Design and Implementation of Hopping Frequency Sequences with Given Minimum Gap Based on FPGA

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Abstract: In order to design given minimum gap hopping sequences based on dual sub-bands for technology requirement, with Matlab simulation software analysis and optimize system, performance and design idea of hopping sequences of given minimum gap is expounded. The design method based on hardware of given minimum gap hopping sequences based on dual sub-bands is given. System software uses Quartus II8.0 platform and VHDL language. The language has fine characteristics of transplantation, long lifecycle, powerful description and support large scale design and logic unit recycled. The design has parameter adjustment repeating program function and reference application value in design of hopping-frequency communication hardware.

Introduction

Frequency hopping (FH) technology has been widely used in military communication with its anti-destructive, anti-interference, low captured probability, high confidentiality and multiple address networking capabilities. Multivalued sequence, which is used to control the carrier frequency, is usually referred to as the FH sequence in frequency hopping communication, and its role is to control the FH in order to realize the spectrum expansion and be as address in frequency hopping networking. The performance of FH sequences is to have conclusive effect on the performance of FH communication system. FH communication is a kind of anti-interference technology of escaping type. If the radio stays at a certain frequency too long, the possibility of interference by a variety of frequency may increase. So for the system of the hopping rate identified, the FH sequences are designed as sequences with given minimum gap. It not only benefits to be against the single-frequency narrow-band interference and partial band blocking interference, but also to be against the tracking interference and anti-multipath fading[1] problem. The design of the ideal performance of hopping sequences with given minimum gap will help prevent the FH pattern to be deciphered, prevent the narrowband interference, and minimize the FH sequence of the collision.

Design requirements of the FH sequence

In order to design the frequency hopping sequence of good anti-interference, the design of FH sequence should meet the following requirements [2]:

- Each FH sequence can be used at all frequencies in the set of FH, in order to achieve maximum processing gain.
- The coincidence times of FH sequence in the set of hopping sequences and its frequency of translation sequence must be as short as possible.
- The number of FH sequence families must be as many as possible, so that it can be replaced in practice, which can improve the confidentiality performance of frequency hopping system.
- The FH sequence can control the realization of FH with given minimum gap, that is to say, the frequency gap of two carrier emit in the adjacent slots is greater than a certain value.
- Uniformity, that is, the number of each frequency occurrences is basically the same in a sequence cycle.

●FH sequence should have good randomness and large linear complexity, so that the enemy can not use the previous transmission frequency information to predict the current and future frequency.
●The generation circuit of FH sequence is relatively simple.

Design of Hopping-Frequency Pattern with Given Minimum Gap

Based on the no-continuous tap model, the method of constructing FH sequence with given minimum gap using dual band method is introduced, the concrete steps of hardware implementation are given below.

3.1 Construction of dual sub-bands method

Let the FH band be f, and let the requirements of FH gaps be not less than d, and then the concrete construction steps of dual sub-bands method are as follows:

The FH band F is divided into two dual gap bands f_1 and f_2, where

$$f_1 = \{f_0, f_1, f_2, \ldots\ldots f_{[q/2]-1}\} \quad (1)$$

$$f_2 = \{f_{q-[q/2]}, f_{q-[q/2]+1}, f_{q-[q/2]+2}, \ldots\ldots f_{q-1}\} \quad (2)$$

Based on f_1 and f_2, dual frequency pairs $(f_i, f_{i+q-[q/2]})\ 0 \le i < [q/2]$ are established, where q is called the number of FH point.

●Firstly, FH sequence $w_u(j)$ is set up on f_1, and at the same time ,the corresponding FH sequences $\{w_u^{'}(j)\}$
$(w_u^{'}(j) = w_u(j) + [(q+1)/2])$ is set up on f_2 through dual frequency relation.

●At the frequency points of f_1, the hopping is in order, each time it calculates the distance between the next frequency point and the previous frequency point. If it meets the distance requirements, the hopping continues on f_1. If not, the hopping changes to the dual frequency pair f_2, when its frequency pair can not meet, the hopping changes on f_1,and so, the previous and later frequencies meet the need of given minimum gap.

