COMPARATIVE PERFORMANCE OF VARIOUS HOPPING TECHNIQUES USING MODULATION METHODS

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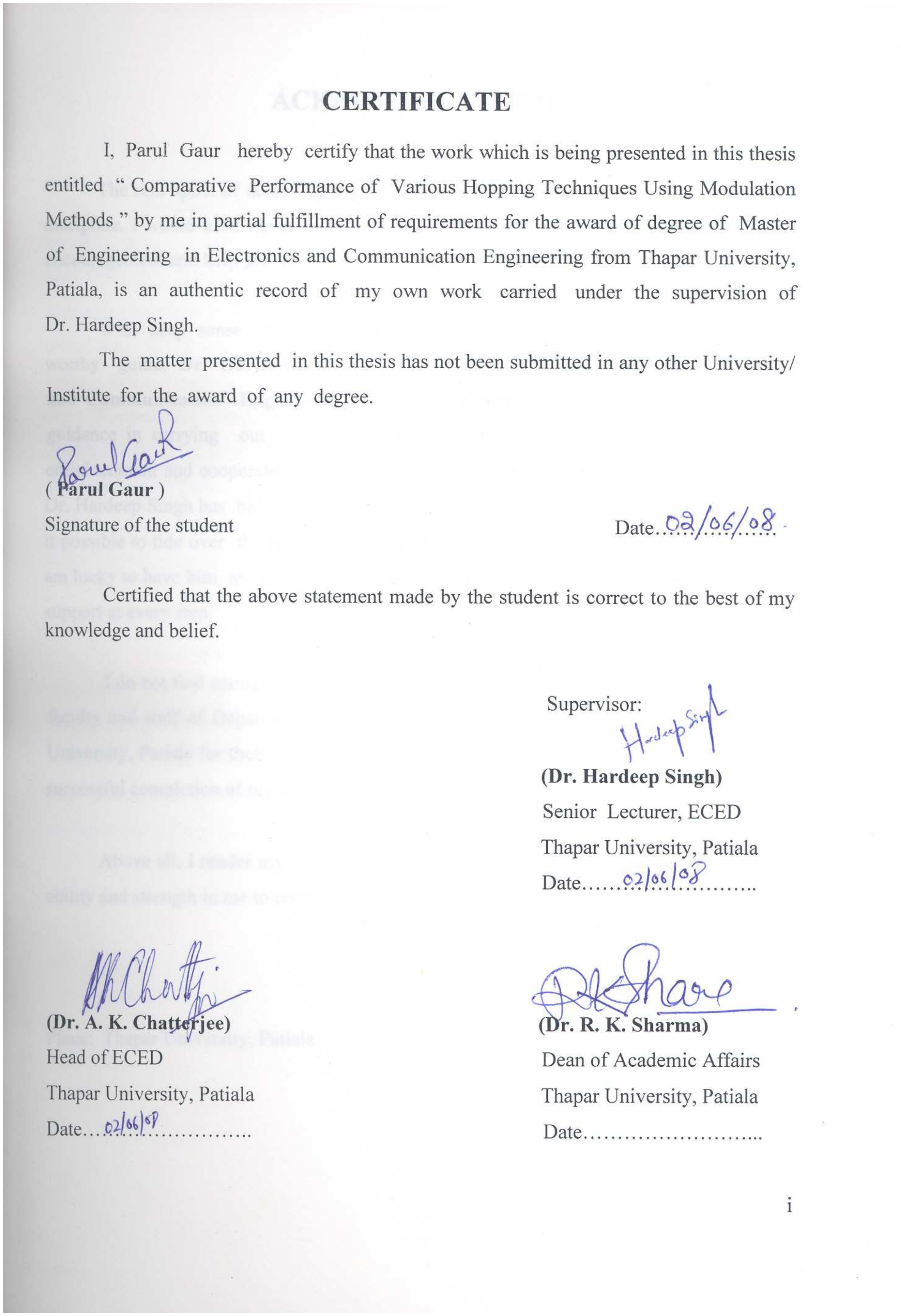

CERTIFICATE

I, Parul Gaur hereby certify that the work which is being presented in this thesis entitled " Comparative Performance of Various Hopping Techniques Using Modulation Methods " by me in partial fulfillment of requirements for the award of degree of Master of Engineering in Electronics and Communication Engineering from Thapar University, Patiala, is an authentic record of my own work carried under the supervision of Dr. Hardeep Singh.

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ABSTRACT

Frequency hopping is one of the spread spectrum techniques. For frequency hopping spread spectrum (FHSS) systems, the diversity may be realized in the form of fast frequency hopping (FFH) and multicarrier transmission. FFH is a conventional diversity technique in FHSS system; multicarrier transmission is an alternative diversity technique in FHSS systems. Previously, performance analysis of these has been done for various fading channels with different modulation techniques in term of BER (bit error rate). Performance comparison of FFH and MCFH has been done for Rayleigh fading channel with BFSK as a modulation technique. Here, performance of these two diversity schemes have been compared for Ricean fading channel with BFSK modulation technique and Rayleigh channel with DBPSK modulation technique in term of various consolidated parameters.

Multi carrier frequency hopping (MCFH) spread spectrum system found to outperform fast frequency hopping (FFH) spread spectrum system in slow frequency selective, fast frequency selective and slow frequency non-selective fading channels. In IEEE 801.11 and IEEE 801.15 MCFH spread spectrum system MCFH is better than FFH spread spectrum system up to 3db and 9db. MATLAB 7 has been used to simulate the performance of these systems.

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LIST OF ABBREVIATIONS

SYMBOL	**DESCRIPTION**
AM	Amplitude modulation
ASK	Amplitude shift keying
AWGN	Additive white Gaussian noise
BER	Bit error rate
BFSK	Binary frequency shift keying
CDMA	Code division multiple access
CW	Continuous wave
DBPSK	Differential binary phase shift keying
DPSK	Differential phase shift keying
DSB	Double side band
DSB-AM	Double side band amplitude modulation
DSB-SC	Double side band suppressed carrier
DSSS	Direct sequence spread spectrum
DS-CDMA	Direct sequence code division multiple access
FDM	Frequency division multiplexing
FFH	Fast frequency hopping
FH	Frequency hopping
FH-CDMA	Frequency hopping code division multiple access
FH-SS	Frequency hopping spread spectrum
FSK	Frequency shift keying
GMSK	Gaussian minimum shift keying
GSM	Global system for mobile communication
IEEE	Institute of electrical and electronics engineers
ISI	Inter symbol interference
ISM	Industrialist scientist and medical
JFPM	Joint frequency phase modulation
LAN	Local area network

LOS	Line of sight
MCFH	Multi carrier frequency hopping
MFSK	M-ary frequency shift keying
MSK	Minimum shift keying
OQPSK	Offset quadriphase phase shift keying
PAN	Personal area network
PN	Pseudo noise
PSD	Power spectral density
PSK	Phase shift keying
QoS	Quality of service
QPSK	Quadriphase phase shift keying
RF	Radio frequency
SNR	Signal to noise ratio
SQPSK	Staggered quadriphase phase shift keying
SS	Spread spectrum
SSMA	Spread spectrum
WLAN	Wireless local area network

CHAPTER 1

INTRODUCTION

1.1 SPREAD SPECTRUM

Over the last eight or nine years a new commercial marketplace has been emerging called spread spectrum, this field covers the art of secure digital communications that is now being exploited for commercial and industrial purposes. In the next several years hardly anyone will escape being involved, in some way, with spread spectrum communications. Applications for commercial spread spectrum range from "wireless" LAN's (computer to computer local area networks), to integrated bar code scanner/ palmtop computer / radio modem devices for warehousing, to digital dispatch, to digital cellular telephone communications, to " information society " city /area /state or country wide networks for passing faxes, computer data, email, or multimedia data.

One way to look at spread spectrum is that it trades a wider signal bandwidth for better signal to noise ratio. Frequency hop and direct sequence are well known techniques today. The following paragraphs will describe each of these common techniques in a little more detail and show that pseudo noise code techniques provide the common thread through all spread spectrum types.

1.1.1 PN SEQUENCE SPREAD SPECTRUM

The most practical, all digital version of SS is direct sequence. A direct sequence system uses a locally generated pseudo noise code to encode digital data to be transmitted. The local code runs at much higher rate than the data rate. Data for transmission is simply logically modulo-2 added (an EXOR operation) with the faster pseudo noise code. The composite pseudo noise and data can be passed through a data scrambler to randomize the output spectrum (and thereby remove discrete spectral lines). A direct sequence modulator is then used to double sideband suppressed carrier modulate the carrier frequency to be transmitted. The resultant DSB suppressed carrier AM modulation can also be thought of as binary phase shift keying (BPSK). Carrier modulation other than BPSK is possible with direct sequence. However, binary phase shift keying is the simplest and most often used SS modulation technique.

An SS receiver uses a locally generated replica pseudo noise code and a receiver correlator to separate only the desired coded information from all possible signals. A SS correlator can be thought of as a very special matched filter, it responds only to signals that are encoded with a pseudo noise code that matches its own code. Thus, an SS correlator can be "tuned" to different codes simply by changing its local code. This correlator does not respond to man made, natural or artificial noise or interference. It responds only to SS signals with identical matched signal characteristics and encoded with the identical pseudo noise code.

The use of these special pseudo noise codes in spread spectrum (SS) communications makes signals appear wide band and noise - like. It is this very characteristic that makes SS signals possess the quality of low probability of intercept. SS signals are hard to detect on narrow band equipment because the signal's energy is spread over a bandwidth of maybe 100 times the information bandwidth [1].

The spread of energy over a wide band, or lower spectral power density, makes SS signals less likely to interfere with narrowband communications. Narrow band communications, conversely, cause little to no interference to SS systems because the correlation receiver effectively integrates over a very wide bandwidth to recover an SS signal. The correlator then "spreads" out a narrow band interferer over the receiver's total detection bandwidth. Since, the total integrated signal density or SNR at the correlator's input determine whether there will be interference or not. All SS systems have a threshold or tolerance level of interference beyond which useful communication ceases. This tolerance or threshold is related to the SS processing gain. Processing gain is essentially the ratio of the RF bandwidth to the information bandwidth.

A typical commercial direct sequence radio might have a processing gain of from 11 to 16 db, depending on data rate. It can tolerate total jammer power levels of 3 from 0 to 5 db stronger than the desired signal. Yes, the system can work at negative SNR in the RF bandwidth. Because of the processing gain of the receiver's correlator, the system functions at positive SNR on the baseband data.

Besides being hard to intercept and jam, spread spectrum signals are hard to exploit or spoof. Signal exploitation is the ability of an enemy (or a non-network member) to listen in to a network and use information from the network without being a valid network member or participant. Spoofing is the act of falsely or maliciously introducing misleading or false traffic or messages to a network. SS signals also are naturally more secure than narrowband radio communications. Thus SS signals can be made to have any degree of message privacy that is desired. Messages can also, be cryptographically encoded to any level of secrecy desired. The very nature of SS allows military or intelligence levels of privacy and security to be had with minimal complexity. While these characteristics may not be very important to everyday business and LAN (local area network) needs, these features are important to understand.

1.1.2 FREQUENCY HOPPING SPREAD SPECTRUM

Frequency - hopping systems achieve the same results provided by direct sequence systems by using different carrier frequency at different time. The frequency hop system's carrier will hop around within the band so that it will avoid the jammer at some frequencies. Frequency hopping is the easiest spread spectrum modulation to use. Any radio with a digitally controlled frequency synthesizer can, theoretically, be converted to a frequency hopping radio. This conversion requires the addition of a pseudo noise (PN) code generator to select the frequencies for transmission or reception. Most hopping systems use uniform frequency hopping over a band of frequencies. This is not absolutely necessary, if both the transmitter and receiver of the system know in advance what frequencies are to be skipped. Thus a frequency hopper in two meters could be made that skipped over commonly used repeater frequency pairs. A frequency hopped system can use analog or digital carrier modulation and can be designed using conventional narrow band radio techniques. De-hopping in the receiver is done by a synchronized pseudo noise code generator that drives the receiver's local oscillator frequency synthesizer. The modulation most commonly used with this technique is M-ary frequency shift keying (MFSK), where $k = \log_2 M$ information bits are used to determine which one of M frequencies is to be transmitted. Depending on the hopping rate, bit rate and number of frequencies simultaneously transmitted frequency hopping can divided as slow frequency hopping, fast frequency hopping and multi carrier frequency hopping which are explained in next paragraphs [2].

1.1.2.1 SLOW FREQUENCY HOPPING

In slow frequency hopping the symbol rate R_s of the MFSK signal is an integer multiple of the hop rate R_h. That is, several symbols are transmitted in each frequency hop which we can be easily understand form figure 1.1. On a single hop, the bandwidth of the transmitted signal is the same as that resulting from the use of a conventional MFSK with an alphabet of $M = 2k$ orthogonal signals. However, for a complete range of $2k$ frequency hops, the transmitted FH/MFSK signal occupies a much larger bandwidth. A slow FH/MFSK signal is characterized by having multiple symbols transmitted per hop. Hence, each symbol of a slow FH/MFSK signal is a chip. Correspondingly, in a slow FH/MFSK system, the bit rate R_b of the incoming binary data, the symbol rate R_s of the MFSK signal, the chip rate R_c, and the hop rate R_h are related by

$$R_C = R_S = R_b \geq R_b / k \quad where\ k = \log_2 M$$

1.1.2.2 FAST FREQUENCY HOPPING

In fast frequency hopping the hop rate R_h is an integer multiple of the symbol rate R_S of the MFSK signal. That is, the carrier frequency will change or hop several times during the transmission of one symbol. Frequency hopping systems, the term “chip” is used to characterize the shortest uninterrupted waveform in the system. For fast frequency hopping, the shortest uninterrupted waveform is that of the hop. Figure 1.2 illustrates an FFH example of a binary FSK system. The diversity is N= 4. There are four chips transmitted per bit. The dashed line in each column corresponds to the center of the data band and the solid lines correspond to symbols frequency. Here, for FFH the chip duration is the hop duration.

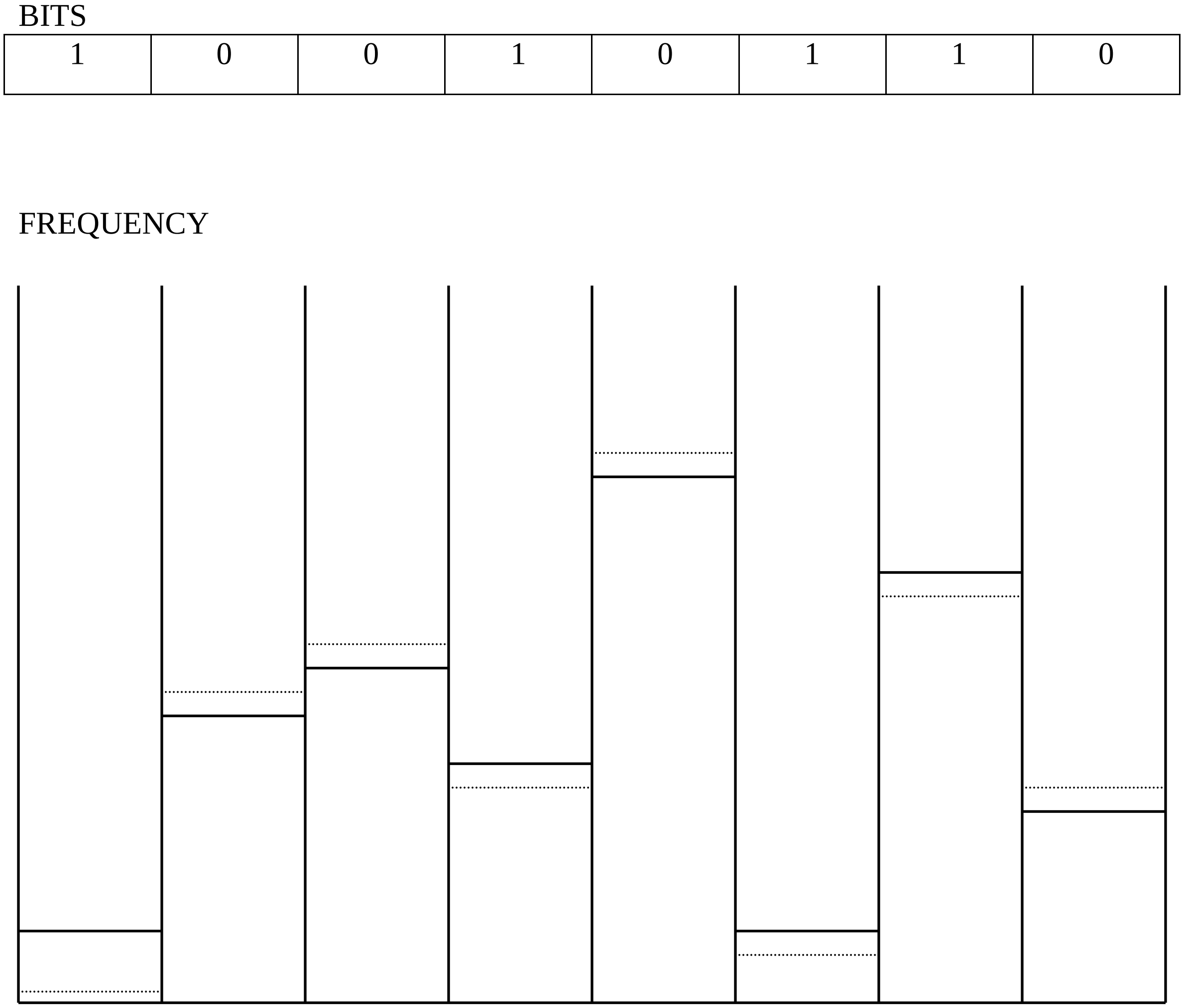

Figure.1.1 SLOW FREQUENCY HOPPING EXAMPLE

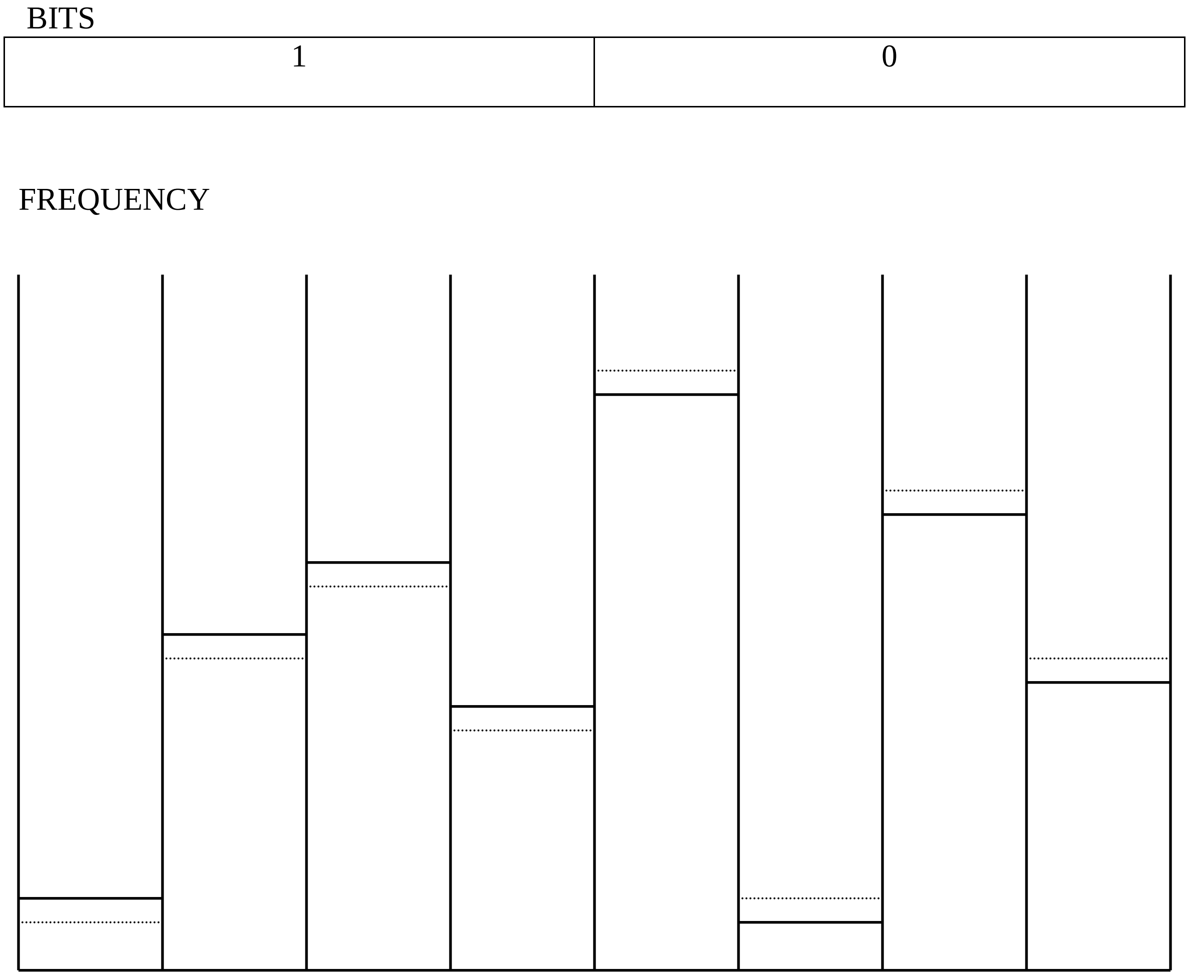

Figure.1.2 FAST FREQUENCY HOPPING EXAMPLE

1.1.2.3 MULTI CARRIER FREQUENCY HOPPING

In an MC-FH-CDMA system, every transmitter sends L carriers for each data bit using BFSK modulation. The carriers are spaced apart in sequential sub-bands. In fact, the total given frequency bandwidth is partitioned into L sub-bands of equal bandwidth. For each bit to be transmitted L carrier frequency are chosen (each from one sub band) and modulated according to the data and transmitted, for every bit these carrier frequency hop in their respective sub band. Figure 1.3 shows the transmitted signal for diversity order 4.

