 1.

TABLE I. PERFORMANCE COMPARISON

Algorithm	Acquisition Time	Adders Consumption
waiting self synchronization acquisition	MT_h	N
frequency parallel searching acquisition	T_h	NM
differential correlation acquisition	$2T_h$	$N+M$

V. CONCLUSIONS

In this paper, a fast acquisition algorithm is presented using differential correlation for DS/FH system. The simulation and analytical results show that the new algorithm could achieve fast acquisition with inconspicuous increase of adder's consumption comparing to conventional acquisition methods, which satisfies the fast requirement of practical system.

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