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STUDY OF CODE ACQUISITION OF FHSS SYSTEM OVER RICIAN CHANNEL

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ABSTRACT

Frequency hopping is used in different communications systems for its robustness by providing frequency diversity against jamming and interfering signals. Successful detection and demodulation of a frequency hopping signal is dependent on proper tuning to transmit frequency and time synchronization of the burst. The sequence of hop frequencies is generally determined by a Pseudo-Noise (PN) sequence and time synchronization is achieved using synchronization preambles in the transmit burst. Successful acquisition of the hop frequency sequence could be achieved when at least a single burst's data is successfully decoded at the receiver. This paper studies the serial search code acquisition which is the first step of synchronization for frequency hopping spread spectrum (FHSS) system over Rician fading channel. Simulation results show the effect of fading channel on the code acquisition.

KEYWORDS: FHSS system, code acquisition, Rician fading channel

1. Introduction

During the Second World War, Americans were encouraged to make whatever manner of contributions to aid the American War Effort. Towards this front, Hedy and George provided their newly conceived idea as their contribution.

Through this novel invention, military espionage by enemies based on information jamming had been thwarted or at least been made a bit more complicated. At the time, information was transmitted under one frequency band. This made it easier for a malicious listening party to simply tune their receiver to only one frequency band of interest. This made for easy tapping (Sklar, 2009; Stallings, 2007).

Spread spectrum communications partly addressed this problem. Under this new technique, information of a given bandwidth could be spread over a much larger bandwidth and transmitted. This had two advantages. On the one hand, it made it more difficult for a potential jammer with finite jamming power to jam the entire frequency band. On the other hand, since the information was spread over a large bandwidth the power spectral density of the transmitted signal was so little that it would easily appear as noise that exists in typical communication channels to the jammer (Simon et al., 2004; Torrieri, 2005).

There are different types of spread spectrum system but in this paper, only frequency hopping spread spectrum (FHSS) system is considered. In FHSS systems**,** the carrier frequency of a transmitted signal is periodically changed. These periodic variations in the transmitted carrier frequencies are carried out based on a predetermined Pseudo-Noise (PN) sequence that determines the frequencies that the carrier frequencies are to hop into.

In order to effectively recover the transmitted signal, the carrier frequency used for demodulation at the receiver should hop into corresponding carrier frequencies that were employed at the

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transmitter at the precise times that messages that have been transmitted based on these carrier frequencies are transmitted (Viterbi, 1995).

However, due to the channel imperfections, the PN sequence used to change the carrier frequency at the transmitter during transmission and the one used to vary the demodulation carrier frequencies at the receiver during reception may not be in syncronized, so code synchronization is necessary. If synchronization is not carried out the transmitted signal will be wrongly demodulated yielding an incorrect signal at the receiver (Zepernick & Finger, 2005; Zhang, Shao & Elhabian, 2005, pp. 161-165)

In FHSS, code synchronization involves two steps namely: code acquisition and code tracking. The code acquisition phase involves bringing the PN sequence to at least within a time period of the PN sequence used to generate the carrier frequency at the receiver. Code tracking involves further refining the acquired PN sequence improving its accuracy to less than half the time period of the transmitted signal (Ogwali, 2009; Zhao, Quan & Cui, 2018).

There are different methods of code acquisition but in this paper, serial search code acquisition is considered. In a serial search acquisition method, the received spreading PN sequence used at the transmitter is correlated with the one that is used at the receiver and periodically delayed until a set threshold is attained. Once this threshold is attained, acquisition is declared and the declaration of acquisition initiates tracking (Ogwali, 2009).

2. Design Methodology

Code acquisition in a FHSS is simulated using the MATLAB Simulink simulation software. Appropriate Simulink block sets are used and their parameters varied to conform to design specifications. For generation of the hopping codes, PN sequences are used due to their correlation properties that allow for easier acquisition. For simulation purposes the Rician fading channel is simulated. The Simulink block diagram in Figure no. 1 outlines the complete design.