1.1.3 COMPARISON OF DS-CDMA AND FH-CDMA

Direct sequence and frequency hopping are the most commonly used methods for the spread spectrum technology. Although the basic idea is the same, these two methods have many distinctive characteristics that result in complete different radio performances. The carrier of the direct – sequence radio stays at a fixed frequency. Narrowband information is spread out into a much larger (at least 10 times) bandwidth by using a pseudo-random chip sequence. The narrowband signal and the spread spectrum signal both use the same amount of transmit power and carry the same information. However, the power density of the spread-spectrum signal is much lower than the narrowband signal. As a result, it is more difficult to detect the presence of the spread spectrum signal. The power density is the amount of power over a certain frequency. At the receiving end of a direct-sequence system, the spread spectrum signal is de-spread to generate the original narrowband signal if there is an interference jammer in the same band, it will be spread out during the de-spreading. As a result, the jammer's impact is greatly reduced. This is the way that the direct-sequence spread-spectrum (DSSS) radio fights the interference. It spreads out the offending jammer by the spreading factor. Since the spreading factor is at least a factor of 10, the offending jammer's amplitude is greatly reduced by at least 90%. Frequency-hopping systems achieve the same results provided by direct-sequence systems by using different carrier frequency at different time. The frequency-hop system's carrier will hop around within the band so that hopefully it will avoid the jammer at some frequencies. The frequency-hopping technique does not spread the signal; as a result, there is no processing gain. The processing gain is the increase in power density when the signal is de-spread and it will improve the received signal's signal-to-noise ratio (SNR). In other words, the frequency hopper needs to put out more power in order to have the same SNR as a direct-sequence radio. The frequency hopper however, is more difficult to synchronize. In these architectures, the receiver and the transmitter must be synchronized in time and frequency in order to ensure proper transmission and reception of signals. In a direct-sequence radio, on the other hand, only the timing of the chips needs to be synchronized. The frequency hopper also needs more time to search the signal and lock to it. As a result, the latency time is usually longer. While a direct-sequence radio can lock in the chip sequence in just a few bits. To make the initial synchronization possible, the

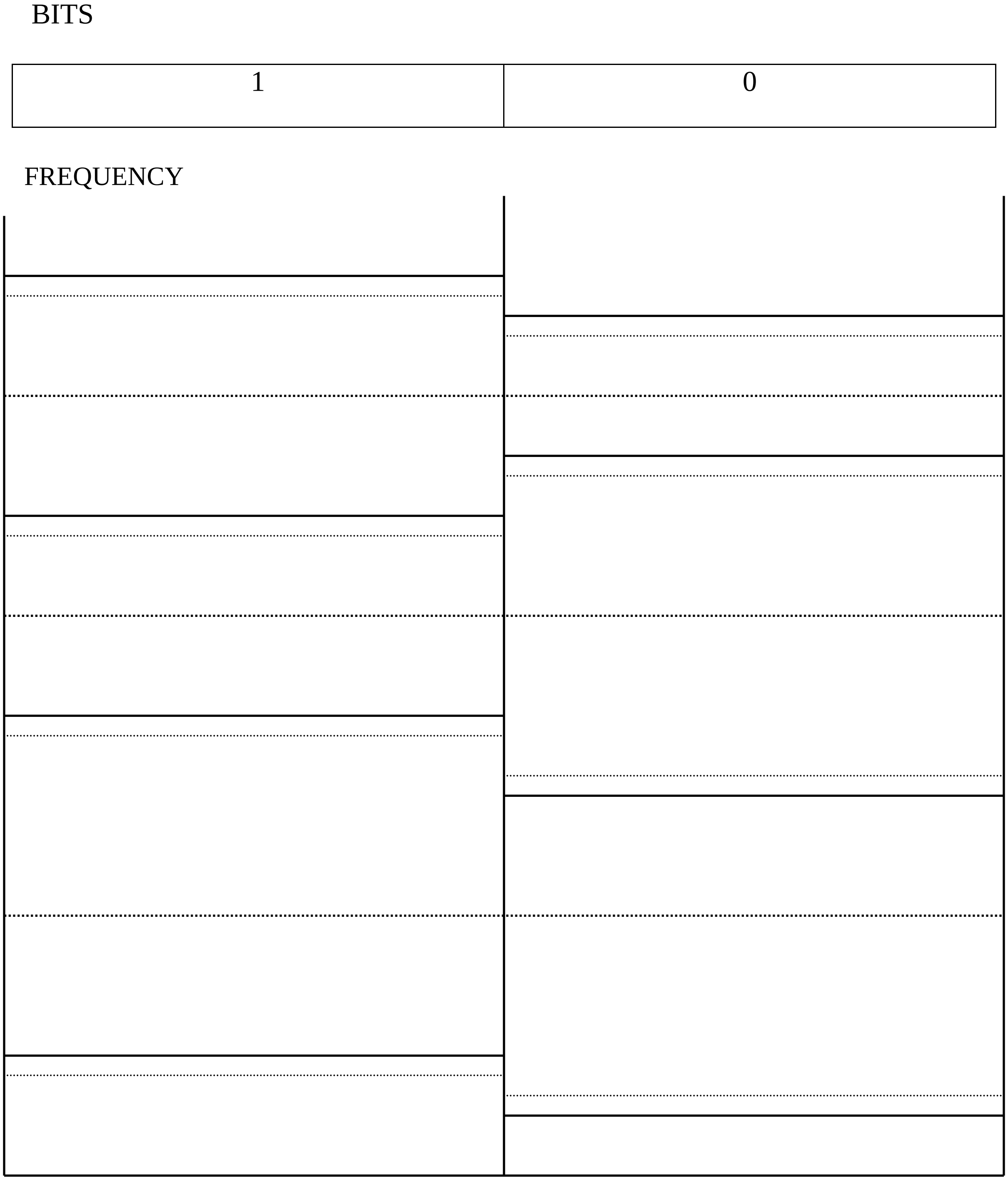

Figure.1.3 MULTI-CARRIER FREQUENCY HOPPING EXAMPLE

frequency hopper will typically park at a fixed frequency before hopping or communication begins. If the jammer happens to locate at the same frequency as the parking frequency, the hopper will not be able to hop at all. And once it hops, it will be very difficult, if not impossible to re-synchronize if the receiver ever lost the sync. The frequency hopper, however, is better than the direct sequence radio when dealing with multipath. Since the hopper does not stay at the same frequency and a null at one frequency is usually not a null at another frequency if it is not too close to the original frequency. So a hopper can usually deal with multipath fading issues better than direct-sequence radio. The hopper itself, however, could suffer performance problems if it interferes with another radio. In these scenarios, the system that survives depends upon which can suffer more data loss. In general, a voice system can survive an error rate as high as 10^{-2} while a data system must have an error rate better than $10^{-4.}$ Voice system can tolerate more data loss because human brain can "guess" between the words while a dumb microprocessor can't [3].

1.1.4 ADVANTAGES OF SPREAD SPECTRUM

Spread-spectrum systems provide some clear advantages to designers. As a recap, here are nine benefits that designers can expect when using a spread-spectrum based wireless system.

a. Reduced crosstalk interference: In spread - spectrum systems, crosstalk interference is greatly attenuated due to the processing gain of the spread spectrum system as described earlier. The effect of the suppressed crosstalk interference can be essentially removed with digital processing where noise below certain threshold results in negligible bit errors. These negligible bit errors will have little effect on voice transmissions.

b. Better voice quality/data integrity and less static noise: Due to the processing gain and digital processing nature of spread spectrum technology, a spread spectrum-based system is more immune to interference and noise. This greatly reduces consumer electronic device-induced static noise that is commonly experienced by conventional analog wireless system users.

c. **Lowered susceptibility to multipath fading:** Because of its inherent frequency diversity properties (thanks to wide spectrum spread), a spread spectrum system is much less susceptible to multipath fading.

d. **Inherent security:** In a spread spectrum system, a PN sequence is used to either modulate the signal in the time domain (direct sequence systems) or select the carrier frequency (frequency hopping systems). Due to the pseudo-random nature of the PN sequence, the signal in the air has been "randomized". Only the receiver having the exact same pseudo-random sequence and synchronous timing can de-spread and retrieve the original signal. Consequently, a spread spectrum system provides signal security that is not available to conventional analog wireless systems.

e. **Co-existence:** A spread spectrum system is less susceptible to interference than other non-spread spectrum systems. In addition, with the proper designing of pseudo-random sequences, multiple spread spectrum systems can co-exist without creating severe interference to other systems. This further increases the system capacity for spread spectrum systems or devices.

f. **Longer operating distances:** A spread spectrum device operated in the ISM band is allowed to have higher transmit power due to its non-interfering nature. Because of the higher transmit power, the operating distance of such a device can be significantly longer than that of a traditional analog wireless communication device.

g. **Hard to detect:** Spread-spectrum signals are much wider than conventional narrowband transmission (of the order of 20 to 254 times the bandwidth of narrowband transmissions). Since the communication band is spread, it can be transmitted at a low power without being detrimentally by background noise. This is because when dispreading takes place, the noise at one frequency is rejected, leaving the desired signal.

h. Hard to intercept or demodulate: The very foundation of the spreading technique is the code use to spread the signal. Without knowing the code it is impossible to decipher the transmission. Also, because the codes are so long (and quick) simply viewing the code would still be next to impossible to solve the code, hence interception is very hard.

i. Harder to jam: The most important feature of spread spectrum is its ability to reject interference. At first glance, it may be considered that spread spectrum would be most effected by interference. However, any signal is spread in the bandwidth, and after it passes through the correlator, the bandwidth signal is equal to its original bandwidth, plus the bandwidth of the local interference. An interference signal with 2 MHz bandwidth being input into a direct-sequence receiver whose signal is 10 MHz wide gives an output from the correlator of 12 MHz. The wider the interference bandwidth, the wider the output signal. Thus the wider the input signal, the less its effect on the system because the power density of the signal after processing is lower, and less power falls in the band pass filter [1-3].

1.2 NEED OF WORK

With the increasing demand of information transfer in day to day life, the high data rate has become a crucial factor in developing communication systems. In high data rate system, the effect of frequency selective fading should be considered due to an increase in the ratio of delay spread to symbol duration. Multi carrier frequency hopping is the technique which tackles with this problem easily due to increase in chip duration. The performance had been compared with conventionally fast frequency hopping in Rayleigh fading channel with BFSK modulation technique. Since Rayleigh fading channel does not represent most practical communication channel in personal communication services and Bluetooth, so their performance have been compared in Ricean fading channels another one DBPSK modulation technique is also used their in practical system. So their performance has also been compared for DBPSK modulation technique.

1.3 OBJECTIVE OF DISSERTATION

To compare the performance of Fast Frequency Hopping (FFH) and multicarrier frequency hopping (MCFH) systems with binary frequency shift keying(BFSK) and non - coherent detection in Ricean fading channels and with differential binary phase shift keying (DBPSK) modulation technique in Rayleigh fading channels. Comparison of performance is to be done by varying (one by one) the parameters given as:-

1. Signal to noise ratio
2. Delay spread
3. Doppler spread
4. Diversity order
5. Normalized frequency deviation

1.4 ORGANIZATION OF DISSERTATION

Spread spectrum systems and its various types i.e. PN sequence spread spectrum and frequency hopping spread spectrum have been discussed in chapter 1. Different types of frequency hopping spread spectrum and advantages of spread spectrum systems have been discussed in this chapter. Finally objective, need and organization of dissertation is given in this chapter. Work which have been already done in frequency hopping spread spectrum, its different types and their comparison is discussed in second chapter i.e. literature survey. Chapter 3 discusses various type of analog and digital modulation techniques used in various communication systems. One of the crucial factors of today’s wireless communication is fading, which is discussed in chapter 4 with various types and models. Bit error rate equations have been modified for fast frequency hopping and multi carrier frequency hopping spread spectrum system for various fading models and modulation techniques in chapter 5, which are given in [2] and [4]. For various input parameters bit error rate is plotted for both FFH and MCFH system in chapter 6, depending upon these graphs conclusion and future scopes are also given in this chapter.

CHAPTER 2

LITERATURE SURVEY

Spread Spectrum (SS) dates back to World War II. A German lady scientist was granted a patent on a simple frequency hopping CW system. The allies also experimented with spread spectrum in World War II. These early research and development efforts tried to provide countermeasures for radar, navigation beacons and communications. The U. S. Military has used SS signals over satellites for at least 25 years. An old, but faithful, highly capable design like the Magnavox USC-28 modem is an example of this kind of equipment. Housed in two or three six foot racks, it had selectable data rates from a few hundred bits per second to about 64 kbits per second. It transmitted a spread bandwidth of 60 MHZ. Many newer commercial satellite systems are now converting to SS to increase channel capacity and reduce costs.

Over the last twenty years, many spread spectrum signals have appeared on the air. The easiest way to characterize these modulations is by their frequency spectra. These SS signals occupy a much greater bandwidth than needed by the information bandwidth of the transmitted data. To rate being called an SS signal, two technicalities must be met:

- The signal bandwidth must be much wider than the information bandwidth.
- Some code or pattern, other than the data to be transmitted, determines the actual on-the-air transmit bandwidth.

In today's commercial spread spectrum systems, bandwidths of 10 to 100 times the information rates are used. Military systems have used spectrum widths from 1000 to 1 million times the information bandwidth. There are two very common spread spectrum modulations: frequency hopping and direct sequence. At least two other types of spreading modulations have been used: time hopping and chirp.

2.1 FAST FREQUENCY HOPPING SPREAD SPECTRUM

Performance analysis have been done in various channels, using various modulation techniques [Frequency shift keying, phase shift keying, joint frequency phase modulation] performance evaluation has been done for various receivers for fast frequency hopping spread spectrum communication. Performance in all these papers has been analyzed in term of bit error rate [BER].

In [5] a fast frequency hopping spread spectrum multiple access (FFH-SSMA) system with binary frequency shift keying (BFSK) modulation scheme is studied. In this paper additive white Gaussian noise (AWGN) plus Rayleigh fading channel is taken and for estimation it uses maximum likelihood decision criterion. Performance has been compared in selective and non-selective fading channel, which show that in non-selective fading channel it performs better than in selective fading channel.

In [6] error performance of an FFH-MFSK system with multitone interference have been analyzed performance is analyzed for two cases first when data rate is fixed and hopping rate is variable and second when hopping rate is fixed and data rate is variable.

In [7] the performance analysis of non-coherent reception in a FFH-BFSK spread spectrum communication system in selective fading environment has been carried out. Expressions are derived for the BER in the context of selective Rayleigh and selective Ricean fading channel. A distinction between selective channels and highly selective channels has been made as a function of multipath time delay spread. In this paper a pseudo random hopping pattern has been proposed in order to improve the performance of the FFH-BFSK modulation scheme in highly selective fading channels.

In [8] an FFH SS communication system, employing DBPSK modulation and differentially coherent detection has been proposed. The hop timing error cause phase imperfection and therefore system performance degrades, for this system a receiver is used which utilized a hop timing tracking loop to lock the hop clock after this its error performance of this system in a phase distorted AWGN channel is presented which shows that the degradation due to phase imperfection caused by timing error is only about a fraction of one db.

[9] presents a comparative study of the use of two modulation techniques for a fast frequency hopping [FFH] spread spectrum system for wireless communication over a non-selective Rayleigh fading channel. The modulation techniques considered are binary frequency shift keying (BFSK) and differential phase shift keying (DPSK). The comparison, standard chosen is that of the signal to noise ratio (SNR) for achieving a given bit error rate (BER). It is found that DPSK is capable of giving a gain of about 3 db over BFSK indicating the potential for employing DPSK for such a spread spectrum.

In [10] performance and capacities of differential phase shift keying (DPSK) fast frequency hopping (FFH) spread spectrum (SS) transmission and multiple access (MA) systems over Nakagami fading channels are analyzed and compared with simulated results. A transmitter proposed which can operate without an output-hopping filter. The secured transmission can be obtained by the proposed DPSK-FFHSS system. Result of this paper shows that BER is improved in the system with higher number of hops/bit. Furthermore, the number of hops/bit can guarantee BER for the most values of Nakagami fading figure with small maximum variation of average signal to noise ratio.

In [11] for joint frequency phase modulation technique a receiver is introduced and an exact expression for the bit error rate is obtained in fast frequency hopping spread spectrum system. After this using this equation performance analyzed of this system is given over Rayleigh fading channels. Result of this paper shows that FFH/JFPM perform better than the conventional FFH systems.

2.2 MULTICARRIER FHSS

First time multi carrier frequency hopping spread spectrum was proposed in [12]. In this paper it was introduced as a diversity technique due to which it can be used with phase coherent detection. This paper gives the model of the transmitter and receiver signal, after this it derive the equation of BER in noisy environment. By simulation it shows that this optimum diversity is 6 db better than conventional non-coherent FH-SS system because smart jammer may present in all sub - bands but cannot destroy all carriers' performance. In this paper is simulation of BER is done with respect to noise power.

In [13] the multi user performance of a multi carrier frequency hopping MC-FHCDMA system employing non- coherent detection is evaluated. In this modulation technique used is BFSK. It derives the bit error rate of the system for both uncoded and coded system in AWGN and slowly frequency selective Rayleigh fading channel, based on gaussian distribution assumption for decision variable, we use a practical low rate convolution error correcting code which does not require any extra bandwidth further than what is need by the uncoded scheme, our numerical results indicate that the coded scheme significantly out performs the uncoded scheme in both AWGN and fading channels. Furthermore, it is also observed that the performance enhancement due to an increase of diversity order is more significant for coded scheme.

In [14] evaluation and comparison of multi user performance of the multi carrier frequency hopping CDMA system using coherent and non-coherent detection in AWGN and slowly frequency s elective Rayleigh channels in a downlink application is done. Modulation technique used is the BFSK. Equations for BER are found for coherent and non-coherent detection. BER is drawn against the variation of number of user and number of sub carrier for both coherent and non-coherent detection. Numerical results of this paper show that in both AWGN and fading channels, the coherent detection substantially outperforms the non-coherent detection. Furthermore, it has realized that the diversity order is only observable for coherent detection.

2.3 COMPARISON OF FFH AND MCFH SPREAD SPECTRUM

Previously analysis of performance of frequency hopping spread spectrum system employing non - coherent reception and transmission diversity has been done for frequency selective Rayleigh fading channels. Two different types of transmission diversity system, a fast frequency hopping [FFH] system and a multi carrier frequency hopping [MCFH] system are investigated. In order to combine received signal from transmit diversity channels, the optimum diversity combining rule based on the maximum likelihood criterion is developed. Probability of error equations are derived and utilized to evaluate the performance of the two systems. The BER is analyzed with variation in noise, delay spread, doppler spread and diversity order in Rayleigh fading channels. MCFH systems are found to out perform FFH systems when the channel delay spread is severe, while FFH systems are superior to MCFH systems when a channel varies rapidly. Performance enhancement due to an increase of diversity order is more significant for MCFH system than for FFH systems in frequency selective fading channels. The effect of frequency selective fading is also investigated in determining optimum frequency deviations of binary frequency shift keying signals.

CHAPTER 3

MODULATION SCHEMES

Modulation is the process of varying a carrier signal in order to use that signal to convey information. The three key parameters of a sinusoid are its amplitude, its phase and its frequency, all of which can be modified in accordance with an information signal to obtain the modulated signal. There are several reasons to modulate a signal before transmission in a medium. These include the ability of different users sharing a medium (multiple access), and making the signal properties physically compatible with the propagation medium [15].

There are of two type modulation schemes depending on information signal described below:

3.1 ANALOG MODULATION

Modulation is called analog modulation, if information signal is analog signal. There are many ways to modulate analog signal:

- Amplitude Modulation
- Frequency Modulation
- Phase Modulation
- Pulse Modulation

Amplitude Modulation (AM): Amplitude Modulation occurs when a voice signal's varying voltage is applied to a carrier frequency. The carrier frequency's amplitude changes in accordance with the modulated voice signal, while the carrier's frequency does not change. When combined the resultant AM signal consists of the carrier frequency, plus upper and lower sidebands. This is known as Double Sideband -Amplitude Modulation (DSB-AM), or more commonly referred to as plain AM. The carrier frequency may be suppressed or transmitted at a relatively low level. This requires that the carrier frequency be generated, or otherwise derived, at the receiving site for demultiplexing. This type of transmission is known as Double Sideband - Suppressed Carrier (DSB-SC).

It is also possible to transmit a single sideband for a slight sacrifice in low frequency response (it is difficult to suppress the carrier and the unwanted sideband, without some low frequency filtering as well). The advantage is a reduction in analog bandwidth needed to transmit the signal. This type of modulation, known as Single Sideband - Suppressed Carrier (SSB-SC), is ideal for Frequency Division Multiplexing (FDM). Another type of analog modulation is known as Vestigial Sideband. Vestigial Sideband modulation is a lot like Single Sideband, except that the carrier frequency is preserved and one of the sidebands is eliminated through filtering. However analog bandwidth requirements are a little more than Single Sideband. Vestigial Sideband transmission is usually found in television broadcasting. Such broadcast channels require 6 MHz of analog bandwidth, in which amplitude modulated picture carrier is transmitted along with a frequency modulated sound carrier.

Frequency Modulation (FM): Frequency Modulation occurs when a carrier's center frequency is changed based upon the input signal's amplitude. Unlike amplitude modulation, the carrier signal's amplitude is unchanged. This makes FM modulation more immune to noise than AM and improves the overall signal-to-noise ratio of the communications system. Power output is also constant, differing from the varying AM power output. The amount of analog bandwidth necessary to transmit a FM signal is greater than the amount necessary for AM, a limiting constraint for some systems.

Phase Modulation: Phase Modulation is similar to Frequency Modulation. Instead of the frequency of the carrier wave changing, the phase of the carrier changes. As you might imagine, this type of modulation is easily adaptable to data modulation applications.

Pulse Modulation (PM): With Pulse Modulation, a "snapshot" (sample) of the waveform is taken at regular intervals. There are a variety of Pulse Modulation schemes:

- Pulse Amplitude Modulation
- Pulse Frequency Modulation
- Pulse Position Modulation
- Pulse Width Modulation

Pulse Amplitude Modulation (PAM): In Pulse Amplitude Modulation, a pulse is generated with amplitude corresponding to that of the modulating waveform. Like AM, it is very sensitive to noise. PAM is an important first step in a modulation scheme known as Pulse Code Modulation.