3.2 Construct FH sequence with L-G model

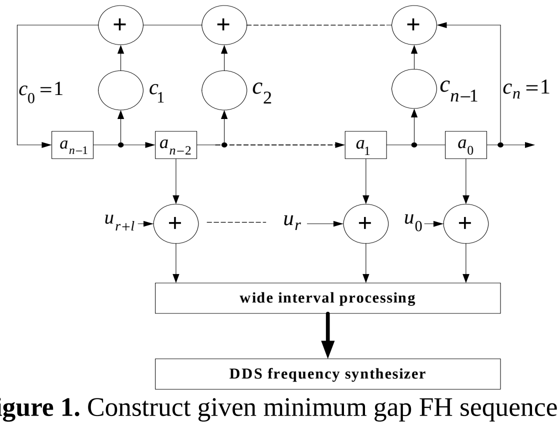

Figure 1. Construct given minimum gap FH sequence by L-G model

FH pattern uses dual sub-bands and m sequence construct FH sequence family with given minimum gap, the best FH sequence using the *p* frequencies and length of *L* = pr-1 is processed with given minimum gap on GF(p). In the figure 1, using the no-continuous tap model of (L-G) constructs FH pseudo-random sequence with given minimum gap, the autocorrelation performance and cross-correlation performance are close to the best FH sequence family, it can improve the anti-interference. The design of FH sequence with given minimum gap is *p*=2, *r*=3, *n*=10, and the number of frequency *q*=16 and FH gap *d*=4, based on the no-continuous tap model of L-G model(Figure 1), using primitive polynomial $x^{10}+x^3+1$ designs FH sequence. The generating formula of FH code is as follows:

$$w_u(j) = 4[(a_j + u_0) \bmod 2] + 2[(a_{j+2} + u_1) \bmod 2] + [(a_{j+4} + u_2) \bmod 2] \quad (3)$$

Let u_0, u_2, u_4 be different values, it can get different sequences $\{S_0, S_1, S_2 \cdots\cdots S_7\}$.

The design makes $u_0 = 0$, $u_2 = 0$, $u_4 = 0$, and the generated FH sequences with given minimum gap based on dual sub-bands are as follows :

S0= 15 7 15 6 14 4 13 1 11 2 14 4 13 8 2 9 5 11 2 7……

The Theoretical Basis Of Measuring Minimum Gap FM (Frequency Modulation) –Hamming Correlation

Because of the differences of the FH starting time and propagation delay, which makes the user's frequency overlap interference, and the overlap interference is called frequency collision or frequency hit. The mathematical term of indicating the parameters is Hamming correlation. Given the limit of hamming cross-correlation and Hamming auto-correlation of the frequency numbers q and the sequence's length L, it is to evaluate the performance of FH sequence family.

Cycle Hamming correlation of the two sequences $S_u = \{s_u(j)\}$ and $S_u = \{s_u(j)\}$ in the relative delay τ, which length is L on set A, is defined as follows:

$$H_{S_u S_v}(\tau) = \sum_{j=0}^{L-1} h[S_u(j), S_v(j+\tau)], 0 \le \tau \le L-1 \qquad (4)$$

In the equation， $S_u(j), S_v(j) \in A$， $j+\tau$ are computed by module p , and

$$h[S_u(j), S_v(j+\tau)] = \begin{cases} 0 & S_u(j) \ne S_v(j+\tau) \\ 1 & S_u(j) = S_v(j+\tau) \end{cases} \qquad (5)$$

When $u \ne v$, t is called Hamming cross-correlation, and when $u = v$, it is called the Hamming autocorrelation.

4.1 Hamming autocorrelation

For each sequence S_u which length is L on frequency set f, the maximum sidelobe of sequence's Hamming autocorrelation is:

$$H(S_u) \ge \frac{(L-b)(L+b-q)}{q(L-1)} \qquad (6)$$

In the equation(6), q—frequency numbers of frequency set f, b—the smallest non-negative of L module q.

Let L=1023, b=L mod q=1023, mod16=15, q=16, and put them into the equation (6), we can get $H(S) \ge 63$.

