Transmitter Receiver Design Based Frequency Hopping Spread Spectrum

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Abstract

‘The objective of this study and research is to study spread spectrum system and its implementation. A simple transceiver employing frequency hopping spread spectrum is designed. Various modulating techniques have also been studied, and there effects on the signal have been shown with the help of graphical representations. All the work is performed in MATLAB. The design can be further modified for hardware implementation as an extension to this project.’

List of Acronyms

FHSS	*Frequency hopping spread spectrum*
FSK	*Frequency shift keying*
MFSK	*Multiple shift keying*
BPSK	*Binary phase shift keying*
BFSK	*Binary frequency shift keying*
CPM	*Continuous phase modulation*
FFT	*Fast Fourier transform*
DSP	*Digital Signal Processing*
PN	*Pseudo-random Number*

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Chapter1 Introduction

1.1 Introduction

The spread spectrum systems are being used since over a half century in military applications to meet two purposes

1. **Covertness** – to hide the signal from eavesdroppers.
2. **Anti-jamming** – to make the signal resistant to intentional interference

The spread spectrum technique is preferred here in this regard because it spreads the signal's spectrum to make it virtually indistinguishable from the background noise. Apart its application in the military, its chief application nowadays is the universal frequency reuse. This is due to the fact that all the users, whether communicating within a neighbourhood, a metropolitan area, or even a nation, occupy a common frequency spectrum allocation.

1.2 Motivation

The Final Year Project has always the most discussed event amongst the student of Electrical Engineering in which there was a lot of mention of 'the tough time' given during the demonstrations and the breath taking viva sessions. With the time approaching to our final year we started to talk and discuss about our areas of interest and began sorting out our options. The drive to do something challenging and interesting was always there. All we needed was a basic idea, a foundation stone to initiate our project. We conceived this idea from a fiction novel "Digital Fortress" by Dan Brown.

Reading the book, and pondering over the state of crisis our nation is going through, triggered within us the desire to develop a secure means of communication. We collectively embraced the idea of developing a communication system that bypasses the jammers, cannot be easily traced, and is even harder to decode. Such a system, we realized, could be of use to our national armed forces, and it's utility to businesses and other sectors cannot be overlooked either. So we zeroed in on this topic and started our research regarding it.

1.3 Previous Work

Among the advantages of Spread Spectrum technologies, one can mention the inherent transmission security, resistance to interference from other radio sources, redundancy, resistance to multipath and fading effects, etc. As a result, Spread Spectrum systems can coexist with other radio systems, without being disturbed by their presence and without disturbing their activity. The immediate effect of this elegant behaviour is that Spread Spectrum systems may be operated without the need for license, and that made the Spread Spectrum modulation to be the chosen technology for license-free WLAN and BWA operation.

Most of the communication systems fall into one of these three categories: bandwidth efficient, power efficient, or cost efficient. The parameter to be optimized depends on the demands of a particular system. If one of these efficiency parameters, that is, the bandwidth, power, or cost, is increased the other one decreases, becomes more complex, or does not perform well in a poor environment. Bandwidth and power are the primary communication resources and so it is necessary to consider them with care in the design of most of the communication systems. At times it is necessary to sacrifice the efficient utilization of the two resources in order to meet certain other design objectives. Due to transmitting the message energy over a bandwidth much wider than the minimum required, Spread Spectrum modulation techniques presents two major advantages

- Low power density
- Redundancy

Low power density relates to the fact that the transmitted energy is spread over a wide band, and therefore, the amount of energy per specific frequency is very low. The effect of the low power density of the transmitted signal is that such a signal will not disturb (interfere with) the activity of other system's receivers in the same area and that such a signal can't be detected by intruders, providing a high level of intrinsic security. [10]

It relates to the fact that the message is (or may be) present on different frequencies from where it may be recovered in case of errors. The effect of redundancy in that Spread

Spectrum systems present high resistance to noises and interference, being able to recover their messages even if noises are present on the medium. [10]

1.4 Aim of the Project

Initially, we had many objectives such as making a transceiver, encoder, and decoder and making the transmission anti jamming, making it high capacity, secure and so forth, but all these objectives could not be met due to the limitation of time. Therefore, the project had to be narrowed down to just making a transmitter receiver design in MATLAB. The aim of the project is to transmit binary data generated by some method such as Bernoulli, modulate it using an encoding technique. This modulated signal is further modulated using frequency hopping. The signal is received demodulated and the data is interpreted. Errors are caused due to the modulation and demodulation in the bits which were to be corrected using bit error calculation. The hardware implementation can be an extension of this project.