Pulse Code Modulation (PCM): In Pulse Code Modulation, PAM samples (collected at regular intervals) are quantized. That is to say, the amplitude of the PAM pulse is assigned a digital value (number). This number is transmitted to a receiver that decodes the digital value and outputs the appropriate analog pulse. The fidelity of this modulation scheme depends upon the number of bits used to represent the amplitude. The frequency range that can be represented through PCM modulation depends upon the sample rate. To prevent a condition known as "aliasing", the sample rate must be at least twice that of the highest supported frequency. For typical voice channels (4 Khz frequency range), the sample rate is 8 KHz.

Pulse Frequency Modulation (PFM): With PFM, pulses of equal amplitude are generated at a rate modulated by the signal's frequency. The random arrival rate of pulses makes this unsuitable for transmission through Time Division Multiplexing (TDM) systems.

Pulse Position Modulation (PPM): Also known as Pulse Time Modulation, PPM is a scheme where the pulses of equal amplitude are generated at a rate controlled by the modulating signal's amplitude. Again, the random arrival rate of pulses makes this unsuitable for transmission using TDM techniques.

Pulse Width Modulation (PWM): In PWM, pulses are generated at a regular rate. The length of the pulse is controlled by the modulating signal's amplitude. PWM is unsuitable for TDM transmission due to the varying pulse width.

3.2 DIGITAL MODULATION

Digital signals need to be processed by an intermediate stage for conversion into analog signals for transmission. There are three major classes of digital modulation techniques used for transmission of digitally represented data. All convey data by changing some aspect of a base signal, the carrier wave, (usually a sinusoid) in response to a data signal.

- Amplitude-shift keying (ASK)
- Frequency-shift keying (FSK)
- Phase-shift keying (PSK)

Amplitude-shift keying (ASK): Amplitude – shift keying is a type of modulation that represents digital data as the presence or absence of a carrier wave. In its simplest form, the presence of a carrier for a specific duration represents a binary one, while its absence for the same duration represents a binary zero. Some more sophisticated schemes vary these durations to convey additional information. Amplitude-shift keying is most commonly used to transmit Morse code over radio frequencies (referred to as continuous wave operation), although in principle any digital encoding scheme may be used.

Amplitude - shift keying has been used in the ISM bands to transfer data between computers, for example. Amplitude-shift keying is not very spectrally efficient due to the abrupt changes in amplitude of the carrier wave. At low to medium signaling speeds, this can be mitigated by adjusting the rise and fall rates of the carrier's amplitude. At high speeds, more efficient modulation modes (such as frequency-shift keying) are normally used instead. Amplitude-shift keying is also called on-off keying.

Frequency-shift keying (FSK): Frequency – shift keying is a form of frequency modulation in which the modulating signal shifts the output frequency between predetermined values. Usually, the instantaneous frequency is shifted between two discrete values termed the mark frequency and the space frequency. This is a noncoherent form of FSK. Coherent forms of FSK exist in which there is no phase discontinuity in the output signal. The example shown at right is of such a form. Other names for FSK are frequency – shift modulation and frequency - shift signaling. Minimum frequency-shift keying or minimum-shift keying (MSK) is a particularly spectrally efficient form of coherent frequency - shift keying. In MSK the difference between the higher and lower frequency is identical to the bit rate . As a result, the number of carrier periods used to represent a 0 and a 1 bit differs by exactly one. This is the smallest FSK modulation index that can be chosen such that the waveforms for 0 and 1 are orthogonal. Gaussian minimum shift keying or GMSK is a kind of continuous phase frequency-shift keying. The baseband modulation is generated by starting with a bit stream 0/1 and a bit-clock giving a time slice for each bit. This is the type of modulation used in Global System for Mobile Communications (GSM). The baseband signal is generated by first transforming the zero/one encoded bits into -1/+1 encoded bits. This -1/+1 signal is then filtered in such a way that the "boxcar" shaped +1/-1 pulses are transformed into Gaussian-shaped signals. The baseband signal is then modulated using frequency modulation, producing a complete GMSK signal. If the Gaussian shapes do not overlap, then the modulation form is called 1-GMSK. If the slots overlap 50 % (½), the modulation is called 2-GMSK, and so on. The more the bits overlap, the more significant intersymbol interference (ISI)

from adjacent bits will be, and for 4- GMSK and up, the ISI seen at any particular point in time is stronger than the signal from the bit currently being decoded. By looking at greater parts of the signal using advanced decoder techniques (including Viterbi algorithm decoders), high density coding can be decoded efficiently. Currently the highest density coding being used is 5-GMSK.

Phase-shift keying (PSK): Phase - shift keying (PSK) is a digital modulation scheme that conveys data by changing, signal and maps it back to the symbol it represents, thus recovering the original data or modulating, the phase of a reference signal (the carrier wave). Any digital modulation scheme uses a finite number of distinct signals to represent digital data. In the case of PSK, a finite number of phases are used. Each of these phases is assigned a unique pattern of binary bits. Usually, each phase encodes an equal number of bits. Each pattern of bits forms the symbol that is represented by the particular phase. The demodulator, which is designed specifically for the symbol set used by the modulator, determines the phase of the received this requires the receiver to be able to compare the phase of the received signal to a reference signal - such a system is termed coherent. Alternatively, instead of using the bit patterns to set the phase of the wave, it can instead be used to change it by a specified amount. The demodulator then determines the changes in the phase of the received signal rather than the phase itself. Since this scheme depends on the difference between successive phases, it is termed differential phase-shift keying (DPSK). DPSK can be significantly simpler to implement than ordinary PSK since there is no need for the demodulator to have a copy of the reference signal to determine the exact phase of the received signal (it is a nonchoerent scheme). In exchange, it produces more erroneous demodulations. The exact requirements of the particular s cenario under consideration determine which scheme is used. BPSK is the simplest form of PSK. It uses two phases which are separated by 180°

and so can also be termed 2-PSK. It does not particularly matter exactly where the constellation points are positioned. This modulation is the most robust of all the PSKs since it takes serious distortion to make the demodulator reach an incorrect decision. It is, however, only able to modulate at 1bit/symbol and so is unsuitable for high data-rate applications. Sometimes known as quaternary or quadriphase PSK or 4-PSK, QPSK uses four points on the constellation diagram, equal spaced around a circle. With four phases, QPSK can encode two bits per symbol, shown in the diagram with Gray coding to minimize the BER — twice the rate of BPSK. Analysis shows that this may be used either to double the data rate compared to a BPSK system while maintaining the bandwidth of the signal or to maintain the data-rate of BPSK but halve the bandwidth needed. Although QPSK can be viewed as a quaternary modulation, it is easier to see it as two independently modulated quadrature carriers. With this interpretation, the even (or odd) bits are used to modulate the in-phase component of the carrier, while the odd (or even) bits are used to modulate the quadrature-phase component of the carrier. BPSK is used on both carriers and they can be independently demodulated. Offset QPSK, sometimes called Staggered QPSK (SQPSK), works by delaying one of the two components by the duration of half symbol (one bit). This limits the phase-jumps that occur at symbol boundaries to no more than 90° and reduces the effects on the amplitude of the signal due to any low-pass filtering. A disadvantage of OQPSK is that it introduces a delay of half a symbol into the demodulation process . In other words, using OQPSK increases the temporal efficiency of normal QPSK. The reason is that the in phase and quadrature phase components of the OQPSK cannot be simultaneously zero. Hence, the range of the fluctuations in the signal is smaller. An additional disadvantage is that the quiescent power is nonzero, which may be a design issue in devices targeted for low power applications. As mentioned for BPSK and QPSK there is an ambiguity of phase if the constellation is rotated by some effect in the communications channel the signal passes through. This problem can be overcome by using the data to change rather than set the phase. For example, in differentially-encoded BPSK a binary '1' may be transmitted by adding 180° to the current phase and a binary '0' by adding 0° to the current phase. In differentially-encoded QPSK, the phase-shifts are 0°, 90°, 180°, -90° corresponding to data '00', '01', '11', '10'. This kind of encoding may be demodulated in the same way as for non - differential PSK but the phase ambiguities can be ignored. Thus, each received symbol is demodulated to one of the M points in the constellation and a comparator then computes the difference in phase between this received signal and the preceding one. The difference encodes the data as described above [1], [15].

CHAPTER 4

DIFFERENT FADING CHANNEL MODELS

Radio waves propagate from a transmitting antenna and travel through free Space undergoing absorption, reflection, refraction, diffraction and scattering. They are greatly affected by the ground terrain, the atmosphere, and the objects in their path, like buildings, bridges and hills, trees etc.

In most of the mobile and cellular systems, the height of the mobile antenna may be smaller than the surrounding structures. Thus the existence of a direct or line of sight path between the transmitter and the receiver is highly unlikely. In such a case the propagation is mainly due to reflection and scattering from the buildings and by diffraction over and around them. Therefore, in practice the transmitted signal arrives at the receiver via several paths with different time delays creating a multipath situation.

At the receiver, these multipath waves with randomly distributed amplitudes and phases combine to give a resultant signal that fluctuates in time and space. Therefore receiver at one location may have a signal that much different from the signal at another location, only a short distance away, because of the change in the phase relationships among incoming waves. This causes significant fluctuations in the signal amplitude. The phenomenon of random fluctuations in the received signal level is termed as fading [1].

Fading are of two type:

- Small scale fading
- Large scale fading

4.1 SMALL SCALE FADING

Small – scale fading refers to fluctuations in the instantaneous received signal strength when the mobile moves over very small distances. Quite often in a mobile environment, there occurs interference between two or more copies of the transmitted signal, which arrive at the receiver at slightly different times. These multiple versions of the same transmitted signal are called multipaths. The multipath waves are generated due to reflection of transmitted signal by objects in the environment between the base station and a user. These objects can be buildings, trees, hills, or even trucks and cars. The reflected signals arrive at the receiver with random phase offsets, because each reflection generally follows a different path to reach the user's receiver. The result is random signal fades as the reflections destructively (and constructively) superimpose on one another, which effectively cancels part of the signal energy for brief periods of time. Fading phenomenon is used to describe these rapid fluctuations of amplitudes and phases of a radio signal over a short duration or distance. In small-scale fading, the received signal power may vary by as much as three or four orders of magnitude (30 or 40 db) when the receiver is moved by only a fraction of a wavelength.

In built-up urban areas, fading occurs due to absence of line-of-sight (LOS) path between base station and mobile. Even when a LOS exists, multipath still occurs due to reflections from ground and surrounding structures. Time dispersion represents distortion to the signal and is manifested by the spreading in time of the modulation symbols. This is better explained by the phenomenon whereby transmission of an extremely short pulse, ideally an impulse, over the time-varying multipath channel will result in a train of pulses at the receiver. This occurs when the channel is band-limited. Consequently, multiple copies of signals arriving at different times spread out the transmitted symbol in time, and cause what is known as intersymbol interference (ISI) (i.e., one data symbol smearing into its adjacent one and thereby causing errors in bit decision making).

Another ill effect of non -stationary mobile channel is the Doppler shift, which describes the apparent frequency shift that each multipath experiences due to relative motion between the mobile and the base station. Multipath, ISI and Doppler shift are all related to variability that is introduced by the mobility of the user and the wide range of environments that signals pass through. The cumulative effect of these phenomena is the severe degradation in received signal strength, poor mobile receiver performance and hence, unsatisfactory quality of service of the wireless system.

4.1.1 FACTORS INFLUENCING SMALL-SCALE FADING

Many physical factors in the radio propagation channel influence small-scale fading. These include the following:

Multipath propagation- The presence of reflecting objects and scatterers in the channel creates a constantly changing environment that dissipates the signal energy in amplitude, phase, and time. These effect result in multiple versions of transmitted signal that arrive at receiving antenna, displaced with respect to one another in time and spatial variation.

Speed of mobile- The relative motion between the base station and the mobile results in the random frequency modulation due to different Doppler shifts on each of the multipath components. Doppler shift will be positive or negative depending on the whether the mobile receiver is moving toward or away from base station.

Speed of surrounding objects - If objects in the radio channel are in motion, they induce a time varying Doppler shift on multipath components. If the surrounding objects move at a greater rate than the mobile, then this effect dominates the small-scale fading.

The transmission bandwidth of the signal- If the transmitted radio signal bandwidth is greater than the bandwidth of multipath channel, the received signal will be distorted, but the received signal strength will not fade much over a local area. As will be shown, the bandwidth of the channel can be quantified by the coherence bandwidth, which is related to the specific multipath structure of the channel. The coherence bandwidth is a measure of the maximum frequency difference for which signals are still strongly correlated in amplitude . If the transmitted signal has a narrow bandwidth as compare to channel, the amplitude of the signal will change rapidly, but the signal will not be distorted in time.

4.1.2 TYPES OF SMALL SCALE FADING

When the waves of multipath signals are out of phase, reduction in signal strength or fade can occur. The type of fading experienced by a signal propagating though a mobile radio channel depends on the nature of the transmitted signal with respect to the characteristics of the channel. Depending on the relation between the signal parameters (such as bandwidth, symbol period, etc.) and the channel parameters (such as rms delay spread and Doppler spread), different transmitted signals will undergo different types of fading. Fade zones tend to be small, multiple areas of space within a multipath environment that cause periodic attenuation of a received signal for users passing through them. In other words, the received signal strength will fluctuate downward, causing a momentary, but periodic, degradation in quality.

The small – scale signal fading due to the time dispersion and frequency dispersion mechanisms in a mobile channel could be classified into four major categories depending on the nature of the transmitted signal, the channel and the mobile velocity:-

- Fast Fading
- Slow Fading
- Frequency Selective Fading
- Flat Fading

Fast fading: A fast fading channel, the channel impulse response changes rapidly within the symbol duration. That is, the coherence time of the channel is smaller than the symbol period of the transmitted signal. This causes frequency dispersion due to Doppler spreading, which leads to signal distortion. Fast fading channel only deals with the rate of change of the channel due to motion. In practice, fast fading only occurs for very low data rates.

Slow Fading: In a slow fading channel, the channel impulse response changes at a much slower rate than the transmitted baseband signal. The channel may be assumed to be static over one or several reciprocal bandwidth intervals. In the frequency domain, this implies that the Doppler spread of the channel is much less than the bandwidth of the baseband signals.

Frequency Selective Fading: The channel creates frequency selective fading on the received signal if the channel possesses a constant-gain and linear phase response over a bandwidth that is smaller than the bandwidth of transmitted signal. Under such conditions, the channel response has a multipath delay spread which is greater than the reciprocal bandwidth of the transmitted message waveform. When this occurs, the received signal includes multiple versions of the transmitted waveform, which are attenuated and delayed in time, and hence the received signal is distorted. When viewed in frequency domain, certain frequency components in the received signal spectrum have greater gains than others. The spectrum of the transmitted signal, for frequency selective fading, has a bandwidth greater than the coherence bandwidth of the channel.

Frequency selective fading channel models are very difficult to model since each multipath must be modeled and the channel must be considered to be a linear filer. Therefore, these models are typically developed from the wideband multipath measurements. However, when analyzing mobile communication systems, statistical impulse response models such as the two-ray Rayleigh fading model are generally used. In two-ray Rayleigh fading model, the consideration is that the impulse response of the channel is made up of two delta functions that fade independently and have sufficient time delay between them to induce frequency selective fading upon the applied signal.

Flat Fading: The received signal will undergo flat fading channel if the mobile radio channel has a constant gain and linear phase response over a bandwidth, which is greater than the bandwidth of the transmitted signal. The multipath structure of the channel is such that the spectral characteristics of the transmitted signal are preserved at the receiver but the strength of the received signal changes with time due to fluctuations in the gain of the channel cause by multipath. Flat fading channels are also known as narrowband channels since the bandwidth of the applied signal is narrow as compared to the channel flat fading bandwidth. Typical flat fading channels generate deep fades and thus required a higher transmitter power of 20 or 30 db to achieve low bit error rates during times of deep fades.

4.2 LARGE SCALE FADING

The long-term variation in the mean signal level causes large scale fading. This effect is a result of movement over distances large enough to cause gross variations in the overall path between the transmitter and receiver. Large scale fading is also known as shadowing because the variations in the mean signal level are caused by the mobile unit moving in shadow of surrounding objects like buildings and hills. Due to effect of multipath, a moving receiver can experience several fades in a very short duration, or in more serious case the vehicle may stop at a location where the signal is in a deep fade.

4.3 FADING CHANNEL MODELS

Multipath fading is due to the constructive and destructive combination of randomly delayed, reflected, scattered and diffracted signal components. This type of fading is relatively fast and is therefore responsible for the short-term signal variations. Depending on the nature of the radio propagation environment, there are different models describing the statistical behavior of the multipath-fading envelope. The Rayleigh, and Ricean are the most commonly used statistical models to represent small-scale fading phenomenon [1].

4.3.1 RAYLEIGH FADING CHANNEL

The Rayleigh distribution is commonly used to describe the statistical time varying nature of the received envelope of a flat fading signal, or the envelope of an individual multipath component. In the Rayleigh flat fading channel model, it is assumed that the channel induces amplitude, which varies in time according to the Rayleigh distribution. When the channel impulse response is modeled as a zero-mean complex valued Gaussian process, the envelope at any instant is Rayleigh - distributed. The Rayleigh distribution of a received complex envelope of a signal $z(t) = |r(t)|$ at any time t is given as:-

$$P(r) = \begin{cases} \left(r/\sigma^2\right)\exp\left(-r^2/2\sigma^2\right) & for\left(0 \le r \le \infty\right) \\ 0 & for\left(r < 0\right) \end{cases} \qquad (4.1)$$

where σ is the root mean square value of the received voltage signal before envelope detection, and σ^2 is the time - average power of the received signal before envelope detection. It is well known that the envelope of the sum of two quadrature Gaussian noise signals obeys a Rayleigh distribution. This fading distribution could be applied to any scenario where there is no LOS path between transmitter and receiver antennas.

4.3.2 RICEAN FADING CHANNEL

When there is a dominant stationary (non-fading) signal component present, such as LOS propagation path, the small-scale fading envelope distribution is Ricean. In such a situation, random multipath components arriving at different angles are superimposed on a stationary dominant signal. At the output of an envelope detector, this has the effect of adding a dc component to the random multipath. The effect of a dominant signal arriving with many weaker multipath signals gives rise to the Ricean distribution. As the dominant signal becomes weaker, the composite signal resembles a noise signal, which has an envelope that is Rayleigh. Thus, the Ricean distribution degenerates to a Rayleigh distribution when the dominant component fades away.

With fixed scatterers or signal reflectors in the medium, in addition to randomly moving scatterers, the channel impulse response will have a non-zero mean value and its envelope will have a Rice distribution. This channel is said to be a Ricean Fading Channel. For a multipath fading channel containing a specular or LOS component, the complex envelope of the received signal can be given by the Ricean distribution:-

$$
\begin{array}{lll}
P(r) = \left(r/\sigma^2\right)\exp\left[-\left(r^2 + A^2\right)/2\sigma^2\right] I_o\left(Ar/\sigma^2\right) & for\left(A \geq 0, r \geq 0\right) & \\
\qquad 0 & for\left(r < 0\right) & (4.2)
\end{array}
$$

where A denotes the peak amplitude of the dominant or LOS signal and $I_o(.)$ is the zeroth order modified Bessel function of the first kind. The Ricean distribution is often described in terms of a parameter K called Ricean factor, which is defined as the ratio between the deterministic signal power and the variance of the multipath [16,17].

CHAPTER 5

SYSTEM MODELING

5.1 INTRODUCTION

Bit error rate equations have been modified for fast frequency hopping and multi carrier frequency hopping spread spectrum system for various fading models and modulation techniques in this chapter, which are given in [2] and [4].

5.2 SYSTEM MODELING OF FFH AND MCFH FOR BFSK

Considered system is frequency hopping spread spectrum system with binary frequency shift keying (BFSK) modulation technique, noncoherent detection, diversity order L . Transmitter block diagram of FFH and MCFH systems are shown, respectively, in figure 5.1 and 5.2. The complex baseband equivalent of the transmitted signal for each system can be represented as:-

For FFH system: -

$$s(t) = \sum_{k=0}^{\infty}\sum_{l=0}^{L-1}\sqrt{2S}\,\exp\left[\,j\left\{2\pi\left(f_{l,k}+b_k f_d\right)+\Phi_{l,k}\right\}\right]p_{T_h}\left(t-kT-lT_h\right) \qquad (5.1)$$

For MCFH system: -

$$s(t) = \sum_{k=0}^{\infty}\sum_{l=0}^{L-1}\sqrt{2S}\,\exp\left[\,j\left\{2\pi\left(f_{l,k}+b_k f_d\right)+\Phi_{l,k}\right\}\right]p_{T_h}\left(t-lT_h\right) \qquad (5.2)$$

where S is the transmit power of each diversity transmission, T is the symbol duration, T_h is the hop duration. $f_{l,k}$ and $\Phi_{l,k}$ are, respectively, the hop frequency and random phase for the l^{th} diversity transmission of the k^{th} symbol. $b_k \in \{-1,+1\}$ is the k^{th} data symbol, and $p_\lambda(t)=1\ for\ t\in(0,\lambda)$ and zero, otherwise.

The frequency deviation of a BFSK signal b_k is denoted by $f_d = h/2T_h = \Delta f/2$, where h is the normalized frequency deviation and Δf is the frequency separation between two BFSK signals.