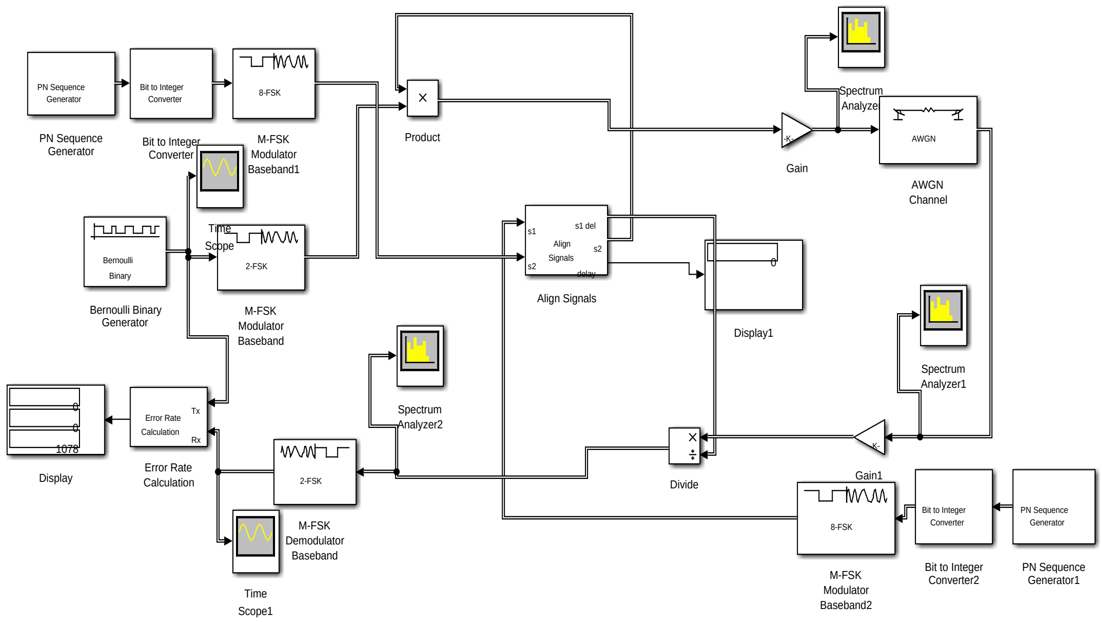

Figure no.1: *Simulation block for serial search acquisition for a FHSS system*

A few of the various design aspects of the common block parameters are designed in the next few paragraphs. The rationale for obtaining at each of the design parameters is also discussed.

2.1. Bernoulli Binary Generator

The Bernoulli binary generator is chosen as the simulation data source since it outputs a random sequence of 0 and 1 bit sequences. The probability of getting a 0 and a 1 are all set to be equal i.e. both have a probability of 0.5. The bit rate for the Bernoulli binary generator is set at 10,000 bits per second. Before the generated Bernoulli sequence is mixed with the carrier frequency generated through the 8-Frequency-Shift-Keying (FSK) modulator, it is first 2-FSK modulated.

At the receiver, a 2-FSK demodulator is used for demodulation. If the demodulation process is effective, an exact replica of what has been transmitted should be received.

2.2. PN Sequence

A 4-stage linear feedback shift register (LFSR) with a PN sequence length of 15 is used. The LFSR used is a maximal sequence LFSR. Similar PN sequence generators are used at both the transmitter and the receiver. The output bit rate for both PN sequence generators is set at 90,000 bits per second.

The generated bits from the PN sequence generator are then clustered into groups of 3 bits and a bit to integer converter is used to generate eight possible integer values ranging from 0 to 7. The output of the bit to integer converter is then fed to an 8-FSK modulator which then outputs the different carrier frequencies that are used to effect frequency hopping.