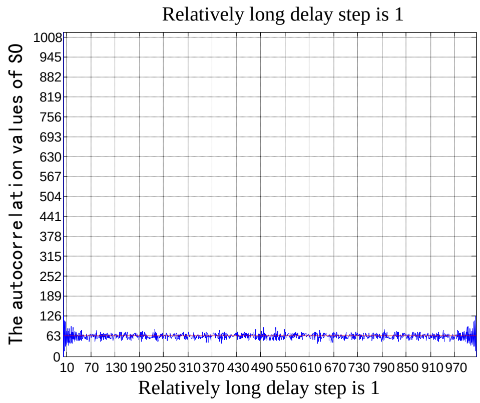

Figure 2. The performance of autocorrelation

In the figure 2, solid line S0 is the Hamming autocorrelation, dashed line is the best FH sequence's Hamming autocorrelation. It can be seen that the Hamming autocorrelation performance of FH sequence with given minimum gap is close to the Hamming autocorrelation performance of the best FH sequence when they use the same frequency numbers. The Hamming autocorrelation of the best FH sequence is 63, and the Hamming autocorrelation of FH sequence with given minimum gap maximum is 127.

4.2 Hamming cross-correlation

For any two sequence $S_u = \{s_u(j)\}$ and $S_v = \{s_v(j)\}$ which length is L on frequency set f, let $(d_1, d_2, ..., d_{q-1})$ and $(e_1, e_2, ..., e_{q-1})$ be the f_i appeared times in the cycle of the two sequences, let all f_i be such arrangement that make e_i form a descending series， that is $e_0 \ge e_1 \ge ... \ge e_{q-1}$. So between S_u and S_v the maximal Hamming correlation[3] is ：

$$M(S_u, S_v) \ge \frac{\sum_{i=0}^{q-1}(e_i^2 + d_i^2 + e_i d_i) - 2L}{3L-2} \quad (7)$$

If it meets the following conditions ,the right of equation (7) is minimum：

- $e_0 - e_{q-1} \le 1$
- $d_0 \le d_1 \le \cdots d_{q-1}, d_i$ Forming a decreasing sequence.
- $d_{q-1} - d_0 \le 1$

According to the equation (7), the Hamming cross-correlation maximum is $H(S_u, S_v) \ge 64$, that any two FH sequences’ Hamming cross-correlation may not be less than 64.

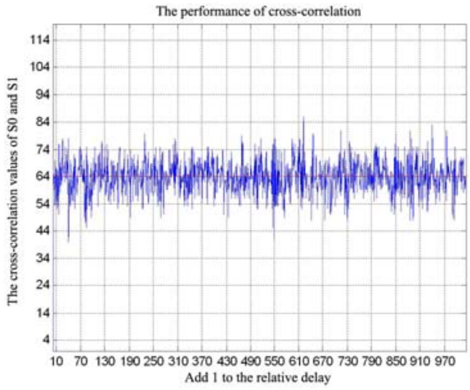

Figure 3. The performance of cross-correlation

In the figure 3, solid line S0 and S1 are the Hamming cross-correlation. It can be seen that the Hamming cross-correlation performance of FH sequence with given minimum gap is a little worse than the Hamming autocorrelation performance of the best FH sequence. The Hamming cross-correlation of the best FH sequence is 4, and the Hamming cross-correlation of FH sequence with given minimum gap is 8.

Hardware Design Implementation

5.1 The design concept

Using primitive polynomial $x^{10} + x^3 + 1$ constructs m sequence generator, selecting no-continuous tap model u_r , u_{r+2} ,and u_{r+4} generates band F_1 ,and at the same time clock CLK to control the generation of dual band F_2 . The frequency point value of band F_1 delays a clock, compared with the two frequency point values, to see if it meets the need of given minimum gap, that is if abs(f_1, f_2) is greater than 4. If it meets, continue to use the band, the output frequency is still the frequency point of band F_1 . If it doesn’t meet, then hopping to the corresponding frequency band F_2 , and the corresponding frequency point is output. The clock state machine controls the running, state machine determines the next state is in the band F_1 or in the band, while each state determines the next state, the state is controlled by the synchronous clock[4, 5].The design model is shown below.