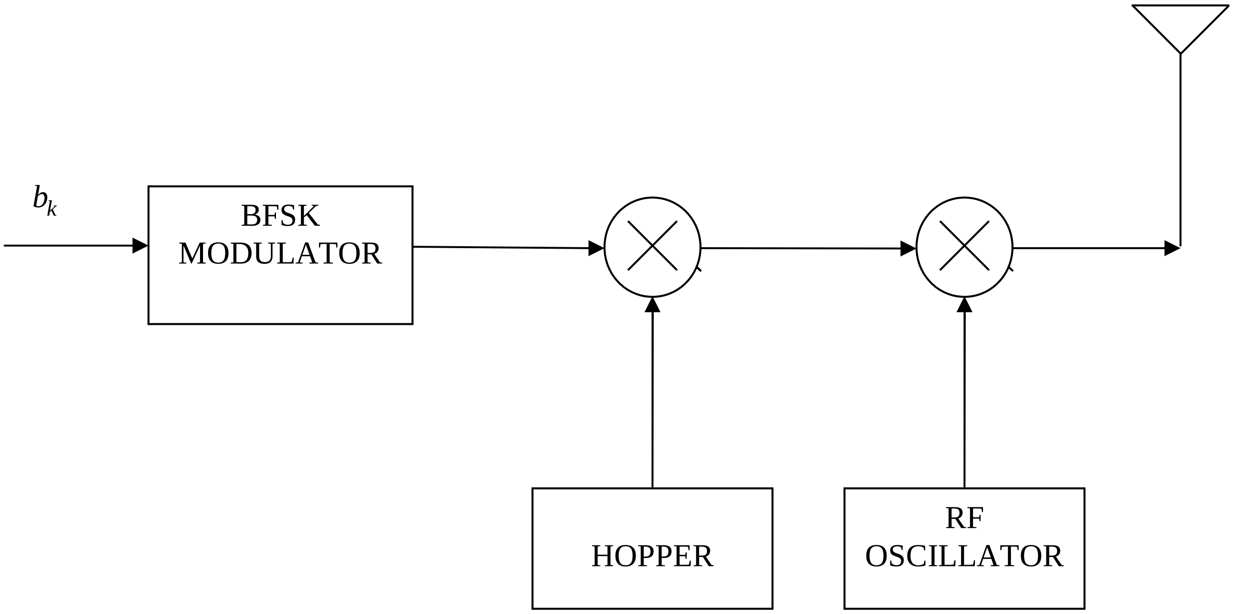

Figure 5.1 BLOCK DIAGRAM OF TRANSMITTER OF FFH SYSTEM

When the total transmit power of $s(t))$ is s_t, the value of S in (5.1) for FFH system is s_t and that of S for an MCFH system is s_t/L.Similarly the value of T_h for an FFH system is T/L and that of T_h for MCFH system is T.Correspondingly, the value of f_d and Δf would be different for two system.

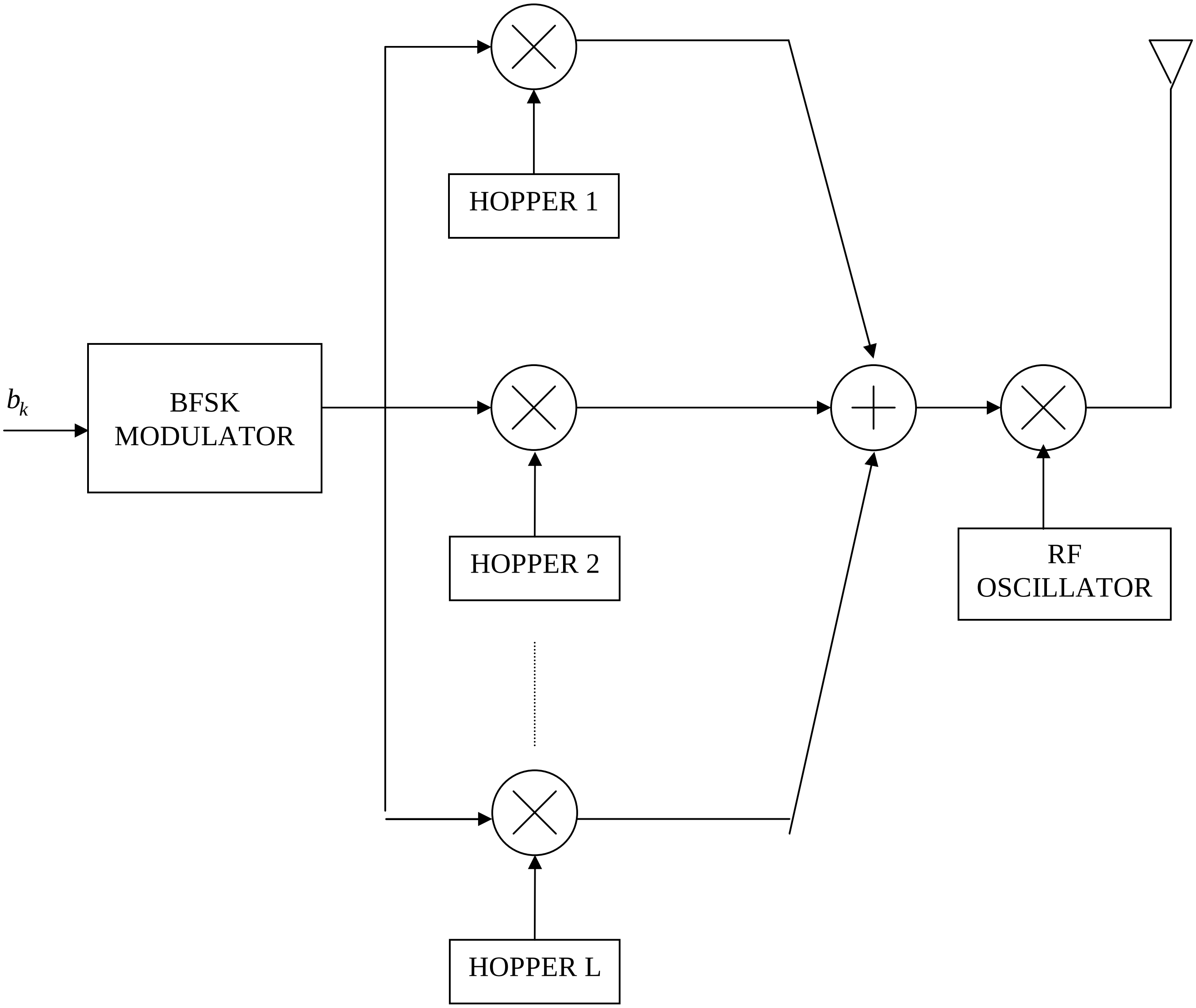

Figure 5.2 BLOCK DIAGRAM OF TRANSMITTER OF MCFH SYSTEM

The channel model is a wide– sense stationary uncorrelated scattering model. The low-pass equivalent impulse response of the l^{th} diversity channel may be written as:-

$$c_l(t;\tau) = \alpha_l(t;\tau)\exp\left[j\xi_l(t;\tau)\right] \quad where\ l = 0,1,2,3,\ldots\ldots\ldots\ldots\ldots\ldots\ldots, L-1 \tag{5.3}$$

where $\alpha_l(t;\tau)$ are independent and identically distributed Ricean random processes over $[0, 2\Pi]$. The autocorrelation function of the WSSUS channel is given as

$$R_c(\Delta;\tau;\tau') = (1/2)E\left[c^*(t;\tau)c(t+\Delta t;\tau')\right]$$

$$R_c(\Delta t;\tau)\delta(\tau-\tau') \tag{5.4}$$

where * denotes a complex conjugate operation. Since the channel response for each diversity transmission is assumed to be i.i.d., the autocorrelation of each channel is same for all l, so that the subscript l is dropped in (5.4). If we let $\Delta t = 0$ in $R_c(\Delta t;\tau)$, the resulting autocorrelation function $R_c(0;\tau)$ is a multipath intensity profile, and denoted as $I_c(\tau)$. Assuming that the multipath intensity profile is time invariant, $R_c(\Delta t;\tau)$ may be represented as

$$R_c(\Delta t;\tau) = I_c(\tau)X_c(\Delta t) \tag{5.5}$$

Value of $X_c(\Delta t)$ can be taken from [12] as

$$X_c(\Delta t) = \frac{J_o(2\pi f_d \Delta t) + K\exp(j2f_d\Delta t)}{1+K} \tag{5.6}$$

where $J(^*)$ is the zeroth order Bessel function. Value of $I_c(\tau)$ for Ricean fading channel is given as [17]

$$I_c(\tau) = \frac{(\mu/T_m)\left[\exp(-\mu\tau/T_m) - \exp(-\mu)\right]}{1-(1+\mu)\exp(-\mu)}(1-K) + K\delta(\tau) \tag{5.7}$$

where μ is the decaying factor. Receiver block diagram are shown in figure 5.3 and 5.4. After down-converting and dehopping, the complex baseband equivalent of the received signal over the first symbol duration may be expressed

For FFH

$$r(t) = n_l(t) + \sum_{l=0}^{L-1} \int_0^{T_m} \sqrt{2S}\alpha_l(t;\tau)\exp\left[j\left\{2\pi b_o f_d t + \theta_l(t;\tau)\right\}\right] d\tau . p_{T_h}(t - lT_h) \qquad (5.8)$$

For MCFH

$$r(t) = n_l(t) + \sum_{l=0}^{L-1} \int_0^{T_m} \sqrt{2S}\alpha_l(t;\tau)\exp\left[j\left\{2\pi b_o f_d t + \theta_l(t;\tau)\right\}\right] d\tau \qquad (5.9)$$

where T_m is the maximum delay spread of each diversity channel. $n_l(t)$ represents a background noise and modeled as a low-pass equivalent additive white Gaussian noise (AWGN) process with PSD n_l. We assume that data symbol b_0 is either +1 or –1 with equal probability. Without loss of generality, it is assumed that data symbol is +1 hereafter. A non-coherent detector demodulates each diversity reception. A noncoherent detector consists of two branch of correlator followed by an envelope detector as shown in figure no 5.5. We assume that the receiver is time synchronous to the first arriving signal. The two correlator outputs of the lth diversity reception are denoted, respectively, by $Z_{l,1}$ and $Z_{l,-1}$ and may be expressed as

$$Z_{l,1} = \frac{1}{T_h}\int_0^{T_h} n_l(t)\exp(-j2\pi f_d t)dt + \frac{1}{T_h}\int_0^{T_m}\int_\tau^{T_h} \sqrt{2S}\alpha_l(t;\tau)\exp\left[j\theta_l(t;\tau)\right] dt d\tau \qquad (5.10)$$

$$Z_{l,-1} = \frac{1}{T_h}\int_0^{T_h} n_l(t)\exp(j2\pi f_d t)dt + \frac{1}{T_h}\int_0^{T_m}\int_\tau^{T_h}\sqrt{2S}\alpha_l(t;\tau)\exp\left[j\theta_l(t;\tau)\right]\exp(j2\pi\Delta f t)\,dt\,d\tau \quad (5.11)$$

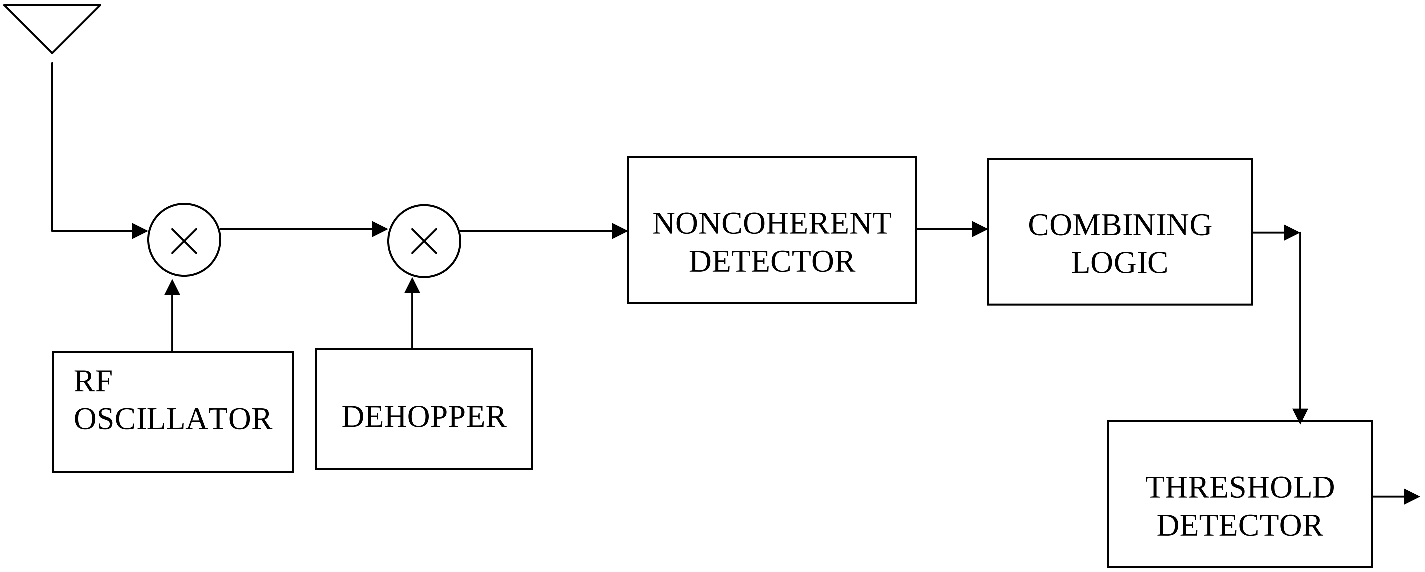

Figure5.3 BLOCK DIAGRAM OF RECEIVER OF FFH SYSTEM

In static environment, when symbol +1 is transmitted in the absence of noise, $Z_{l,-1}$ is zero if an orthogonal BFSK is employed. However, in fading environment, $Z_{l,-1}$ is not zero, since multipath signal components and signal variation over one hop duration may destruct orthogonality. This term is represented as the second term of (5.11), which will be referred to, hereafter, as interference component. The first term in (5.10) and (5.11) represent an AWGN component. In case of Ricean fading channel $Z_{l,1}$ and $Z_{l,-1}$ will not remain zero mean because there is a line of sight component whose phase and amplitude are fix, so means, variances and correlation coefficient of $Z_{l,1}$ and $Z_{l,-1}$ are given by

$$E\left[Z_{l,1}\right]=\sqrt{2KS} \qquad (5.12)$$

$$E\left[Z_{l,-1}\right]=\frac{1}{\pi h}\sqrt{KS\left\{1-\cos\left(2\pi h\right)\right\}} \qquad (5.13)$$

$$\sigma^2{}_{l,1}=\frac{1}{2}E\left[\left|Z_{l,1}\right|^2\right]=\frac{2S}{T_h}\int_0^{T_m}\int_0^{T_h-\tau}R_c\left(t;\tau\right)\left(1-\frac{t+\tau}{T_h}\right)dtd\tau+\frac{N_l}{T_h}-2KS \qquad (5.14)$$

$$\sigma^2{}_{l,-1}=\frac{1}{2}E\left[\left|Z_{l,-1}\right|^2\right]=\frac{2S}{T_h}\int_0^{T_m}\int_0^{T_h-\tau}R_c\left(t;\tau\right)\cos\left(2\pi\Delta ft\right)\left(1-\frac{t+\tau}{T_h}\right)dtd\tau+\frac{N_l}{T_h}-\frac{KS\left\{1-\cos\left(2\pi h\right)\right\}}{\left(\pi h\right)^2} \qquad (5.15)$$

$$p_l=\frac{1}{2}E\left[Z^*{}_{l,1}Z_{l,-1}\right]/\,\sigma_{l,1}\sigma_{l,-1}=\left(\frac{S}{T_h{}^2}\int_0^{T_m}\int_0^{T_h}\int_0^{T_h}R_c\left(t_1-t_2;\tau\right)\exp\left(j2\pi\Delta ft_1\right)dt_1dt_2d\tau+\frac{N_l}{T_h{}^2}\int_0^{T_h}\exp\left(j2\pi\Delta ft\right)dt\right)/\,\sigma_{l,1}\sigma_{l,-1} \qquad (5.16)$$

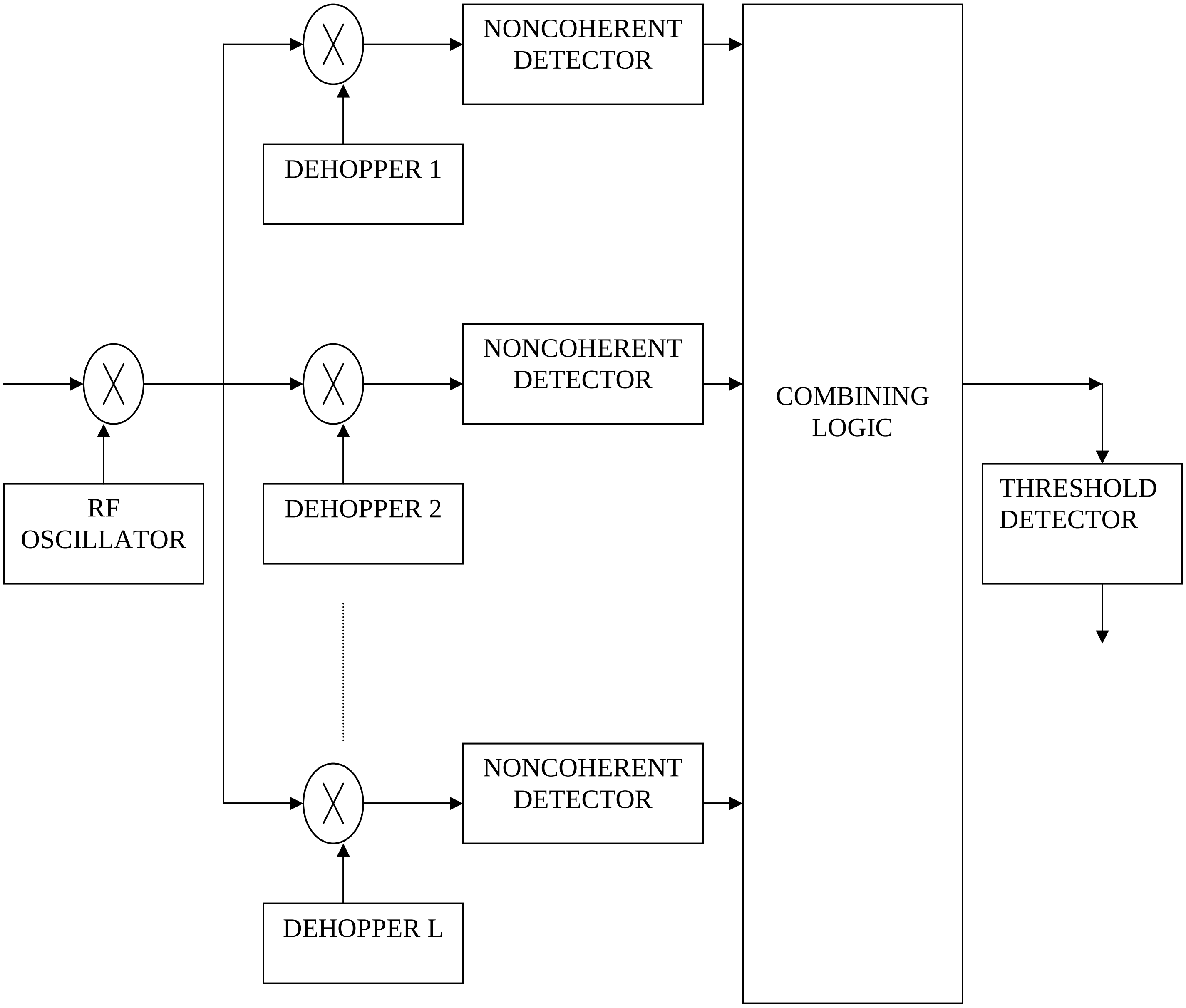

Figure 5.4 BLOCK DIAGRAM OF RECEIVER OF MCFH SYSTEM

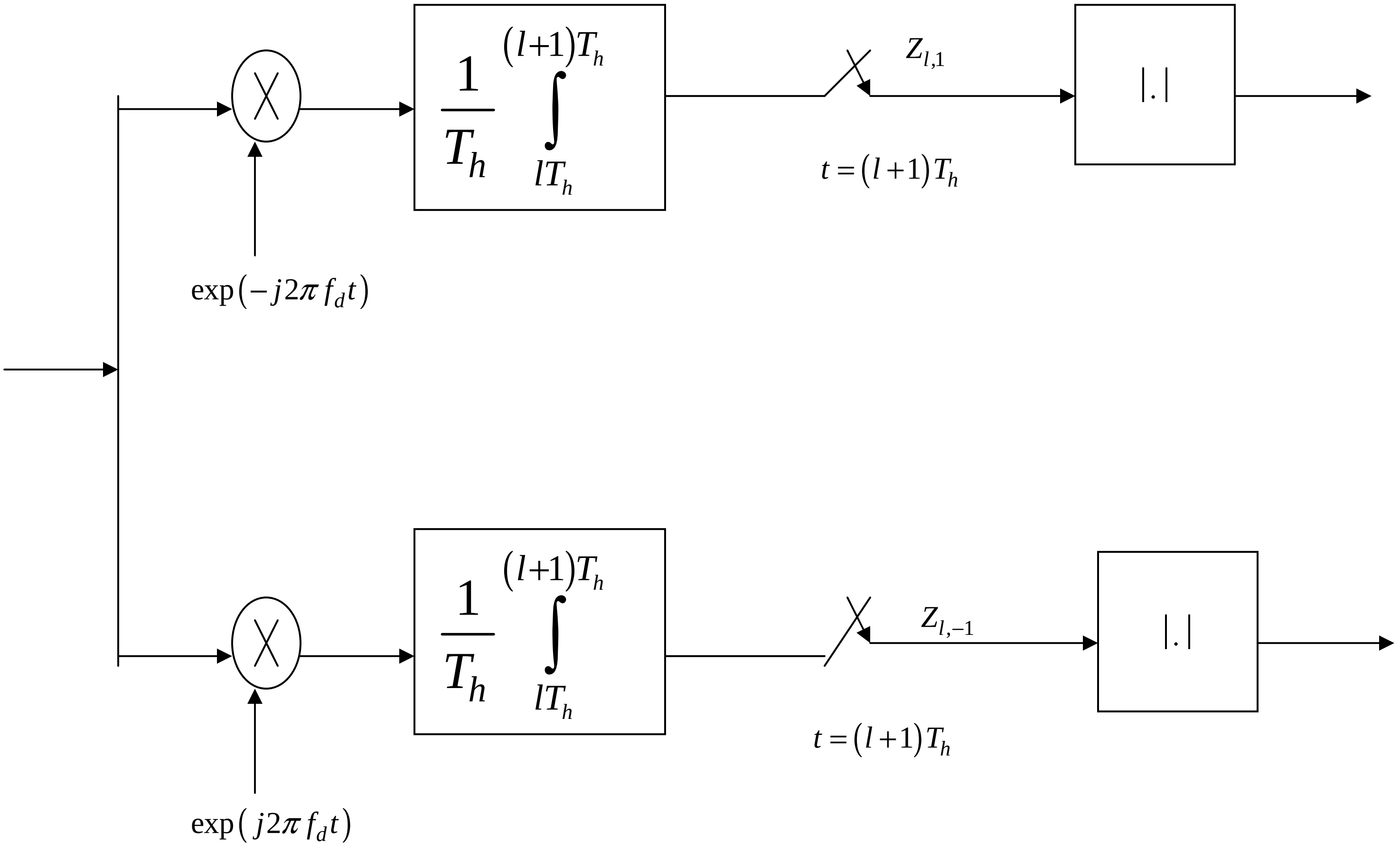

Figure 5.5 NON-COHERENT DETECTOR FOR THE l^{th} DIVERSITY

Decision is made based on L pairs of noncoherent detector outputs so they should be combined in some way to form decision statistic for the receiver. To find the optimum diversity combining rule based on the maximum-likelihood criterion, we should find the conditional joint probability function of noncoherent detector outputs, $R_{l,1}$ and $R_{l,-1}$ *for* $l \in \{0,1,2,3,4,..................,L-1\}$, conditioned on data symbol. $R_{l,1}$ and $R_{l,-1}$ are Ricean distributed function with Ricean factor K and variances $\sigma^2_{l,1}$ and $\sigma^2_{l,-1}$ given by equation (5.14) and (5.15). This pdf is referred to as a likelihood function. Decision rule used is same as in [4] i.e.