Since the output bit rate from the PN sequence generator is 90,000 bits per second and they are grouped into clusters of 3, there are 30,000 clusters generated per second. Therefore, ideally, the output frequency of the 8-FSK modulator varies 3 times per symbol of the data sequence generated by the Bernoulli Binary Generator.

2.3. 8-FSK Modulator

The 8-FSK modulator is set to have a carrier frequency separation of 100 kHz. The eight possible carrier frequencies therefore range from 100 kHz to 800 kHz.

2.4. Align Signals Block

The align signals block is the block that performs the serial search acquisition. The align signals block compares two signals by correlating them and then adjusts the signal to be adjusted based on the correlation peak. PN sequences offer a lot of demodulation ease since they have specific correlation peaks.

In the design highlighted above, before the PN sequence that is used at the transmitter is transmitted to the align signal block at the receiver, it is first 8-FSK modulated. The PN sequence at the receiver is also 8-FSK modulated and after this the PN sequence at the receiver is aligned to that received from the transmitter. The align signal block periodically delays the PN sequence at the receiver until it is aligned to the one at the receiver.

2.5. Doppler Frequency Shift

For the channels that are to be used, the Doppler frequency shift is an important parameter that will have to be set. The worst case Doppler shift situation will be set. The maximum possible Doppler shift is given by

Maximum possible
Doppler shift = $\left(\frac{v}{c}\right) f_c$ (1)

where, v= relative velocity between the transmitter and the receiver, assumed to be 100 km/h

c= speed of light (300,000,000 m/s)

f_c= carrier frequency, in this case the maximum carrier frequency is 800 MHz

By substituting the above values into Eq.1, the maximum Doppler shift is found to be roughly 74 Hz. A value of 75 Hz is used in the designs since this offers a value way above the maximum possible Doppler shift and gives a guarantee as to the worst case design scenario.

2.6. Multipath Rician Fading Channel

A multipath Rician fading channel is similar to a multipath Rayleigh fading channel in the sense that multipath propagation is involved. However, the difference between the two channel types arises from the Doppler effect.

In the case of the multipath Rayleigh fading channel, both the transmitter and the receiver were assumed to be stationary. However, in the case of a multipath Rician fading channel, both the transmitter and the receiver move relative to each other. This introduces Doppler shifts which calls for a more rigorous analysis of the system. Such a channel is as a consequence best modeled using the multipath Rician fading channel.

3. Simulation Results

3.1. PN Sequence Results

The properties of the PN sequence used are first tested for their randomness pr operties. Figure no. 2 shows the timing diagram for a 4-stage LFSR maximal length sequence.

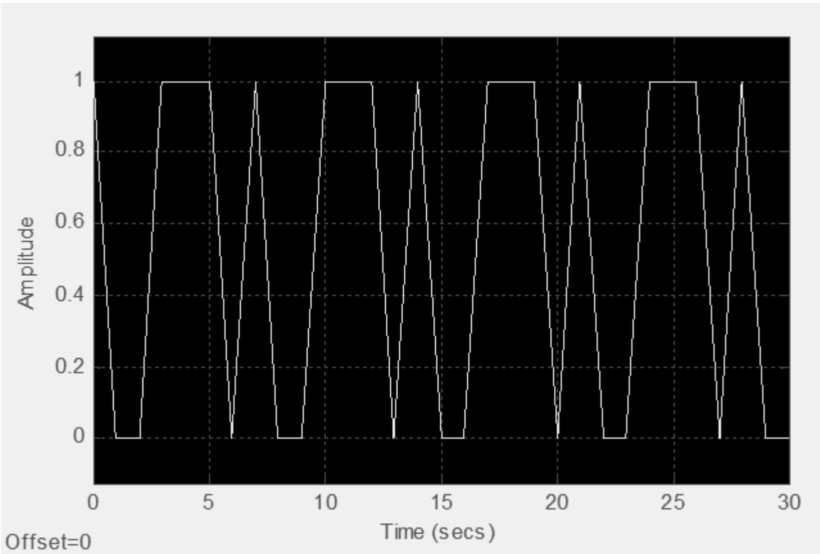

Figure no. 2: *PN sequence timing diagram*

The sample time for the PN sequence is set at 1 sec just for illustrative purposes. For a larger sampling frequency, the basic properties will remain the same. Since the sample time is 1 sec, and a maximal length sequence is utilized, the expected PN sequence period is 15 sec. From the graph, after a time interval of roughly 15 sec the sequence repeats itself.