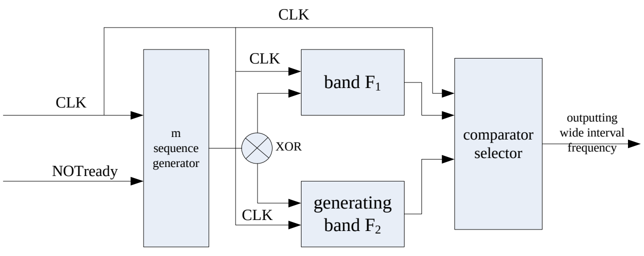

Figure 4. VHDL design model

5.2 The VHDL language implementation

The VHDL codes achieved for the comparator and the selector of band switching in the design model is as follows:

```
Case (state) is
        when '0'=> if abs(mid1-mid0)<5    then
                  normal_hopset<=mid2;state<='1';
              else     normal_hopset<=mid0;
          end if;

       when '1'=> if abs(mid3-mid2)<5 then
                normal_hopset<=mid0;state<='0';
            else   normal_hopset<=mid2;
                end if;
   end case;
 end if;
```

Using the “if” sequential statements realizes the comparison of the frequency point gap, it ensures the sequential execution. The application of state machine makes the order of execution of each sequential execution statement no chaos, thus eliminating a large blur.

5.3 Analysis of simulation results

Figure 5 is the timing simulation diagram of construction FH sequences of given minimum with dual sub-bands method and based on L-G model. From the figure we can see the sequence of the generated band F_1 :7 6 4 5 1 3 2 6 4 5 6 0 2 1 ......,generated band F_2 :8 15 1 4 12 13 9 11 10 14 12 13 8 10 9 ......, and the simulated hopping sequence with given minimum gap is 8 15 7 15 7 15 6 14 4 13 1 11 2 14 4 13 8 2 9 5 11 2 7 .... The simulated FH sequence with given minimum gap meets the design requirements. Selecting high performance FPGA, it would not have burr. According to the waveform, the first calculated data is obtained in the second CLK rising edge arriving, before it is the 0. Band F_1 delays a clock, compared with the band F_2 .It directly selects frequency point 8 of band F_2 as the frequency value of FH sequence with given minimum, but the frequency value has not been over the comparator and selector, and giving it up. From the beginning of the second rising edge of CLK, the FH sequence with given minimum gap is obtained as follows. The result shows that the hopping patterns with given minimum gap using VHDL language have parameters adjustment, and can be reprogrammed. It has great reference value in the FH communications hardware implementation.

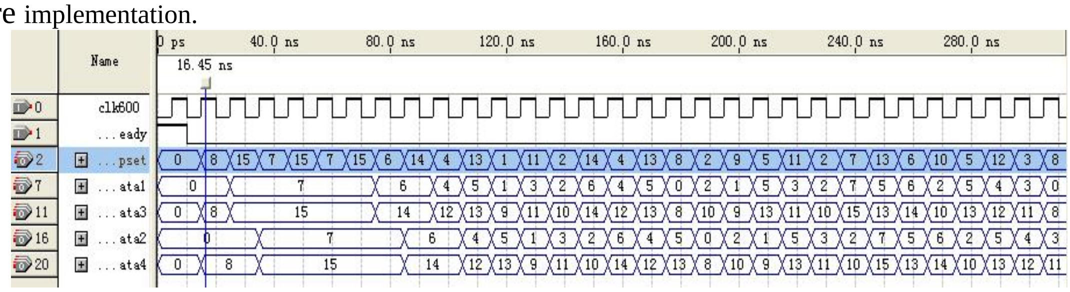

Figure 5. VHDL simulation figure of dual given minimum gap FH sequence

Conclusion

The selection of excellent FH pattern is an important issue in FH communication, and Matlab simulation tools is used to analyze the performance of autocorrelation and cross-correlation of FH pattern with given minimum gap used dual band method. It can be seen that given minimum gap FH sequences have excellent property of autocorrelation and cross-correlation, and they can be close to the theoretical value of the FH sequence design, which also makes the FH sequence with given minimum gap the important considered object in communication engineering application[6]. This paper gives the hardware implementation scheme, and uses VHDL language to design dual given minimum gap FH sequence. The sequence can be used to generate the given minimum gap FH signal which meets the need, which directly applied on the hardware circuit of FH generator. It has the high application value in the communication model of field programmable gate array and digital up converter.

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