$$\sum_{0}^{L-1}\frac{\sigma^2_{l,1}-\sigma^2_{l,-1}}{\sigma^2_{l,1}\sigma^2_{l,-1}\left(1-\left|p_l\right|^2\right)}\left(R_{l,1}{}^2-R_{l,-1}{}^2\right)\underset{\underset{<}{b_o=-1}}{\overset{\overset{b_o=+1}{>}}{}}0 \qquad (5.17)$$

Based on (5.17), the probability of error for optimally combined signal may be expressed as:-

$$P_e=\frac{1}{2\pi}\int_{-\infty}^{0}p\left(D\middle|b_o=+1\right)dD \qquad (5.18)$$

where D is the decision variable defined as $D=D_1+D_2+D_3+\ldots\ldots\ldots\ldots\ldots\ldots+D_{L-1}$ and D_1 is defined as $D_1 = \left(R_{l,1}\right)^2-\left(R_{l,-1}\right)^2$.$p\left(D/b_o=+1\right)$ is the conditional pdf of D. It can be shown that the decision variable D in (5.18) may be viewed as a special case of general quadratic form. Equation (5.18) may be rewritten in terms of the characteristic function of D, which is denoted by $\varphi_D\left(jv\right)$, as

$$P_e=-\frac{1}{2\pi j}\int_{-\infty}^{\infty}\frac{\varphi_D\left(jv\right)}{v}dv \qquad (5.19)$$

since D is the sum L i.i.d. random variables D_1, the characteristic function of D is simply the Lth power of that of D_1. The characteristic function of D_1 is given as

$$\varphi_D\left(jv\right)=\frac{v_1v_2}{\left(v+jv_1\right)\left(v+jv_2\right)} \qquad (5.20)$$

where v_1 and v_2 are defined as

$$v_1 = -\frac{\sigma_1{}^2 - \sigma_{-1}{}^2}{4\sigma_1{}^2\sigma_{-1}{}^2\left(1-|p|^2\right)} + \sqrt{\left(\frac{\sigma_1{}^2 - \sigma_{-1}{}^2}{4\sigma_1{}^2\sigma_{-1}{}^2\left(1-|p|^2\right)}\right)^2 + \frac{1}{4\sigma_1{}^2\sigma_{-1}{}^2\left(1-|p|^2\right)}} \qquad (5.21)$$

$$v_2 = \frac{\sigma_1{}^2 - \sigma_{-1}{}^2}{4\sigma_1{}^2\sigma_{-1}{}^2\left(1-|p|^2\right)} + \sqrt{\left(\frac{\sigma_1{}^2 - \sigma_{-1}{}^2}{4\sigma_1{}^2\sigma_{-1}{}^2\left(1-|p|^2\right)}\right)^2 + \frac{1}{4\sigma_1{}^2\sigma_{-1}{}^2\left(1-|p|^2\right)}} \qquad (5.22)$$

Through the use of a conformal transformation from the v plane to the change in variable $u = -\left(v_1 / v_2\right).\left[v - jv_2 / v - jv_1\right]$ and the binomial series expansion of a term, (5.19) may be expressed as

$$P_e = \frac{1}{\left(1+\gamma\right)^{2L-1}} \sum_{l=0}^{2L-1} C_l{}^{2L-1}.\gamma^l \, \frac{1}{2\pi j} \oint_{\Gamma} \frac{1}{u^{L-1}\left(1-u\right)} du \qquad (5.23)$$

where Γ is a circular contour of radius less than unity that enclose the origin, and γ is defined as

$$\gamma = \frac{v_2}{v_1} = \frac{\sigma_1{}^2 - \sigma_{-1}{}^2 + \sqrt{\left(\sigma_1{}^2 + \sigma_{-1}{}^2\right)^2 - 4|p|^2\sigma_1{}^2\sigma_{-1}{}^2}}{\sigma_{-1}{}^2 - \sigma_1{}^2 + \sqrt{\left(\sigma_1{}^2 + \sigma_{-1}{}^2\right)^2 - 4|p|^2\sigma_1{}^2\sigma_{-1}{}^2}} \qquad (5.24)$$

For $l \geq L$, the contour integral is zero by Cauchy's theorem, since the integrad $1/u^{L-1}\left(1-u\right)$ is an analytic function in Γ. Thus, the probability of error expression in (5.23) may be simplified to

$$P_e = \sum_{l=0}^{L-1} C_l^{\,2L-1} \frac{\gamma^l}{(1+\gamma)^{2L-1}} \qquad (5.25)$$

Now BER is function of signal to noise ratio, diversity order, Ricean factor, delay spread, Doppler spread, normalized frequency deviation, bit duration and type of diversity i.e. FFH or MCFH. Depending on various values of these parameters BER can be plotted using Matlab 7 [18,19].

5.3 SYSTEM MODELING OF FFH AND MCFH FOR DBPSK

Considered system is frequency hopping spread spectrum system with differential binary phase shift keying (DBPSK) modulation technique, noncoherent detection, diversity order L. Transmitter block diagram of FFH and MCFH systems are shown, respectively, in figure 5.6 and 5.7. The complex baseband equivalent of the transmitted signal for each system can be represented as

For FFH system: -

$$s(t) = \sum_{k=0}^{\infty} \sum_{l=0}^{L-1} g(t) \exp\left[j\left\{ 2\pi f_{l,k} + \varphi_{l,k} + \pi(n-1) \right\} \right] p_{T_h}(t - kT - lT_h) \qquad (5.26)$$

For MCFH system: -

$$s(t) = \sum_{k=0}^{\infty} \sum_{l=0}^{L-1} g(t) \exp\left[j\left\{ 2\pi f_{l,k} + \varphi_{l,k} + \pi(n-1) \right\} \right] p_{T_h}(t - lT_h) \qquad (5.27)$$

where $g(t)$ is the transmit baseband signal, T is the symbol duration, T_h is the hop duration. $f_{l,k}$ and $\varphi_{l,k}$ are respectively, the hop frequency and random phase for the l^{th} diversity transmission of the k^{th} symbol. $n \in \{1,2\}$ is the k^{th} data symbol, and $p_\lambda(t) = 1 \ for \ t \in (0,\lambda)$ and zero, otherwise.

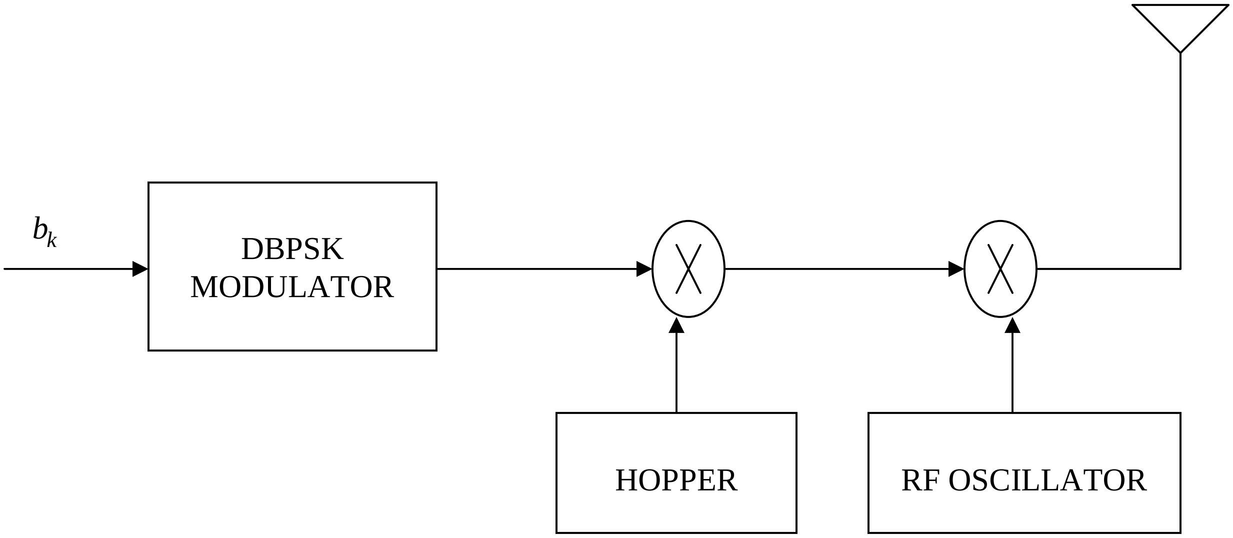

Figure 5.6 BLOCK DIAGRAM OF TRANSMITTER OF FFH SYSTEM

The channel model is a wide-sense stationary uncorrelated scattering model. The low-pass equivalent impulse response of the l^{th} diversity channel may be written as

$$c_l(t;\tau) = \alpha_l(t;\tau)\exp\left[j\xi_l(t;\tau)\right] \quad where\ l = 0,1,2,3,.....................,L-1 \tag{5.28}$$

where $\alpha_l(t;\tau)$ are independent and identically distributed Rayleigh random processes over $[0,2\Pi]$. The autocorrelation function of the WSSUS channel is given as

$$R_c(\Delta;\tau;\tau') = (1/2)E\left[c^*(t;\tau)c(t+\Delta t;\tau')\right]$$
$$R_c(\Delta t;\tau)\delta(\tau-\tau') \tag{5.29}$$

where $*$ denotes a complex conjugate operation. Since the channel response for each diversity transmission is assumed to be i.i.d., the autocorrelation of each channel is same for all l, so that the subscript l is dropped in (5.29). If we let $\Delta t = 0$ in $R_c(\Delta t;\tau)$, the resulting autocorrelation function $R_c = (0;\tau)$ is a multipath intensity profile, and denoted as $Ic(\tau)$.

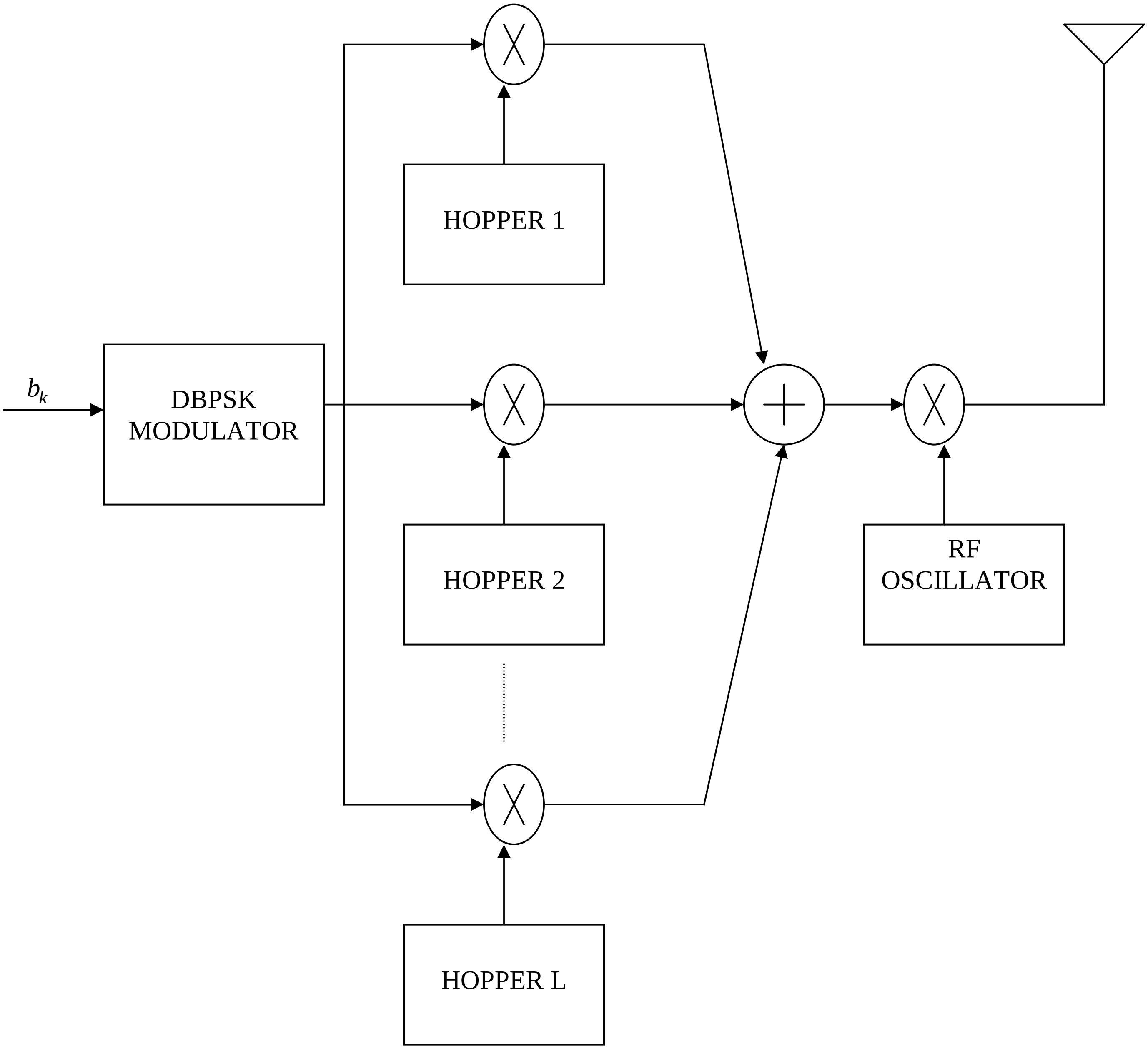

Figure 5.7 BLOCK DIAGRAM OF TRANSMITTER OF MCFH SYSTEM

Assuming that the multipath intensity profile is time invariant, $R_c = (\Delta t; \tau)$ may be represented as

$$R_c(\Delta t; \tau) = I_c(\tau) X_c(\Delta t) \tag{5.30}$$

Value of $X_c(\Delta t)$ can be taken from [12] as

$$X_c(\Delta t) = J_o(2\pi f_d \Delta t) \tag{5.31}$$

where $J(^*)$ is the zeroth order Bessel function. Value of $I_c(\tau)$ for Rayleigh fading channel is given as[11]

$$I_c(\tau) = \frac{(\mu / T_m)\left[\exp(-\mu\tau / T_m) - \exp(-\mu)\right]}{1-(1+\mu)\exp(-\mu)} \tag{5.32}$$

where μ is the decaying factor.

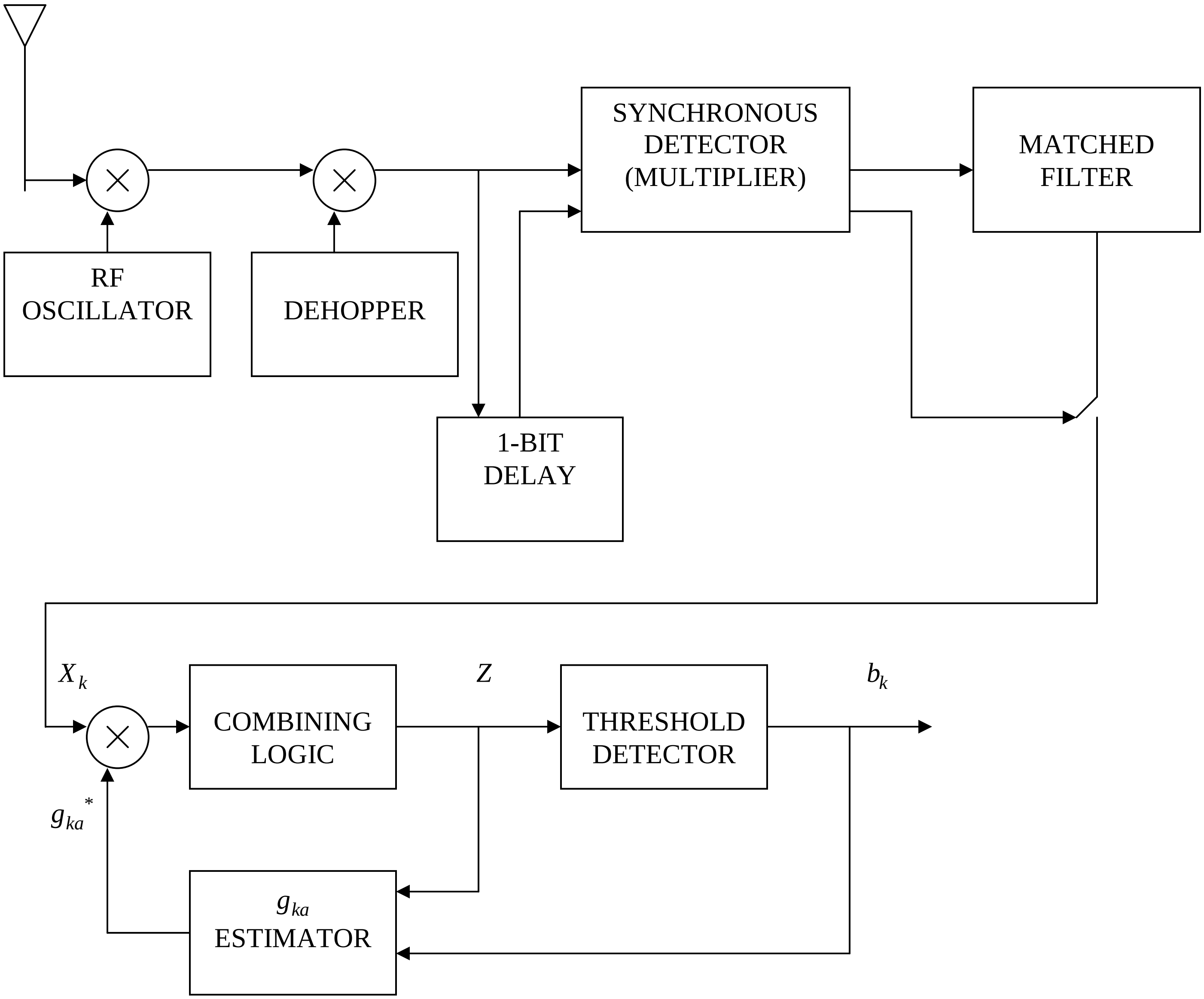

Figure 5.8 BLOCK DIAGRAM OF RECEIVER OF FFH SYSTEM

Assume that each of the channels corrupts the signaling waveform transmitted through it by introducing a multiplicative gain and phase shift, represented by the complex valued number g_k, and an additive noise $n(t)$.However g_k is not constant throughout the chip duration but it can be considered constant for slow varying fading channels. Thus, when the transmitted waveform is $s(t)$, the waveform received over the k^{th} channel is

$$r(t) = g_k s(t) + n(t) \qquad 0 \le t \le T_h, \quad k = 1, 2, 3, ..., L \tag{5.33}$$

$$g_k = \frac{1}{T_h} \int_0^{T_m} \int_\tau^{T_h} \alpha_l(t;\tau) \exp\left(j\theta_l(t;\tau)\right) dt d\tau \tag{5.34}$$

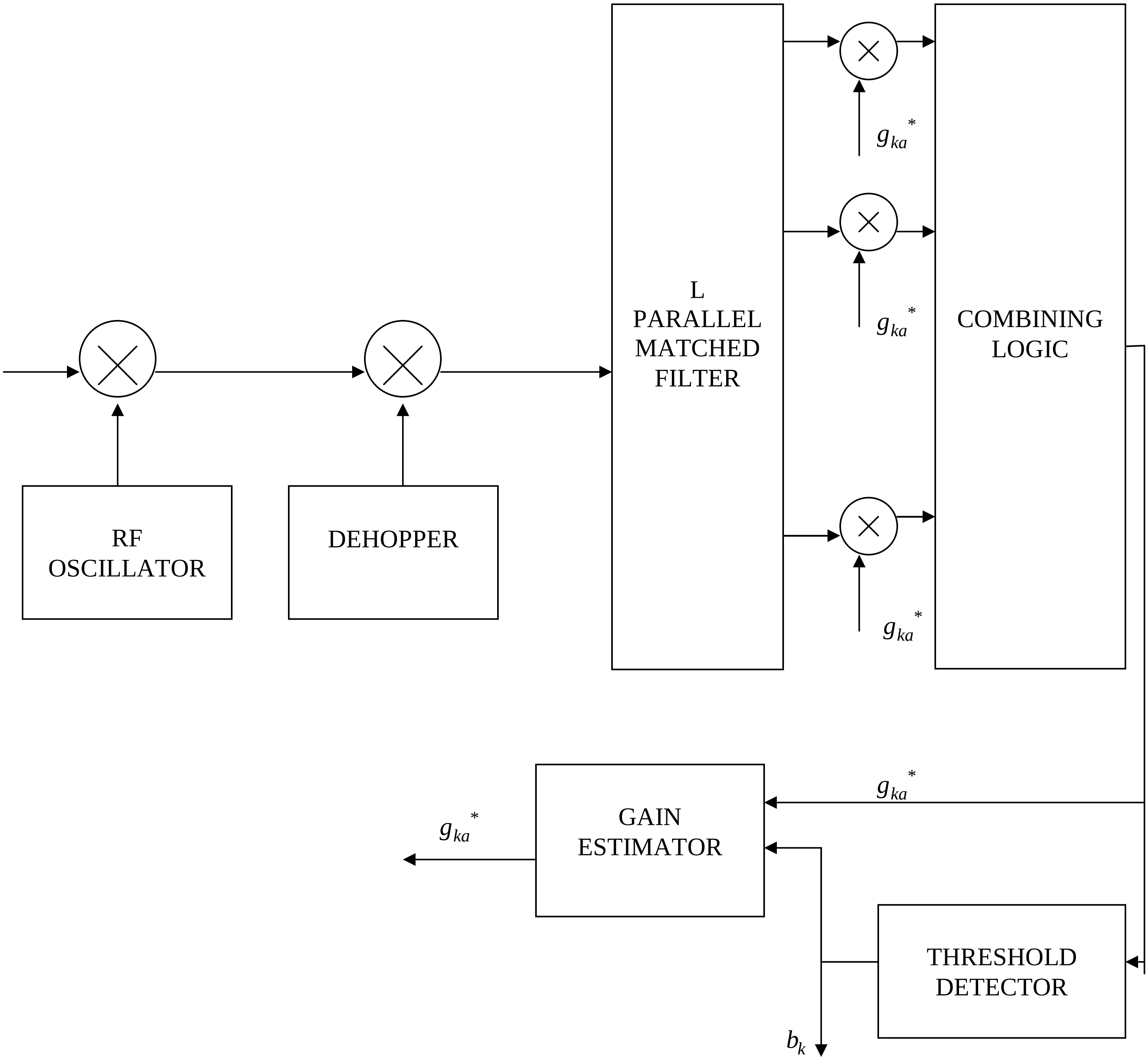

Figure 5.9 BLOCK DIAGRAM OF RECEIVER OF MCFH SYSTEM

The noises $n(t)$ are assumed to be sample functions of a stationary white Gaussian random process with zero mean and autocorrelation function $N_o\delta(\tau)$, where N_o is the value of the spectral density. These sample functions are assumed to be mutually statistically independent.