Chapter2 Spread Spectrum Systems

Spread spectrum is a means of transmission in which the data of interest occupies a bandwidth in excess of the minimum bandwidth necessary to send the data. [1]

Or

The spectrum spreading is accomplished before transmission through the use of a code that is independent of the data sequence. The same code is used in the receiver (operating in synchronism with the transmitter) to de-spread the received signal so that the original data may be recovered. [3]

Spread spectrum technique was originally developed for military applications where resistance to jamming (interference) is of major concern. However there are civilian applications that also benefit from the unique characteristics of spread spectrum modulation, for example multi-path rejection and multiple access communication. To be classified as a spread spectrum system the modem must have the following characteristics:

1. The transmitted signal energy must occupy a bandwidth which is larger than the information bit rate and which is approximately independent of the information bit rate.

2. Demodulation must be accomplished, in part by correlation of the received signal with a replica of the signal used in transmitter to spread the information signal.

A number of modulation techniques use a transmission bandwidth larger than the minimum required for data transmission but are not spread spectrum modulation techniques because they do not satisfy the above mentioned conditions. For example: low-rate coding and wideband frequency modulation.

Spread spectrum technique can be used to solve various complex communication problems. The amount of performance improvement that is achieved through the use of spread spectrum is referred as *processing gain* of the spread spectrum system. Below is shown a block diagram of a typical communication system with the difference that the modulator and demodulator, each one has an additional input which is the spreading generator.

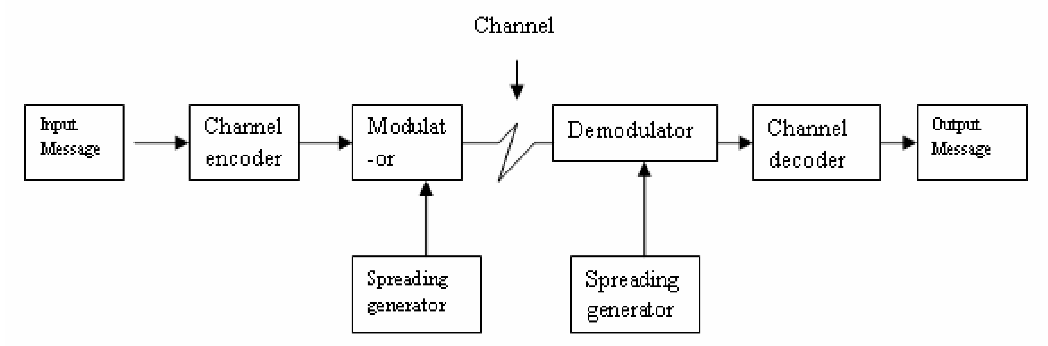

Figure Error! No text of specified style in document. General block diagram for Spread Spectrum Communication System [4]

On the transmitting terminal, the input message/data signal is sent to the channel encoder, for channel encoding so that the message signal can be transmitted easily through the allocated channel. It is then sent to the modulator and the second input of the modulator is a spreading code coming through a spreading generator. Then a channel is allocated to this modulated signal through which it travels and reaches the destination point.

At the receiving end a demodulator is used to demodulate the received signal, with a spreading code as a second input to the demodulator. This spreading code has been chosen in synchronism with the transmitted spreading code. Channel decoding is the next step for this demodulated signal to convert it into its original form.

In this chapter, we are going to discuss the basic principles of spread spectrum technique that can be used as an aid in reducing the effect of different type of interferences, with basic emphasis on direct sequence and frequency hopping techniques. For their operation both of these techniques rely on the presence of noise like spreading code called a pseudo-random or pseudo-noise sequence. Since such a sequence is basic to the operation of spread-spectrum modulation, we shall describe its generation and properties as well.