The correlation properties of the PN sequences are also tested. From Figure no. 2 above, if a sequence similar to the one in the Figure no. 2 is compared for the number of agreements and disagreements for every 1sec interval for 15 sec, the number of agreements would be 15 while the number of disagreements would be zero. This would yield the maximum correlation value. Any shift by a value that is not a multiple of 15 sec would increase the number of disagreements between the un-delayed and delayed version of the PN sequence. This would effectively reduce the correlation between the two signals.

Figure no. 3 shows the correlation output for two perfectly aligned PN sequences while Figure no. 4 shows the correlation output between two PN sequences with a misalignment of 1 sec between each other.

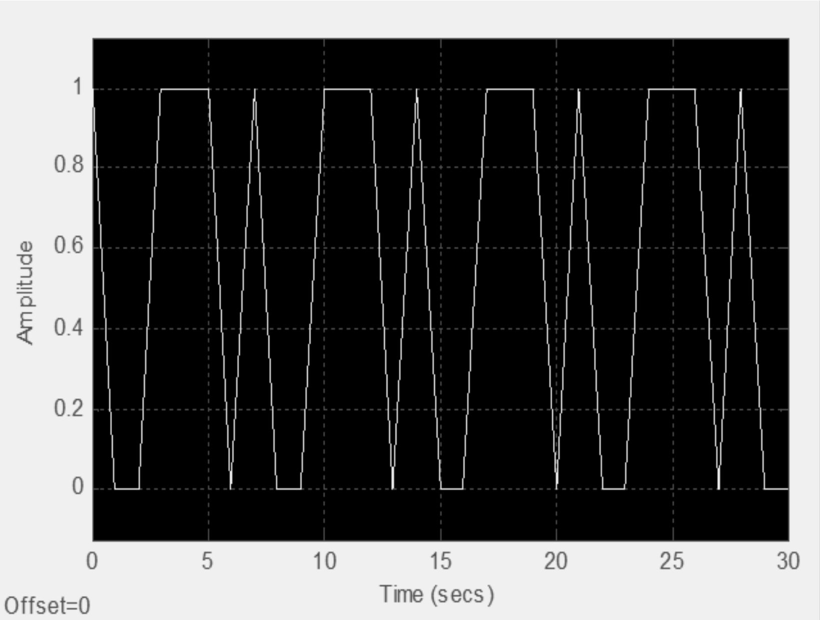

Figure no. 3: *Correlation between two perfectly aligned PN sequences*

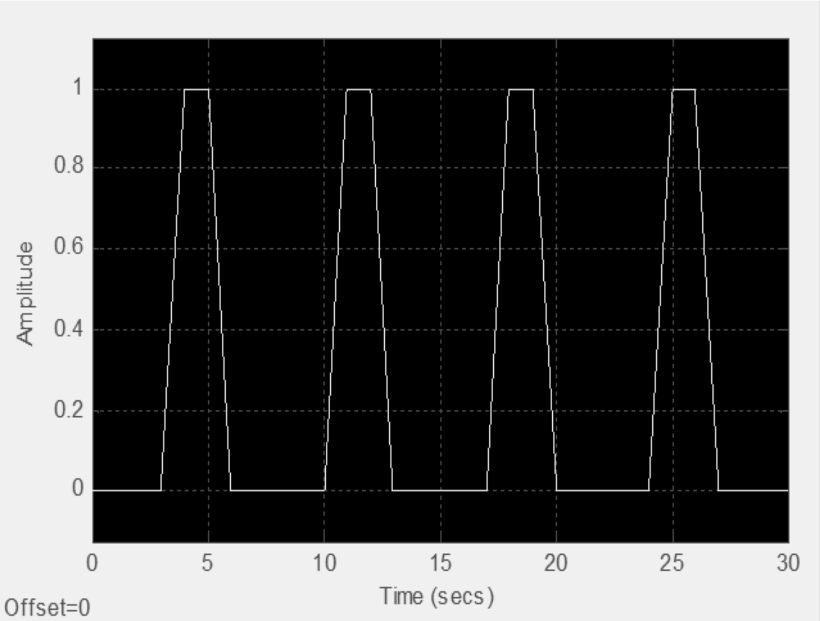

Figure no. 4: *Correlation between two PN sequences with a misalignment of 1 sec*

Accumulating the output of Figure no. 3 over a period of 15 sec and doing the same thing for the output in Figure no. 4, the output of Figure no. 3 yields a larger accumulated value than that of Figure no. 4. The output of Figure no. 4 represents the situation for all other cyclic shifts. It is therefore evident that the PN sequence has a finite accumulated correlation maximum only when two PN sequences generated by the same generator polynomial are in synchronization.

3.2. Results for the Transmission Over Multipath Rician Channel

The continuous-time time scopes for both the transmitted and the received signals are shown in Figure no. 5 and Figure no. 6. The bit error rate in this case is in the range of 10^{-5}.