At the demodulator, $r(t)$ is passed through a filter whose impulse response is matched to the waveform $g(t)$. The output of this filter, sampled at time $t = T_h$ is denoted as

$$X_k = 2\xi g_k \exp\left[j\pi(n-1)\right] + N_k \tag{5.35}$$

where ξ is the transmitted signal energy per channel and N_k is the noise sample from the k^{th} filter. In order for the demodulator to decide which of the two phases were transmitted in the signaling interval $0 \le t \le T$, it attempts to undo the phase shift introduced by each channel. In practice, this is accomplished by multiplying the matched filter output X_k by the complex conjugate of an estimate g_{ka} of the channel gain and phase shift. The result is a weighted and phase shifted sampled output from the k^{th} channel filter, which is then added to the other $L-1$ channel filters.

The estimate g_{ka} of the gain and phase shift of the k^{th} channel is assumed to be derived by undoing the modulation on the information bearing signals received in previous signaling intervals. If one knew the information component contained on the matched filter output then an estimate of g_k could be obtained by properly normalizing this output. For example, the information component in the filter output given by (5.35) is $2\xi g_k \exp\left[j\pi(n-1)\right]$, and hence, the estimate is

$$g_{ka} = \frac{X_k}{2\xi}\exp\left[-j\pi\left(n-1\right)\right] = g_k + \frac{N_{ka}}{2\xi} \tag{5.36}$$

where $N_{ka} = N_k \exp\left[-j\pi\left(n-1\right)\right]$ and pdf of N_{ka} is identical to the pdf of N_k, an estimate that is obtained from the information bearing signal in this manner is called a clairvoyant estimate. The estimate can be improved by extending the time interval over which it is formed to include several prior signaling intervals, as a result of extending the measurement interval, the signal to noise ratio in the estimate of g_k is increased. The clairvoyant estimate that is obtained from the information bearing signal by undoing the modulation over the infinite past is

$$g_{ka} = g_k + \frac{\sum_{i=1}^{\infty} c_i N_{ki}}{2\xi \sum_{i=1}^{\infty} c_i} \tag{5.37}$$

As indicated, the demodulator forms the product between $g_{ka}{}^{*}$ and X_k and adds this to the products of the other $L-1$ channels. The random variable that results is

$$Z = \sum_{k=1}^{L} X_{ka} g_{ka}{}^{*} = \sum_{k=1}^{L} X_k Y_k{}^{*} = Z_r + jZ_i \tag{5.38}$$

where, by definition, $Y_k = g_{ka}$, $Z_r = \mathrm{Re}\left(Z\right)$, and $Z_i = \mathrm{Im}\left(Z\right)$ the phase of Z is the decision variable. This is simply

$$\theta = \tan^{-1}\left(\frac{Z_i}{Z_r}\right) = \tan^{-1}\left[\frac{\mathrm{Im}\left(\sum_{k=1}^{L} X_k Y_k^{*}\right)}{\mathrm{Re}\left(\sum_{k=1}^{L} X_k Y_k^{*}\right)}\right] \tag{5.39}$$

The following derivation is based on the assumption that the transmitted signal phase is zero, i.e., $n = 1$. If desired, the pdf of θ conditional on any other transmitted signal phase can s obtained by translating $p(\theta)$ by the angle $\pi(n-1)$. We also assume that the complex valued number g_k, which characterize the L channels, are mutually statistically independent and identically distributed zero mean Gaussian random variables. For this condition value of $p(\theta)$ comes out [15]:

$$p(\theta) = \frac{(-1)^{L-1}\left(1-|\mu|^2\right)^L}{2\pi(L-1)!}\left\{\frac{\delta^{L-1}}{\delta b^{L-1}}\left[\frac{1}{b-|\mu|^2\cos^2(\theta-\varepsilon)} + \frac{|\mu|\cos^2(\theta-\varepsilon)}{\left[b-|\mu|^2\cos^2(\theta-\varepsilon)\right]^{3/2}}\cos^{-1}\left(\frac{-|\mu|\cos(\theta-\varepsilon)}{b^{1/2}}\right)\right]\right\}_{b=1} \tag{5.40}$$

In this case, the probability of a binary digit error is obtained by integrating the pdf $p(\theta)$ over the range$1/2\pi < \theta < 3\pi$. Since $p(\theta)$ is an even function and the signals are priori equally likely, this probability can be written as

$$P_e = 2\int_{\frac{\pi}{2}}^{\pi} p(\theta)\, d\theta \tag{5.41}$$

It is easily derived from [15] that

$$P_e = \frac{1}{2}\left[1-\mu\sum\left(C^{2k}{}_k\right)\left(\frac{1-\mu^2}{4}\right)^k\right] \tag{5.42}$$

where $\mu = \gamma / (1+\gamma)$, and

$$\gamma = \frac{\xi}{N_o} E\left(|g_k|^2\right) \qquad k = 1, 2, 3, ..., L \qquad (5.43)$$

$$E\left(|g_k|^2\right) = \frac{2}{T_h} \int_0^{T_m} \int_0^{T_h - \tau} R_c(t;\tau)\left(1 - \frac{t+\tau}{T_h}\right) dt d\tau \qquad (5.44)$$

Now BER is function of signal to noise ratio, diversity order, delay spread, Doppler spread, bit duration and type of diversity i.e. FFH or MCFH. Depending on various values of these parameters BER can be plotted using Matlab 7 [19].

CHAPTER 6

RESULTS, CONCLUSION AND FUTURE SCOPE

6.1 RESULTS

To compare the performance of the fast frequency hopping spread spectrum system and multi carrier frequency hopping spread spectrum system probability of error equation (5.25) and (5.42) have been plotted for both systems. Values of input parameters are written below every graph. Figure 6.1 to 6.28 are graph for frequency hopping spread spectrum system with BFSK modulation technique in Ricean fading channel and figure. 6.29 to 6.52 are for frequency hopping spread spectrum system with DBPSK modulation technique in Rayleigh fading channel.

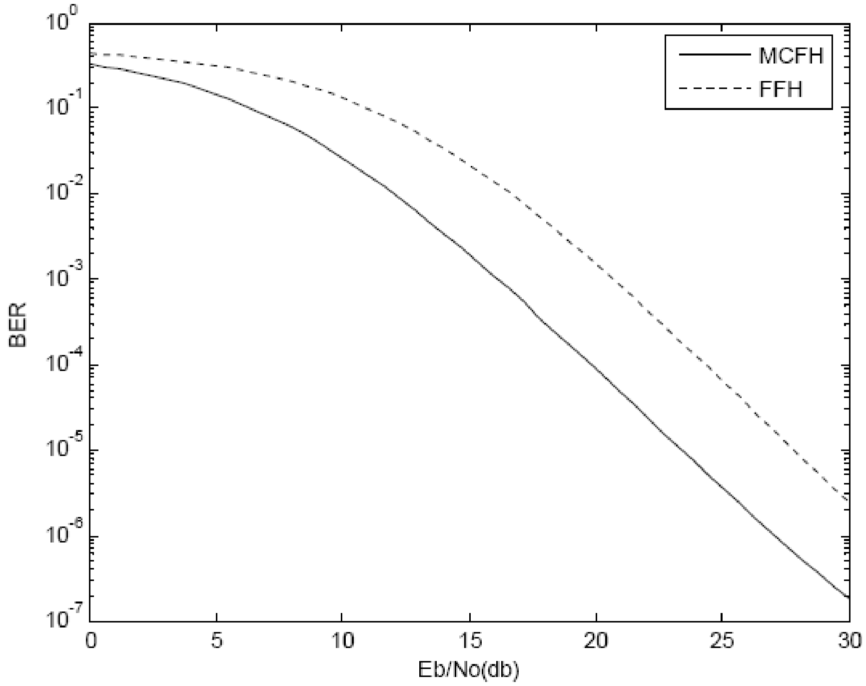

Figure 6.1. Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-4} second, Delay spread =$3*10^{-6}$ second, Doppler spread =50 Hz.

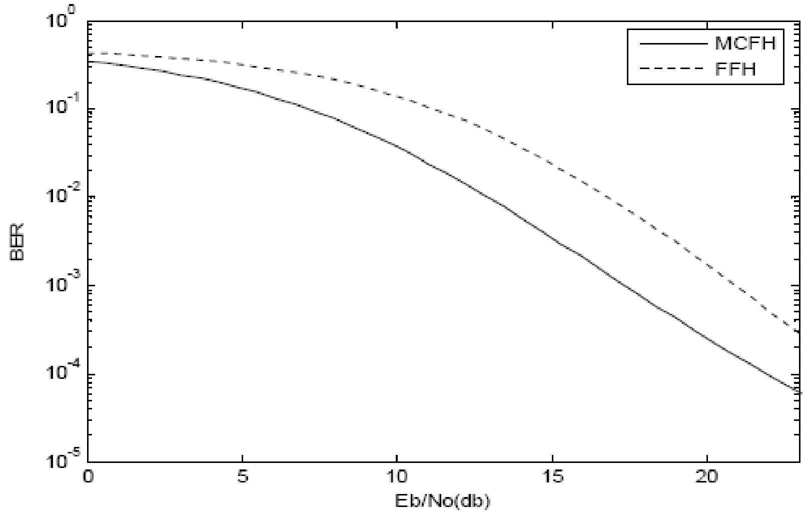

Figure 6.2. Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-4} second, Delay spread =$10*10^{-6}$ second, Doppler spread =50 Hz.

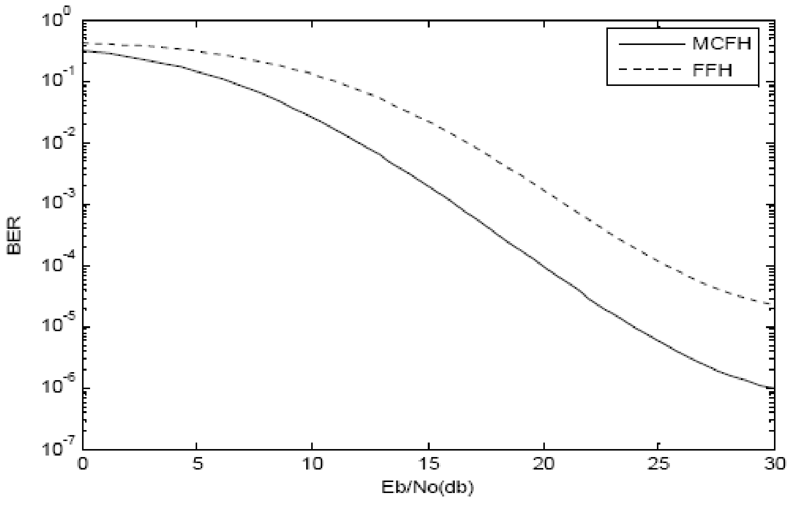

Figure 6.3. Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-4} second, Delay spread =$3*10^{-6}$ second, Doppler spread =500 Hz.

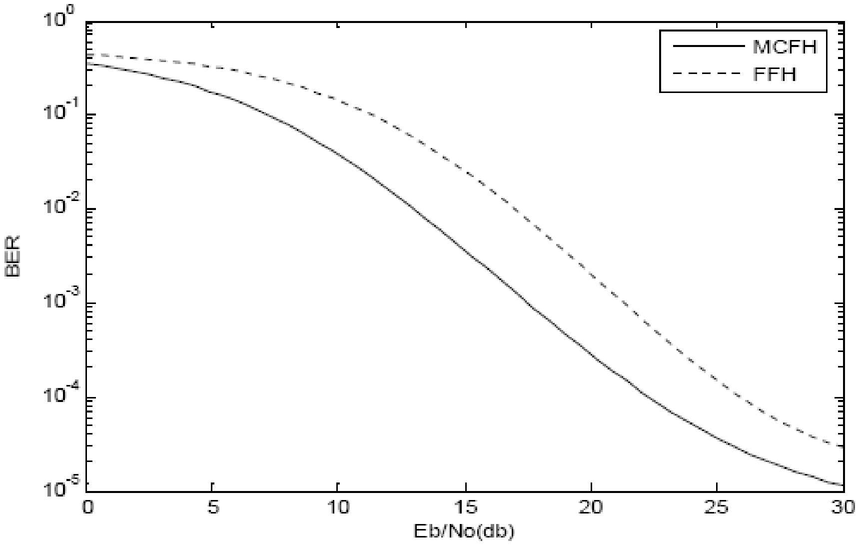

Figure 6.4. Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-4} second, Delay spread =$10*10^{-6}$ second, Doppler spread =500 Hz.

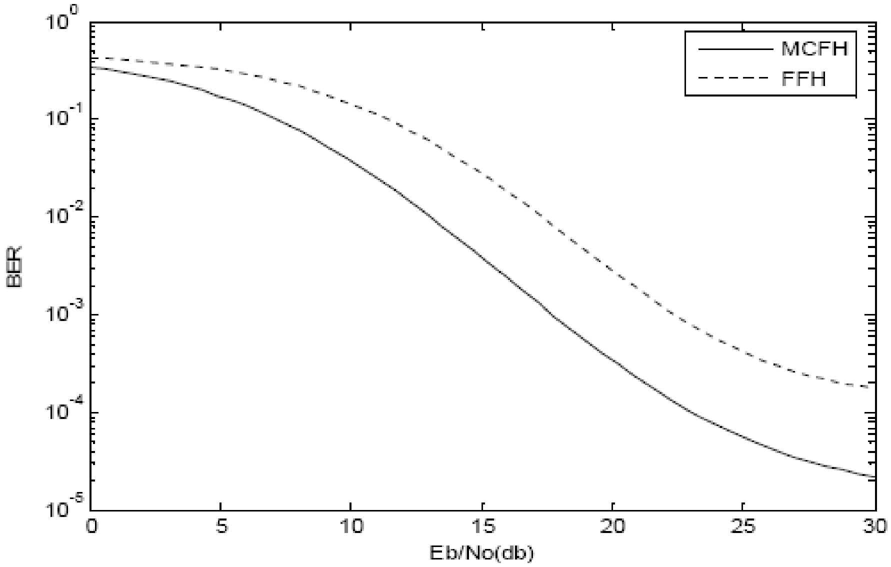

Figure 6.5. Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-4} second, Delay spread =$10*10^{-6}$ second, Doppler spread =1000 Hz.

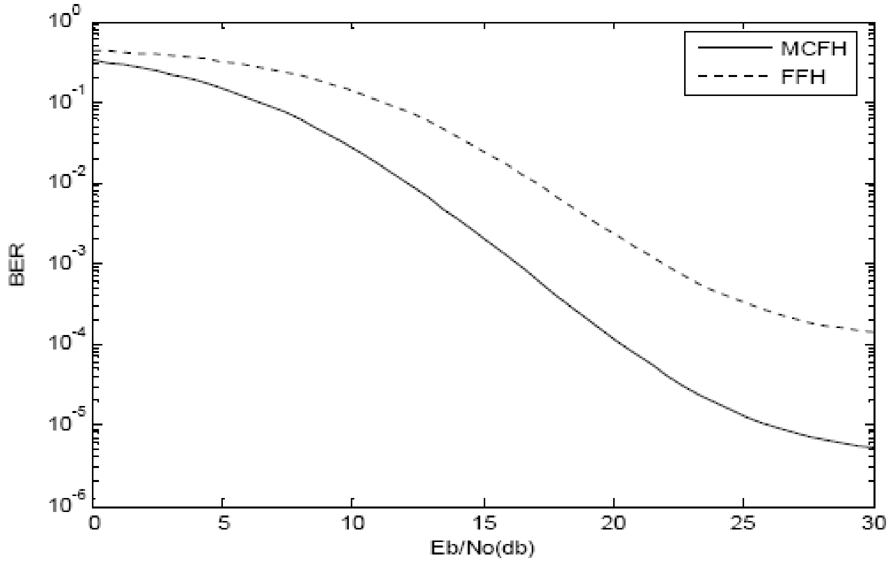

Figure 6.6. Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-4} second, Delay spread =$3*10^{-6}$ second, Doppler spread =1000 Hz.

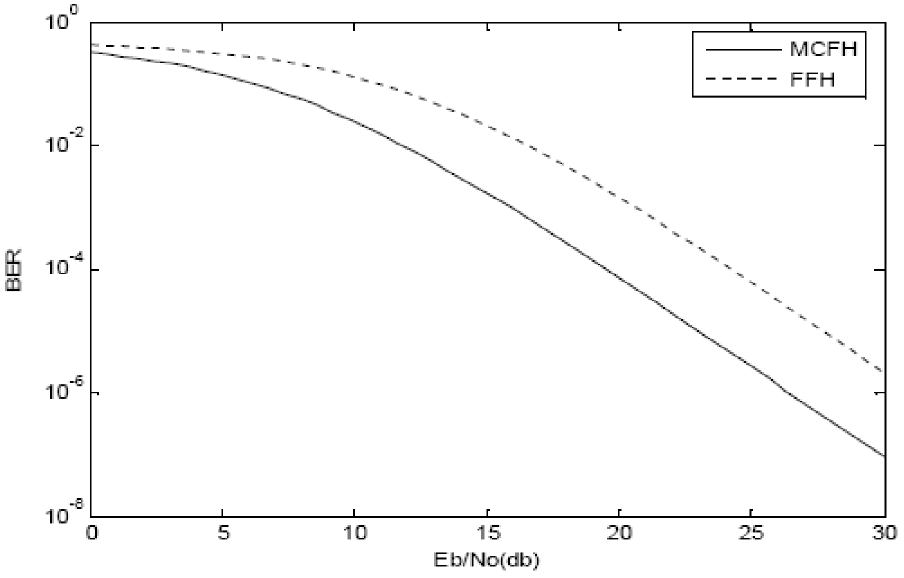

Figure 6.7. Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-6} second, Delay spread =$10*10^{-9}$ second, Doppler spread =50 Hz.

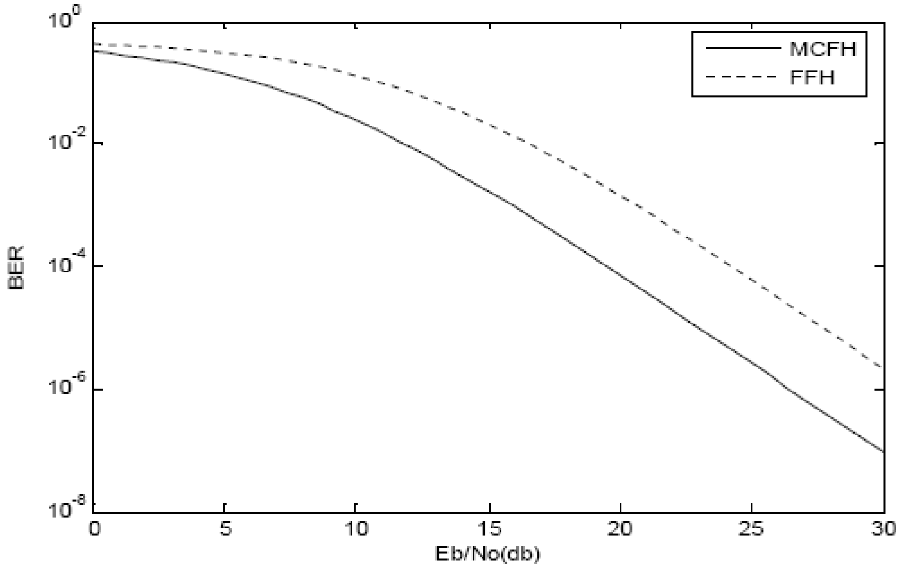

Figure 6.8. Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-6} second, Delay spread =10*10^{-9} second, Doppler spread =1000 Hz.