2.1 Types of Spread Spectrum Communication

There are two major ways to spread the bandwidth of the signal:

Frequency Hopping Spread Spectrum (FHSS) The signal is rapidly switched between different frequencies within the hopping bandwidth pseudo-randomly, and the receiver knows before hand where to find the signal at any given time.

Direct Sequence Spread Spectrum (DSSS) The digital data is directly coded at a much higher frequency. The code is generated pseudo-randomly, the receiver knows how to generate the same code, and correlates the received signal with that code to extract the data.

2.2 Frequency Hopping Spread Spectrum (FHSS)

A method of widening the spectrum of data modulated carrier is to change the frequency of the carrier periodically. Frequency Hopper (FH) is a better technique of spread spectrum techniques than the simpler Direct Sequence Spread Spectrum systems. But Frequency Hopping Spread Spectrum Systems are significantly more complex than Direct Sequence Spread Systems.

Frequency Hopping Spread Spectrum (FHSS) systems have an implementation concept similar to that of DSSS systems. The binary PN code generator drives the frequency synthesizer to hop to one of the many available frequencies chosen by the PN sequence generator.

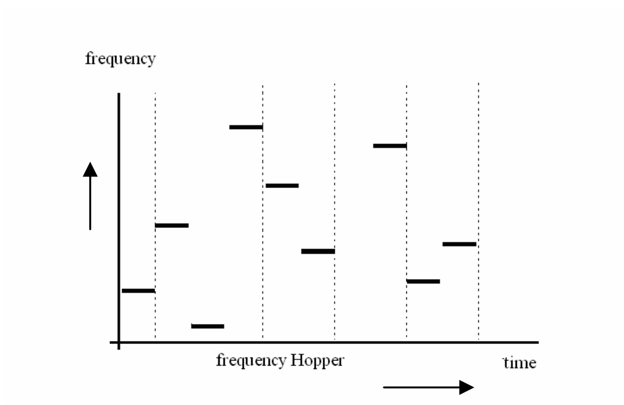

Figure 2.2.1-1 Frequency Hopper[4]

The central idea behind a Frequency Hopping Spread System is to retune the transmitter RF carrier frequency to a pseudo-randomly determined frequency value. In this way the carrier keeps popping up different frequencies, in a pseudorandom pattern. The carrier itself may be modulated directly with the data using one of many possible schemes. The available radio spectrum is thus split up into a discrete number of frequency channels, which are occupied by the RF carrier pseudo randomly in time.

Unless we know the PN code used, we have no idea where the carrier wave is likely to pop up next; therefore eavesdropping will be quite difficult. Frequency hoppers are typically divided into fast and slow hoppers. A slow frequency hopper will change carrier frequency pseudo-randomly at a frequency which is much slower than the data bit rate on the carrier. A fast frequency hopper will do so at a frequency which is faster than that of the data message.

2.2.1 Frequency Hopping Spread Spectrum Components

Most of the time frequency hopping is done non-coherently, however a fully coherent frequency hopping system is possible and is also very interesting.

a. FHSS Transmitter

For transmission, binary data are fed into a modulator using some digital to analog encoding scheme, such as frequency-shift keying (FSK) or binary phase-shift keying (BPSK). The resulting signal $s_d(t)$ is centred on some base frequency .A pseudo- noise (PN), or pseudorandom number , source serves as an index into a table of frequencies, this is the spreading code. Each k bits of the PN source specifies one of the 2^k carrier frequencies .At each successive interval a new carrier frequency is selected .This frequency is then modulated by the signal produced from the initial modulator to produce a new signal s(t) with the same shape but now centred on the selected carrier frequency.