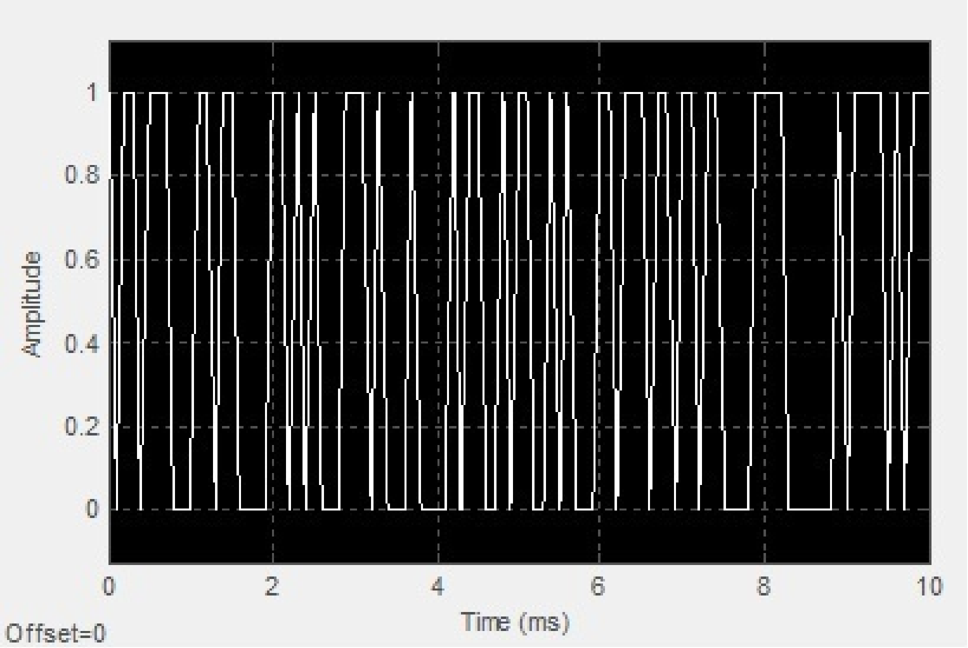

Figure no. 5: *Time scope showing transmitted signal*

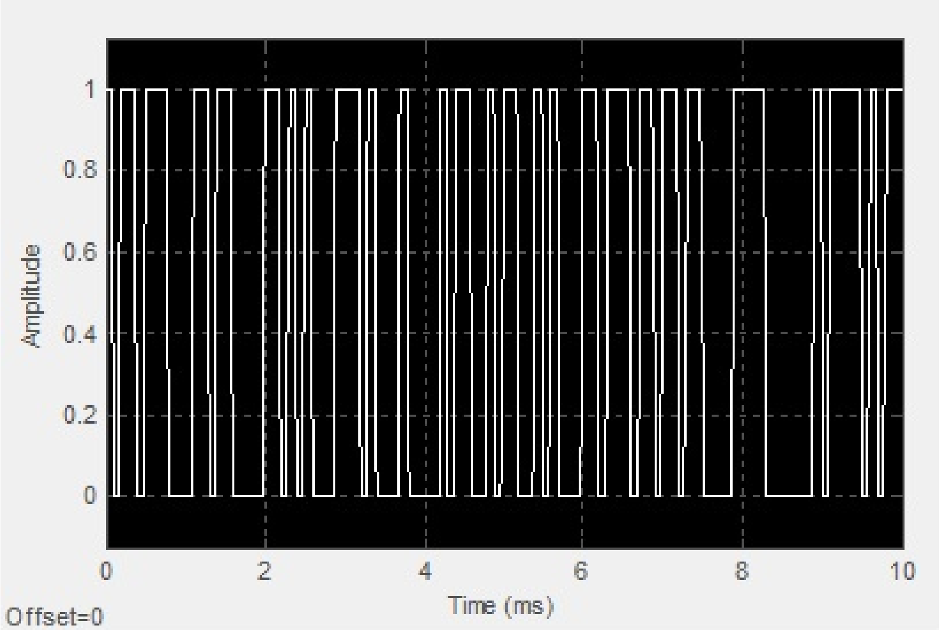

Figure no. 6: *Time scope showing received signal*

Figure no. 7, Figure no. 8, and Figure no. 9 show the frequency spectrum of the transmitted signal, the frequency spectrum after frequency hopping and the frequency spectrum after code acquisition respectively.