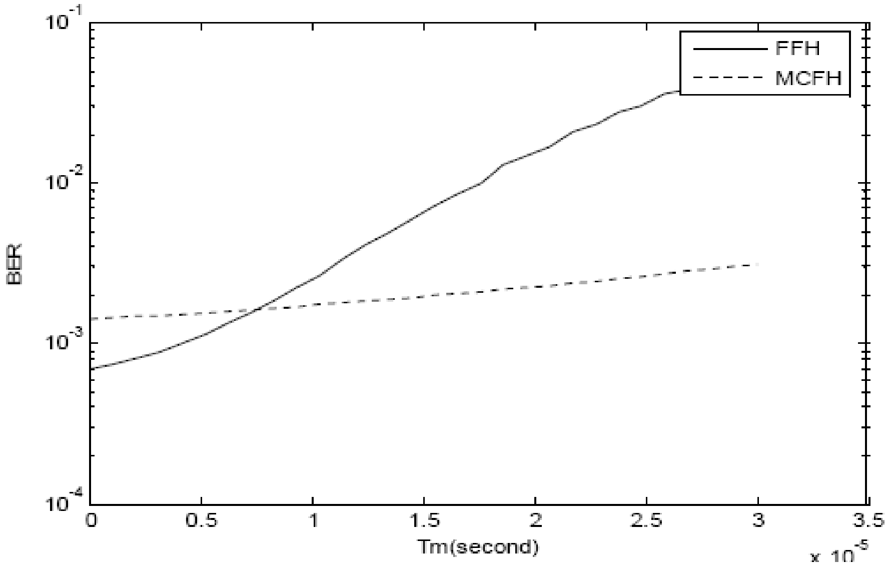

Figure 6.9. E_b/N_0 = 20db, Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-4} second, Doppler spread =10 Hz.

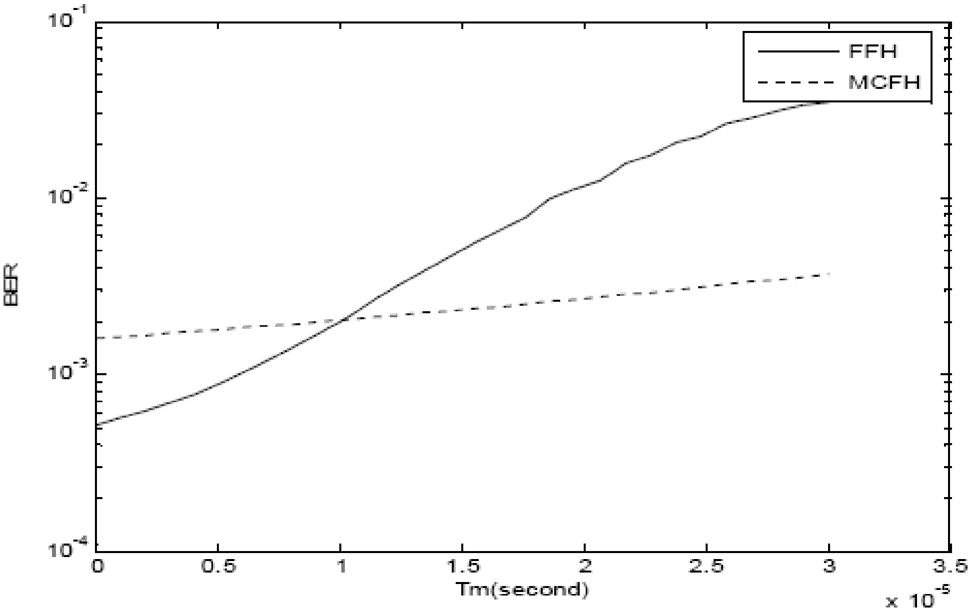

Figure 6.10. E_b/N_0 = 20db, Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-4} second, Doppler spread =500 Hz.

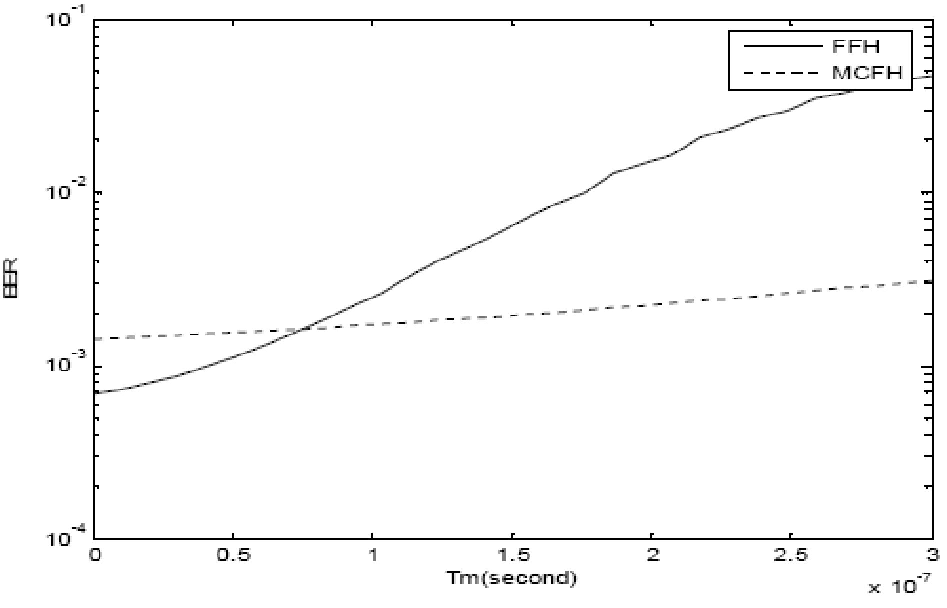

Figure 6.11. E_b/N_0 = 20db, Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-6} second, Doppler spread =10 Hz.

Bit error rate (BER) and signal-to-noise (E_b/N_o) plot is drawn for two techniques i.e fast frequency hopping (FFH) and multi-carrier frequency hopping (MCFH) techniques. Ricean factor, diversity order and normalized frequency deviation are kept constant while the parameter which varies are:-

- Bit Duration
- Delay Spread
- Doppler Spread

With increase in delay spread bit error rate decreases for a particular value of signal-to-noise ration for both fast frequency hopping and multi-carrier hopping techniques as shown in figure 6.1 and 6.2. For example if signal-to-noise ratio is 20 db bit error rate is 10^{-4} approximately in case of delay spread is $3*10^{-6}$ and for delay spread $10*10^{-6}$, it is less than 10^{-4}. For an increase in Doppler spread, bit error rate decreases.

On increasing bit duration bit error rate decreases as shown in figure 6.6 and 6.7. Bit error rate is less in multi-carrier frequency hopping technique as compare to fast frequency hopping technique.

Figure 6.9 shows the plot between bit error rate and maximum delay spread (T_m). As maximum delay spread increase bit error rate also increases. For fast frequency hopping technique plot is almost linear but for multi-carrier frequency hopping variation is very less.

By keeping bit duration constant i.e 10^{-4} if we increases the Doppler spread then BER decreases. Further on decrease in bit duration bit error rate decreases as shown in figure 6.11.

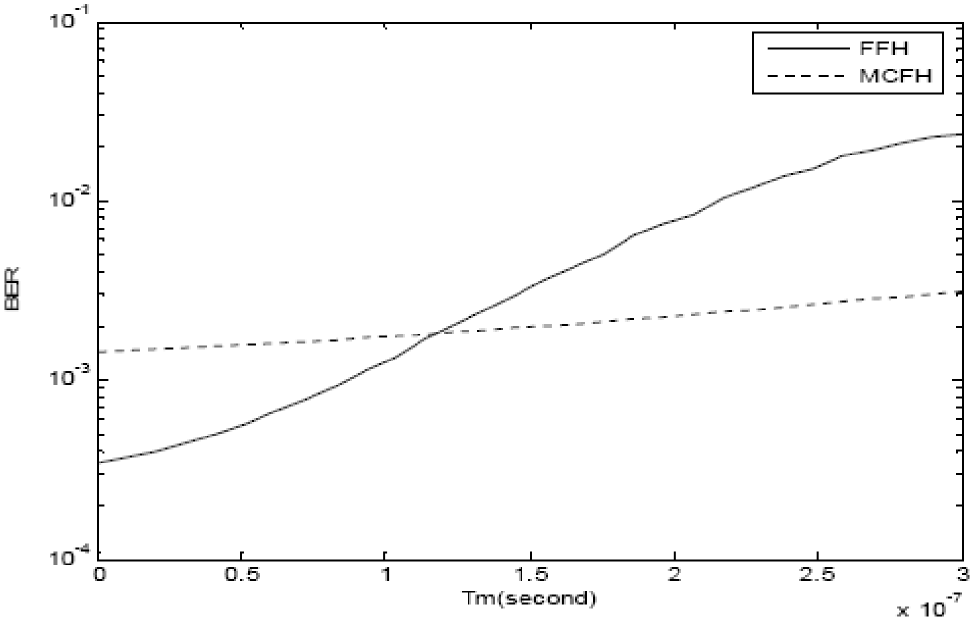

Figure 6.12. E_b/N_0 = 20db, Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-6} second, Doppler spread =1000 Hz.

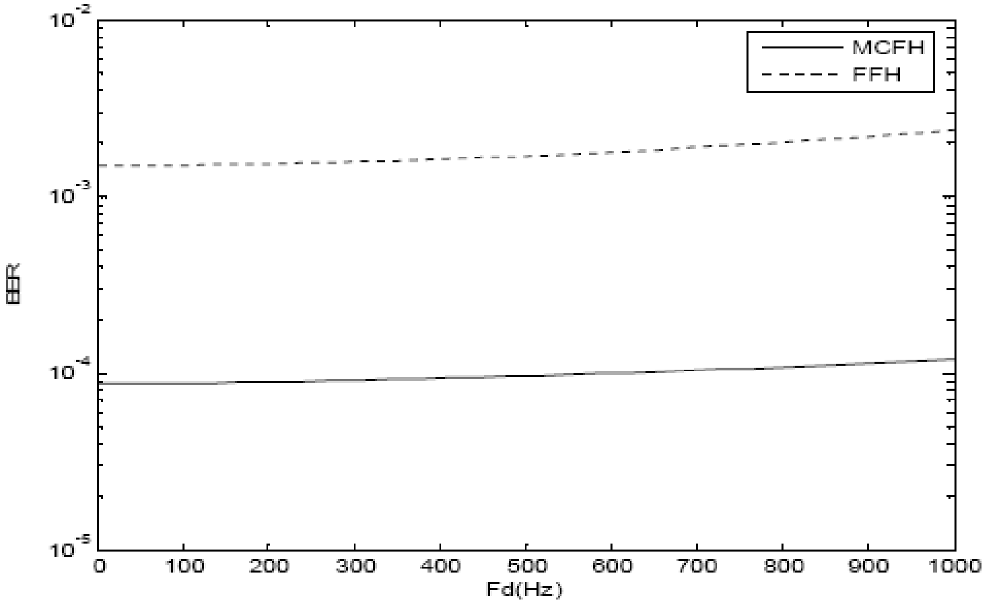

Figure 6.13. E_b/N_0 = 20db, Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-4} second, Delay spread =$3*10^{-6}$ second.

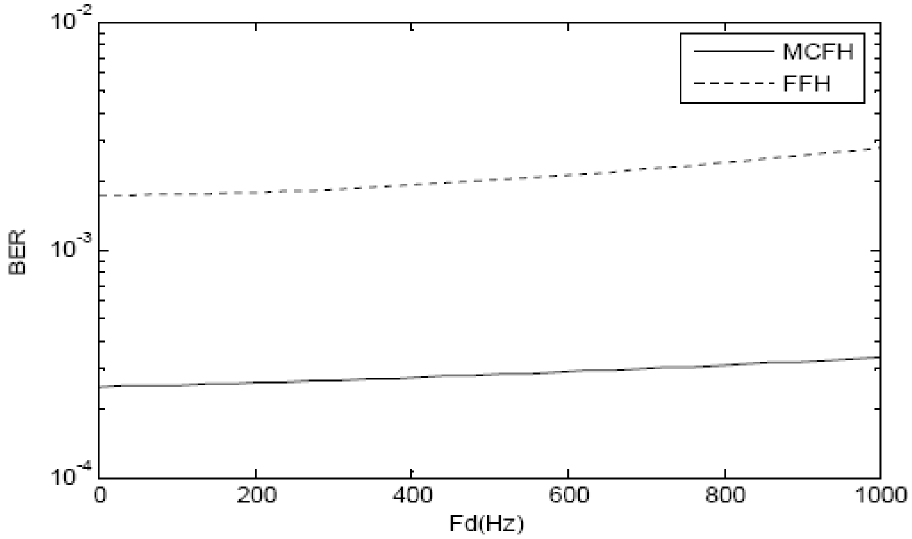

Figure 6.14. E_b/N_0 = 20db, Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-4} second, Delay spread =10^{-5} second.

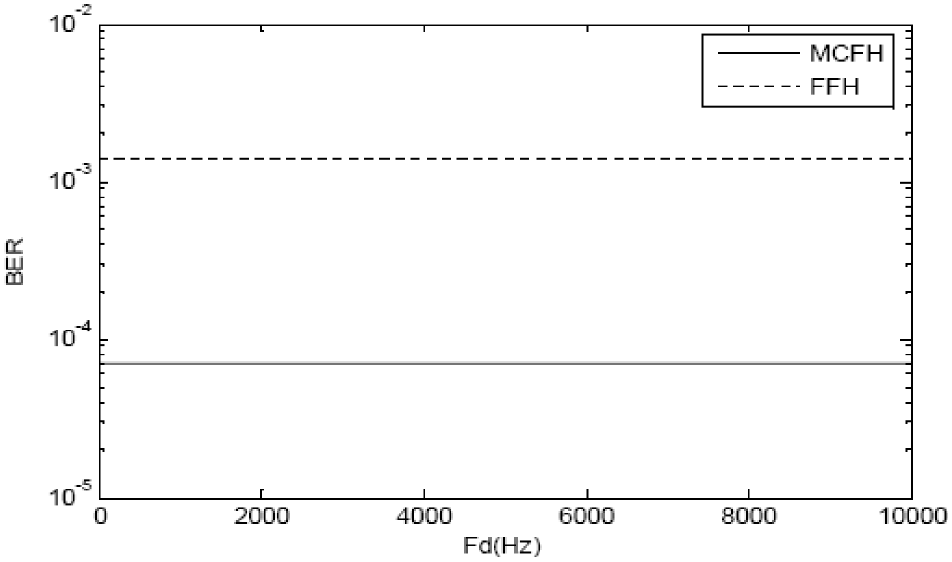

Figure 6.15. E_b/N_0 = 20db, Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-6} second, Delay spread =$3*10^{-9}$ second.

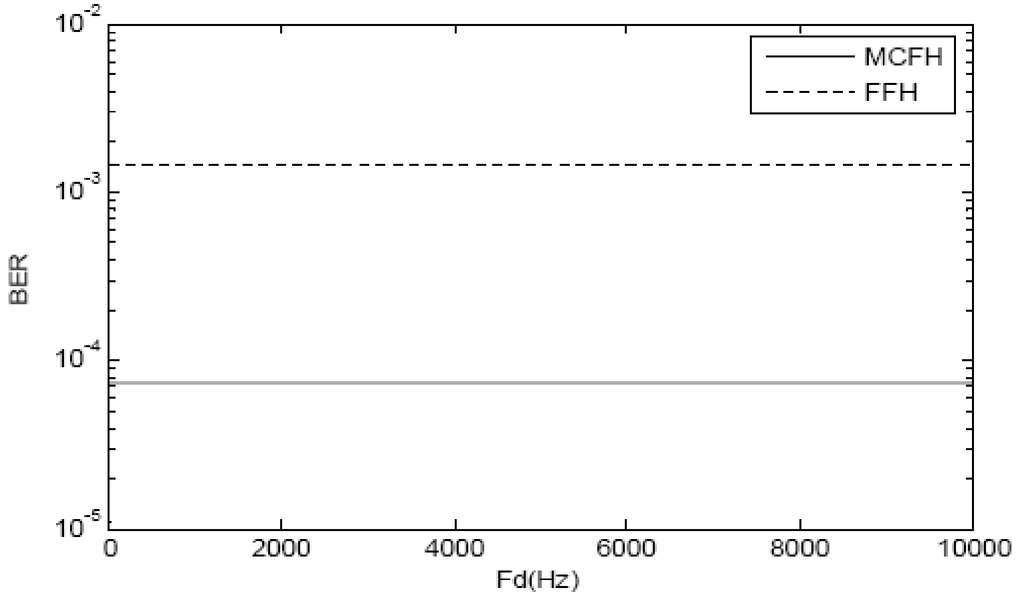

Figure 6.16. E_b/N_0 = 20db, Ricean factor = 0.5, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-6} second, Delay spread =10^{-8} second.

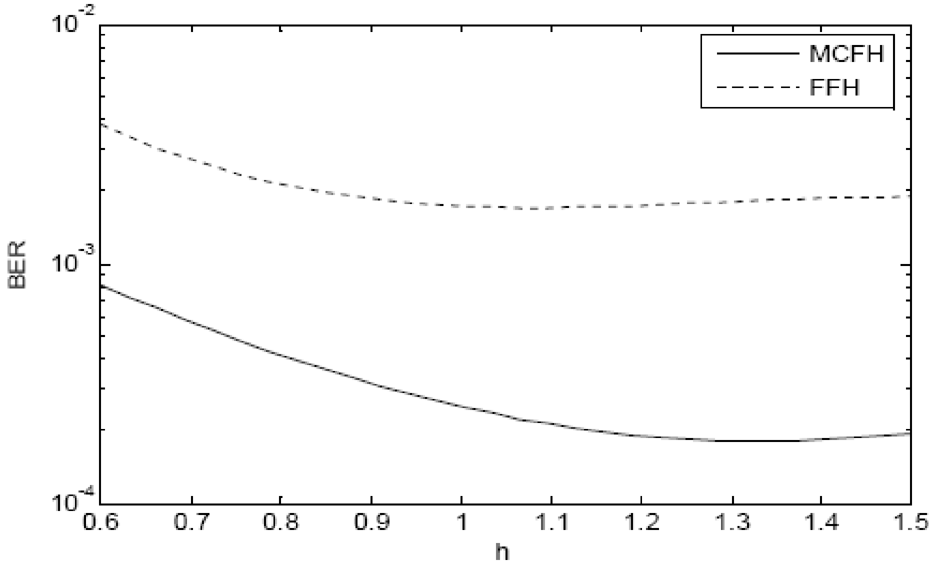

Figure 6.17. E_b/N_0 = 20db, Ricean factor = 0.5, Diversity order = 3, Bit duration = 10^{-4} second, Delay spread =10^{-5} second, Doppler spread = 10Hz.

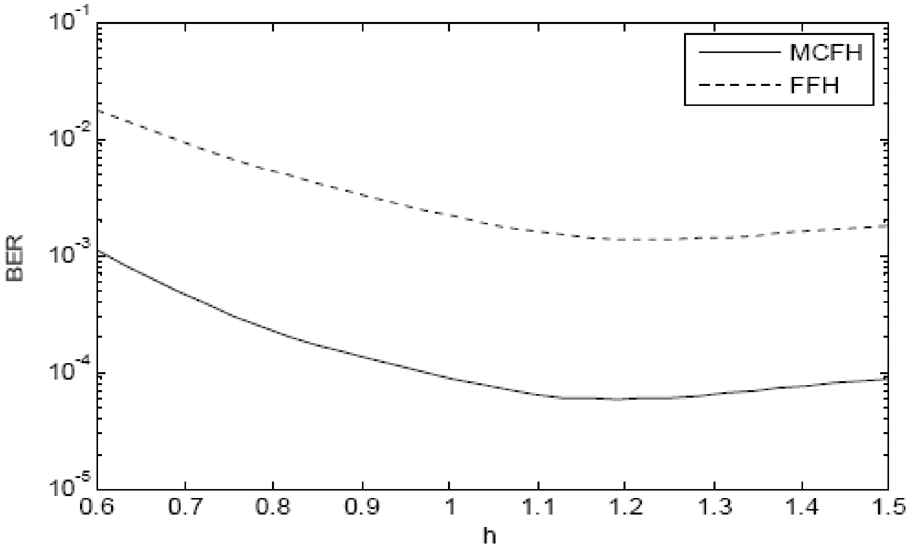

Figure 6.18. E_b/N_0 = 20db, Ricean factor = 0.5, Diversity order = 3, Bit duration = 10^{-4} second, Delay spread =10^{-8} second, Doppler spread = 1000Hz.

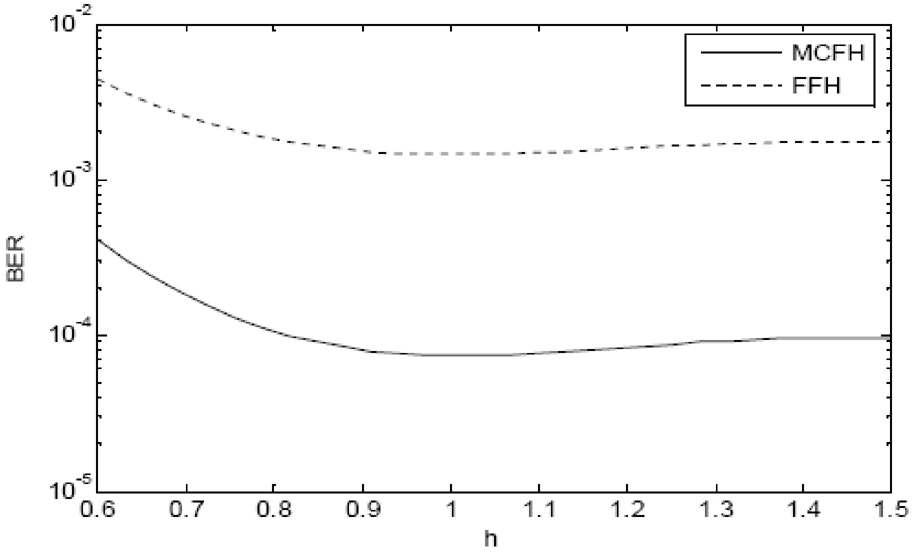

Figure 6.19. E_b/N_0 = 20db, Ricean factor = 0.5, Diversity order = 3, Bit duration = 10^{-6} second, Delay spread =10^{-8} second, Doppler spread = 10Hz.