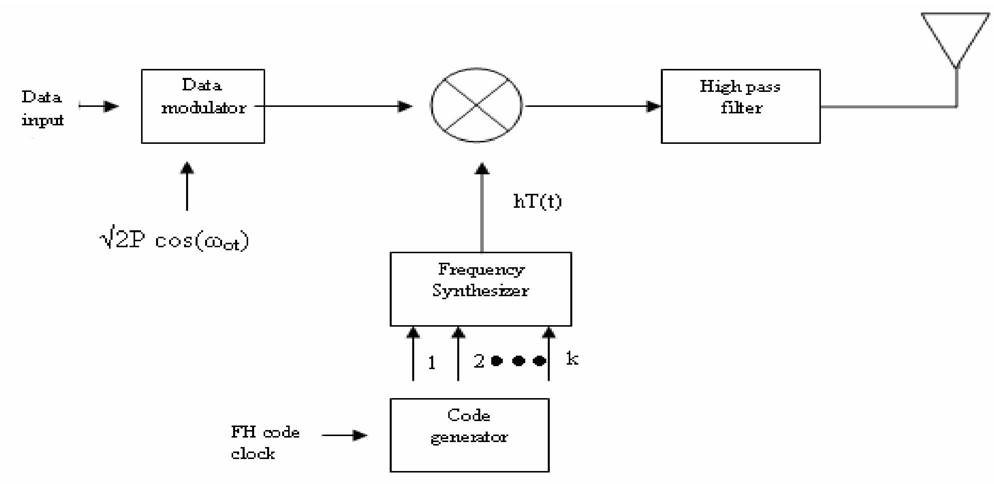

Figure 2.2.1-1 Frequency Hopping Spread Spectrum Transmitter [1]

The frequency is taken from a set of 2k frequencies. If we compare it to the Direct Sequence Spread Spectrum System where spreading code was used one bit at a time, the spreading code here is used k bits at a time. The transmitted signal is the data-modulated carrier up-converted to the new frequency for each frequency hopper chip. The frequency synthesizer output is a sequence of tones of duration T_c, so $h_T(t)$ can be given by the following equation

$$hT(t) = \Sigma\, 2p(t - nTc)\cos(\omega n\ \ t + \varphi n) \qquad \textbf{(2.1)}$$

P(t) = unit amplitude pulse of duration T_c ,starting at time zero. ω_n and φ_n are the radian frequency and phase during the nth frequency hop interval.The transmitted signal is the data modulated carrier up converted to a new frequency for each FH chip.

$$St(t) = [\, sd(t)\Sigma\ \ 2p(t - nTc)\ \cos(\omega n\ \ t + \varphi n)] \qquad \textbf{(2.2)}$$

Transmitted power here can be calculated by using the frequency convolution theorem of fourier transform.

S_d(f) = power spectral density of the data modulated carrier

S_h(f) = power spectral density of hop carrier.

These two signals are independent so that the power spectrum of the transmitted signal is the sum frequency term of the convolution of the two signals.

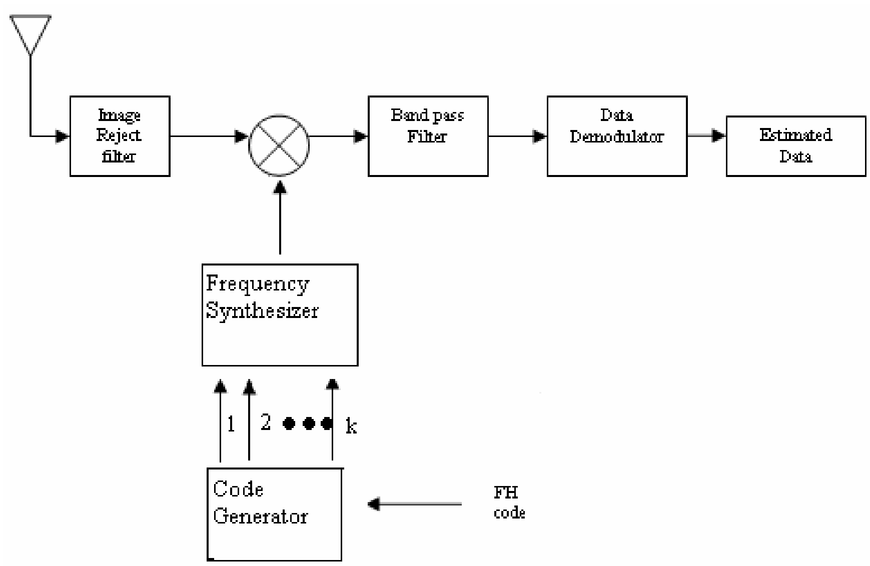

Figure 2.2.1-2 Frequency Hopping Spread Spectrum (FHSS) Receiver [1]

b. FHSS Receiver

On the receiving end, the spread spectrum signal is demodulated using the same sequence (synchronized with the spreading sequence used for modulation at the transmitter's end) of PN derived frequencies from the frequency synthesizer. The signal is then passed through a Band pass filter to let the required band of frequencies to pass. Then the signal is demodulated to get the original or the estimated data signal.