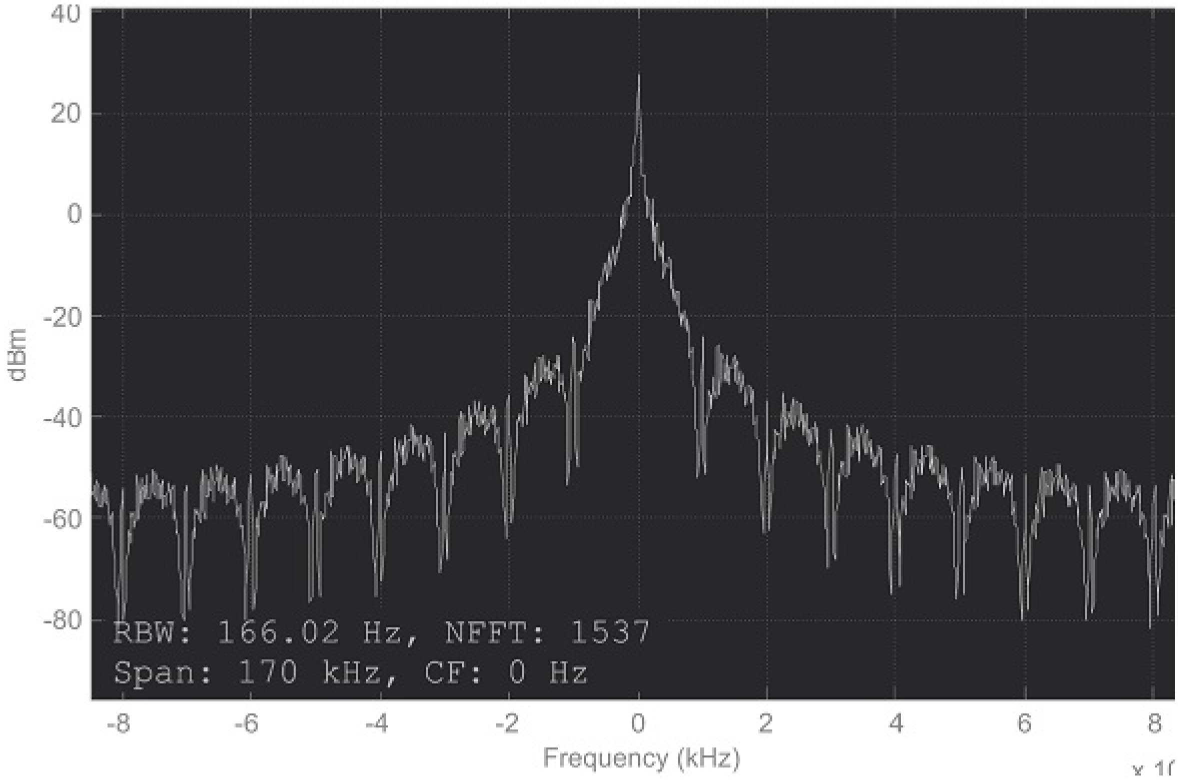

Figure no. 7: *Frequency spectrum of the transmitted signal after 2-FSK modulation*

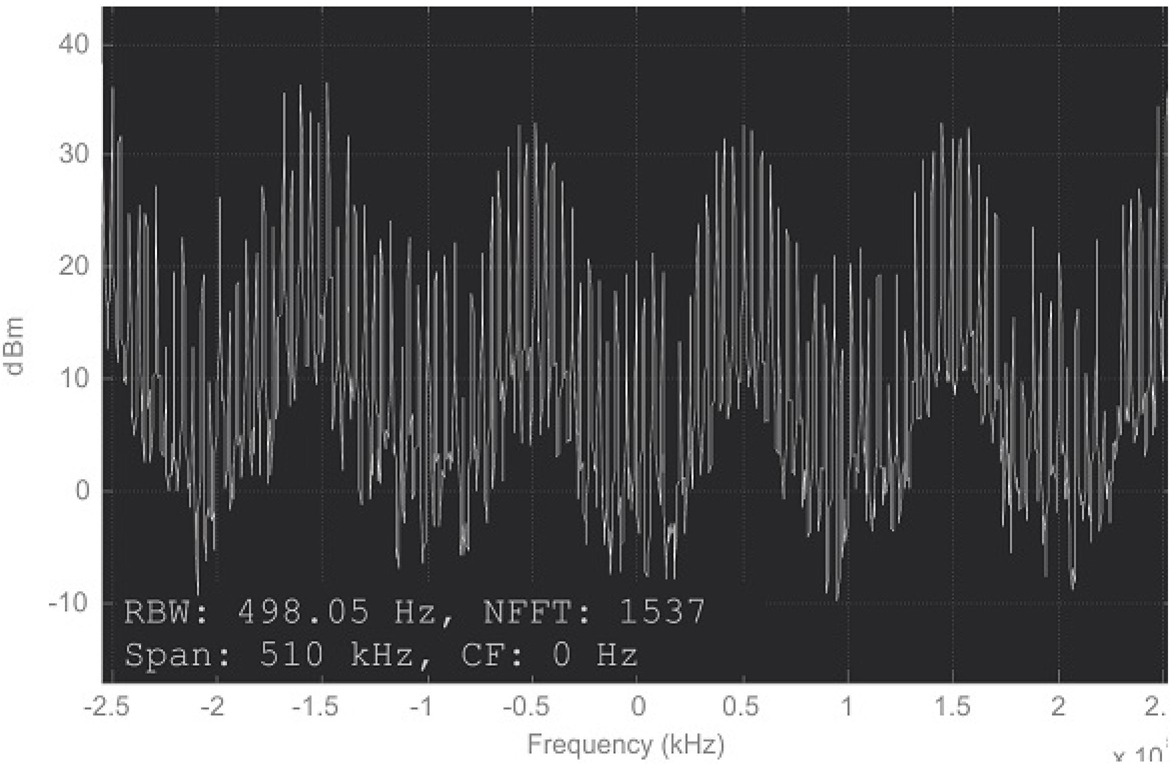

Figure no. 8: *Frequency spectrum after frequency hopping*

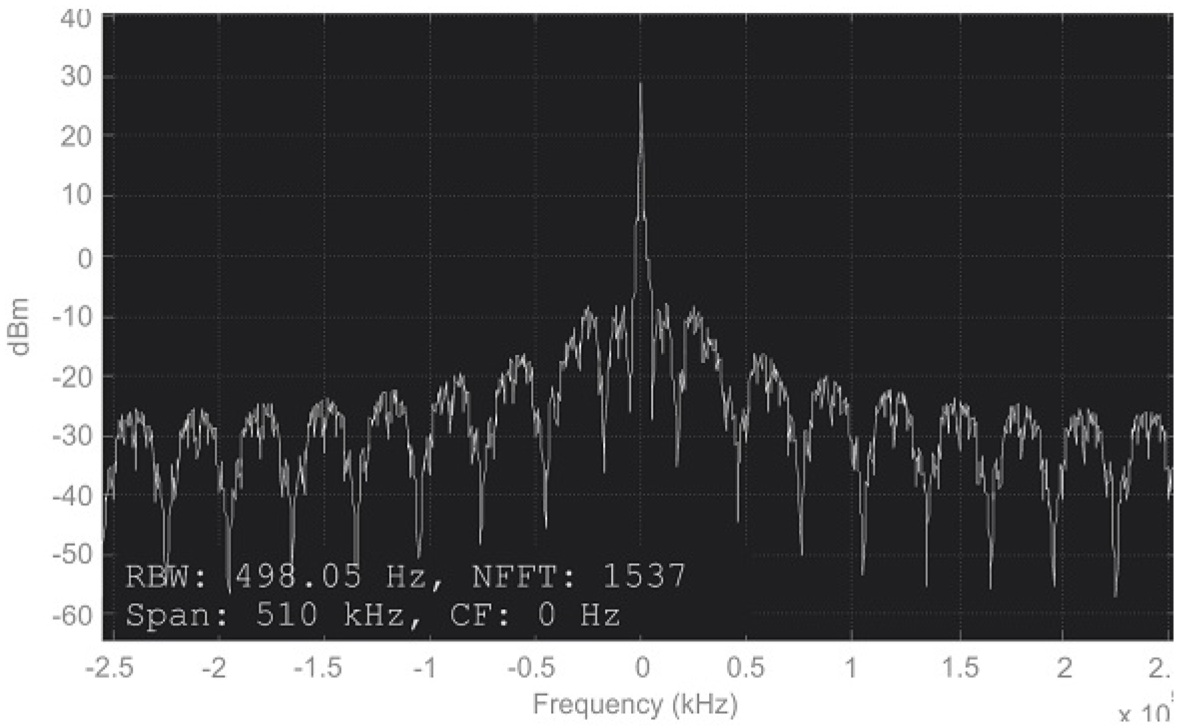

Figure no. 9: *Frequency spectrum after code acquisition*

4. Conclusion and Discussion

In this paper, spread spectrum communication systems were studied over Rayleigh channel and the importance of code acquisition in frequency hopping spread spectrum communication systems was observed. The need for code acquisition in FHSS systems arises due to clocking instabilities at the receiver and uncertainty in the propagation delay of signals. Code acquisition is a precursor to the fine alignment process of code tracking. Therefore, the results obtained from code acquisition process are not perfect but fine alignment improves the accuracy. A serial search acquisition system was designed and simulated with the performance under a range of channel conditions getting noted. The reason for settling for a serial search acquisition system is informed by its use of fewer components as compared to the matched filter acquisition technique which requires a bank of bandpass filters.

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