2.2.2 Frequency Hopping Spread Spectrum using MFSK

It is difficult to build a truly coherent frequency synthesizer. Many Frequency Hopping Spread Spectrum Systems use non-coherent or differentially coherent data modulation schemes. A common modulation technique used in conjunction with FHSS is MFSK. MFSK uses $M = 2^L$ different frequencies to encode the digital input L bits at a time T (duration of one information bit). The transmitted signal is of the form

$$s_i(t) = A \cos 2\pi f_i t \qquad (2.3)$$

$f_i = f_c + (2i-1-M) f_d$

f_c = denotes the carrier frequency

f_d = denotes the difference frequency

M= number of different signal elements $=2^L$

L= number of bits per signal element.

For FHSS, the MFSK signal is translated to new frequency every T seconds by modulating the MFSK signal with the FHSS carrier signal. The effect is to translate the MFSK signal into the appropriate FHSS channel .For it data rate of R, the duration of a bit is T=1/R seconds and the duration of a signal element is T_s= LT seconds. If T_C is greater than or equal to T_s the spreading modulation is referred to as slow frequency hop spread spectrum , otherwise it is known as fast frequency hop spread spectrum .The output of this slow frequency hopping system is illustrated in the figure below.

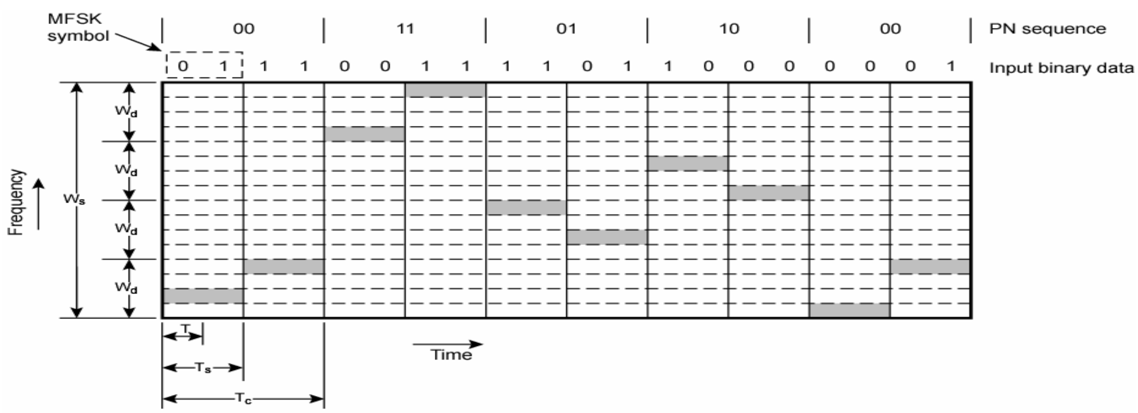

Figure 2.2.2-1 Slow Frequency Hop Spread Spectrum Using MFSK (M=4, k=2) [4]

The frequency is shifted after every Tc seconds; the duration of signal element is Ts seconds. For slow frequency hopping spread spectrum system Tc ≥ Ts.

In the receiver the transmitted signal is down converted using a local oscillator which outputs the sequence of frequencies 0,5$W_{d,}$ 6$W_{d....}$ and the output of the down conversion is a sequence of tones. This signal can be demodulated by using the conventional methods for non-coherent MFSK.

Processing gain of Frequency hopping system can be obtained by considering noise jammer. In the absence of frequency hopping the jammer selects a bandwidth 'W_d' centred on the proper frequency and forces the receiver signal to noise ratio to be

$$\frac{E_b}{N_j} = E_b \; W_d \frac{}{J} \quad \textbf{(2.4)}$$ **(2.4)**