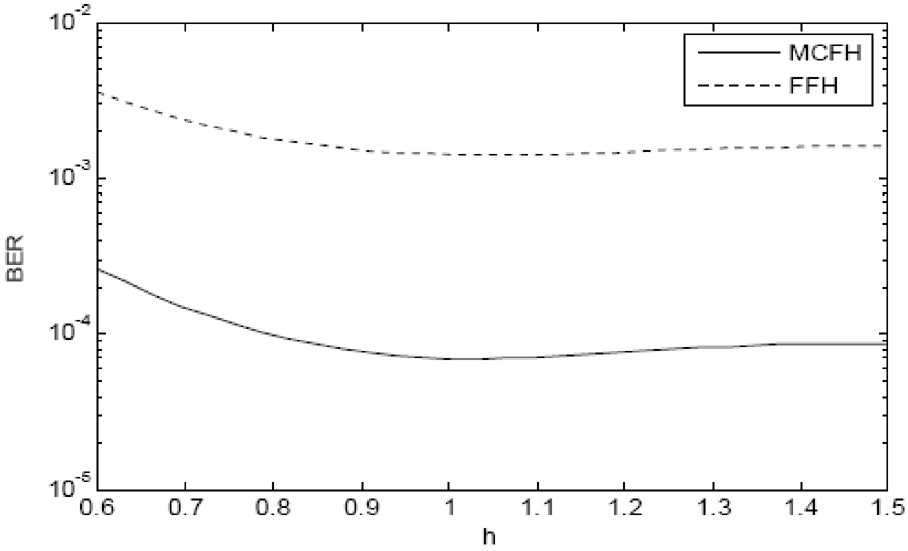

Figure 6.20. E_b/N_0 = 20db, Ricean factor = 0.5, Diversity order = 3, Bit duration = 10^{-6} second, Delay spread =10^{-11} second, Doppler spread = 10000Hz.

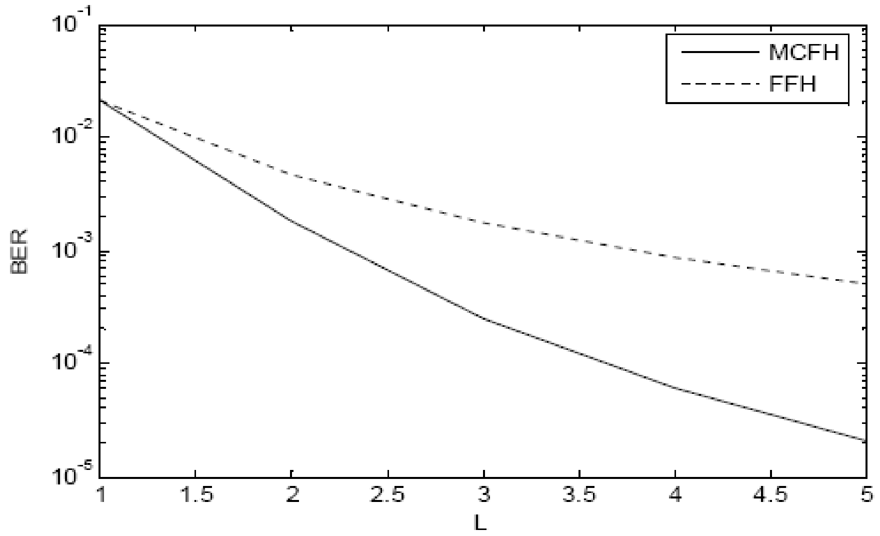

Figure 6.21. E_b/N_0 = 20db, Ricean factor = 0.5, Normalized frequency deviation = 1, Bit duration = 10^{-4} second, Delay spread =10^{-5} second, Doppler spread = 10Hz.

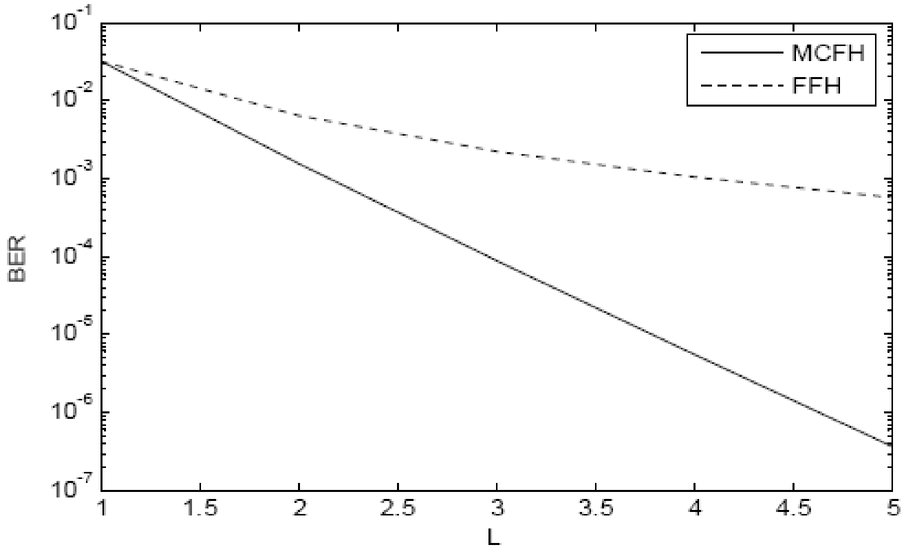

Figure 6.22. E_b/N_0 = 20db, Ricean factor = 0.5, Normalized frequency deviation = 1, Bit duration = 10^{-4} second, Delay spread =10^{-8} second, Doppler spread = 1000Hz.

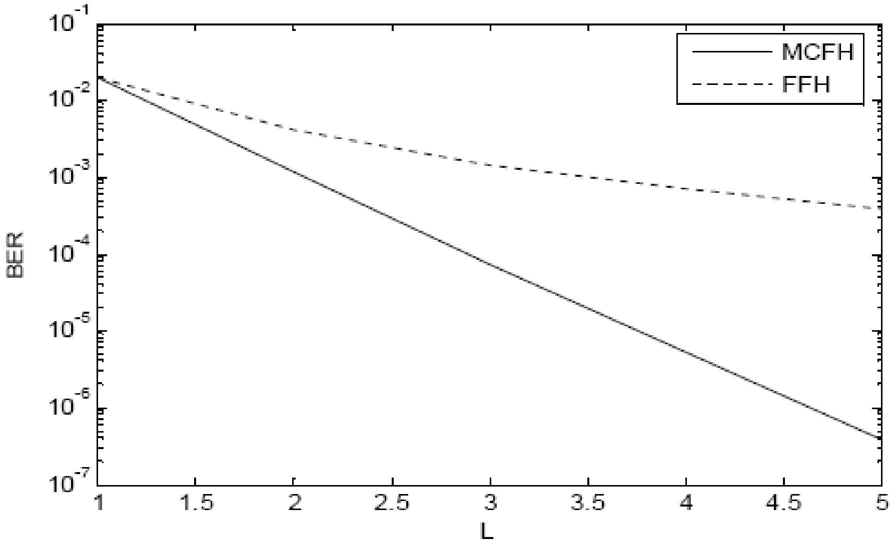

Figure 6.23. E_b/N_0 = 20db, Ricean factor = 0.5, Normalized frequency deviation = 1, Bit duration = 10^{-6} second, Delay spread =10^{-8} second, Doppler spread = 10Hz.

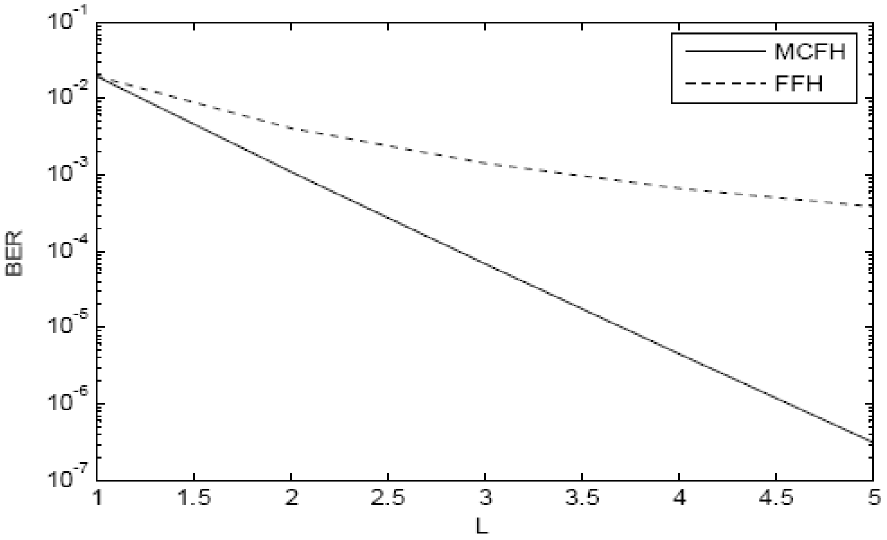

Figure 6.24. E_b/N_0 = 20db, Ricean factor = 0.5, Normalized frequency deviation = 1, Bit duration = 10^{-6} second, Delay spread =10^{-11} second, Doppler spread = 10000Hz.

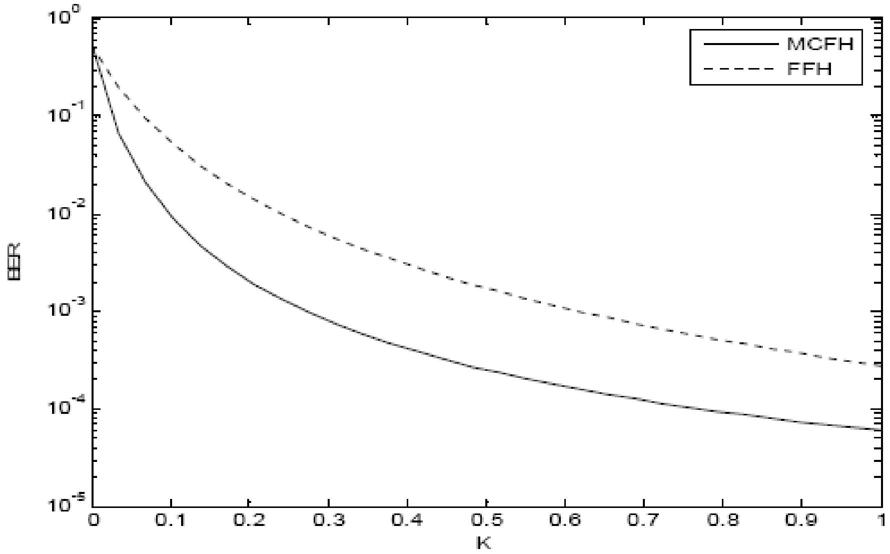

Figure 6.25. E_b/N_0 = 20db, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-4} second, Delay spread =10^{-5} second, Doppler spread = 10Hz.

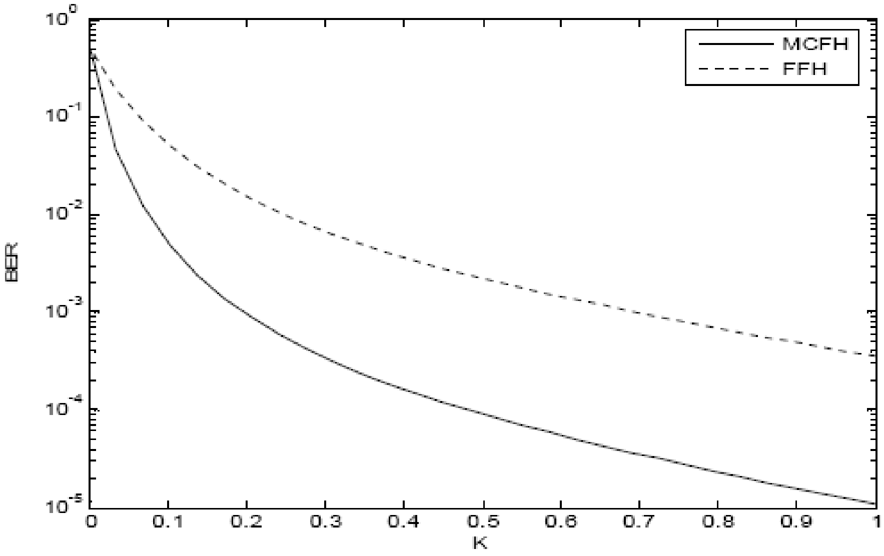

Figure 6.26. E_b/N_0 = 20db, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-4} second, Delay spread =10^{-8} second, Doppler spread = 1000Hz.

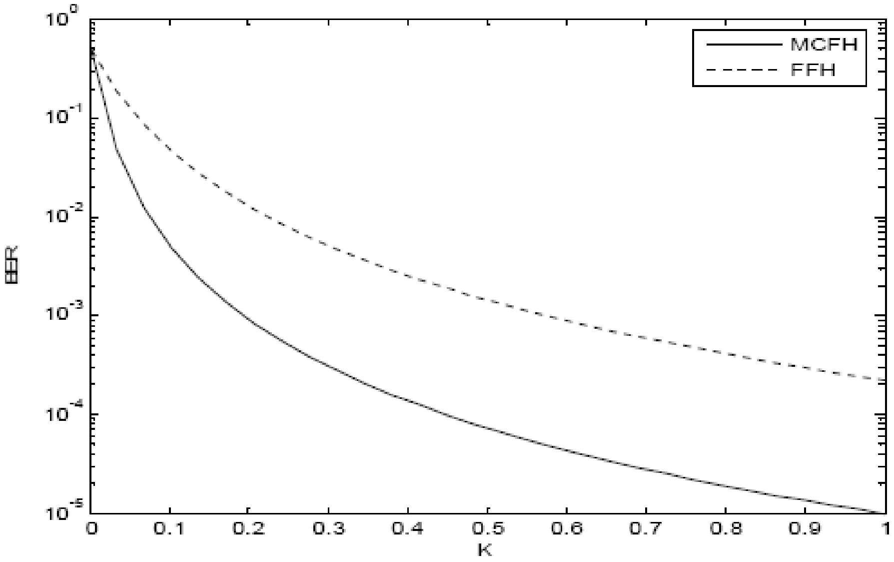

Figure 6.27. E_b/N_0 = 20db, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-6} second, Delay spread =10^{-8} second, Doppler spread = 10Hz.

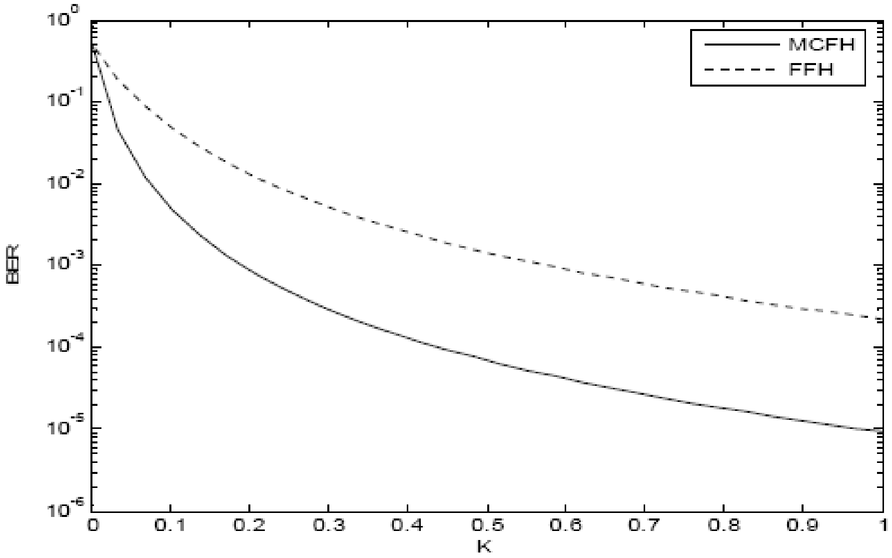

Figure 6.28. E_b/N_0 = 20db, Diversity order = 3, Normalized frequency deviation = 1, Bit duration = 10^{-6} second, Delay spread =10^{-11} second, Doppler spread = 10000Hz.

The above plots are for binary frequency shift keying (BFSK) technique in ricean fading channel. It is found from figure 6.13 that with increase in frequency, bit error rate increases in both fast frequency hopping and multi-carrier frequency hopping techniques. However bit error rate is less in multi-carrier frequency hopping technique than in fast frequency hopping technique.

With increase in delay spread BER increases. But after a particular value of delay spread with increase in frequency bit error rate remains constant as shown in figure 6.16. On increasing ricean factor k, bit error rate decreases for both techniques as it is clear from figure 6.25.

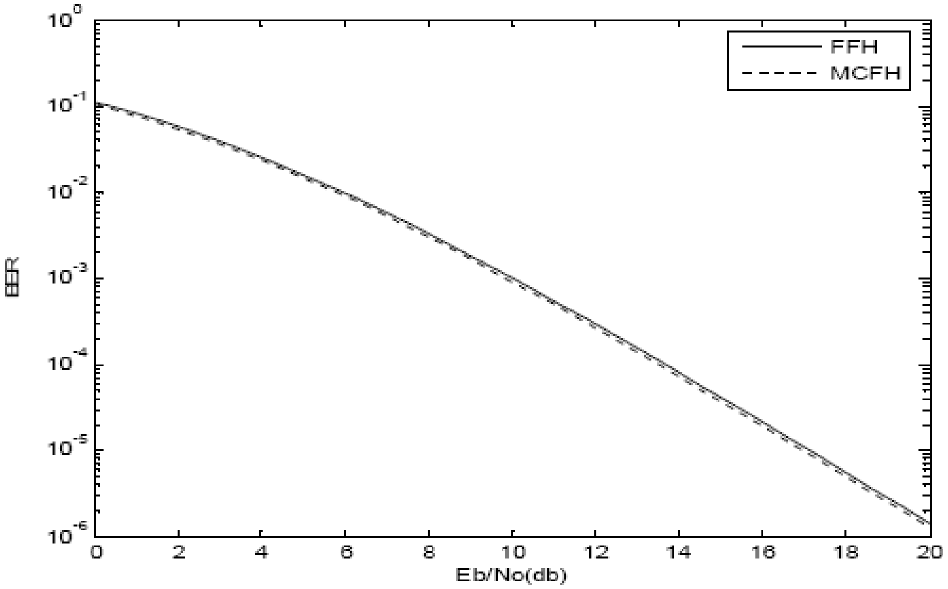

Figure 6.29. Diversity order = 3, Bit duration = 10^{-4} second, Delay spread =$3*10^{-6}$ second, Doppler spread = 50Hz.

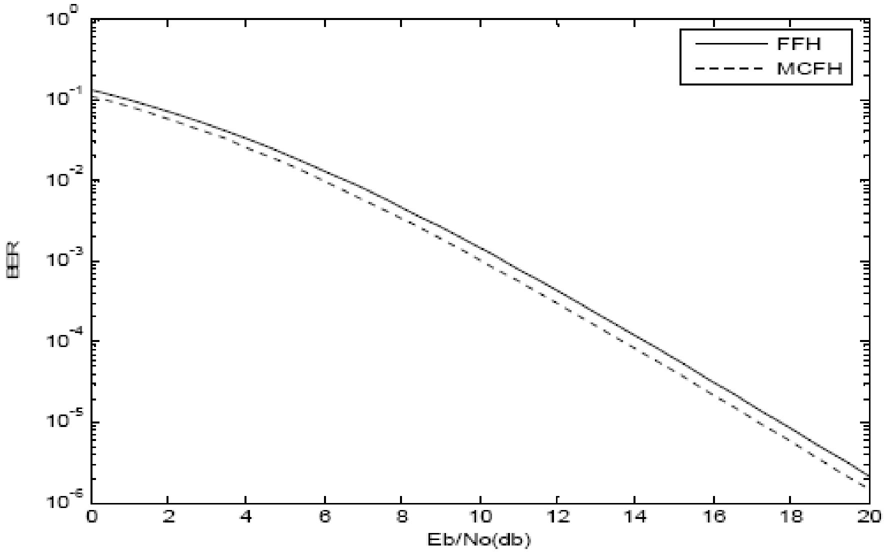

Figure 6.30. . Diversity order = 3, Bit duration = 10^{-4} second, Delay spread =10^{-5} second, Doppler spread = 50Hz.

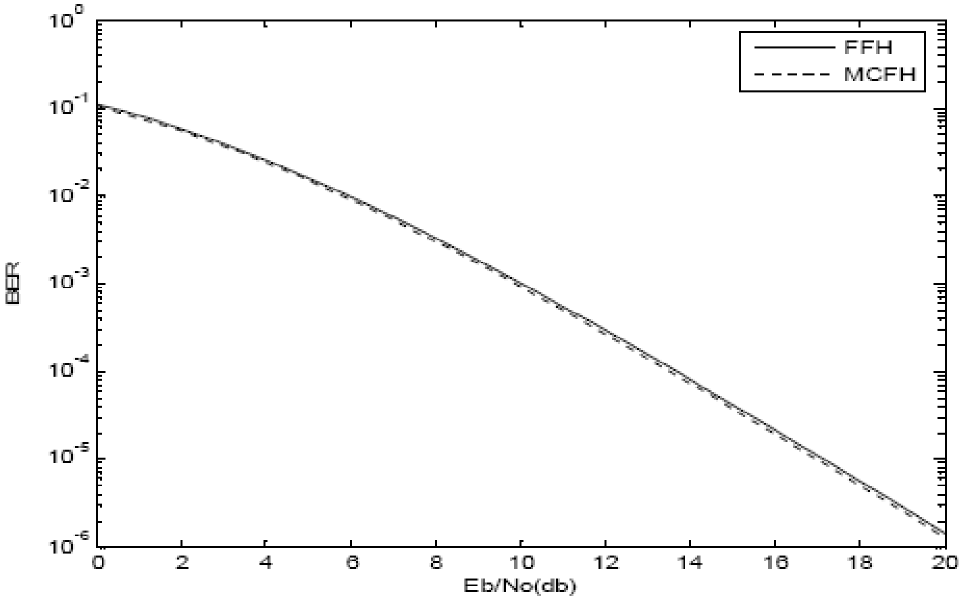

Figure 6.31. Diversity order = 3, Bit duration = 10^{-4} second, Delay spread =$3*10^{-6}$ second, Doppler spread = 500Hz.

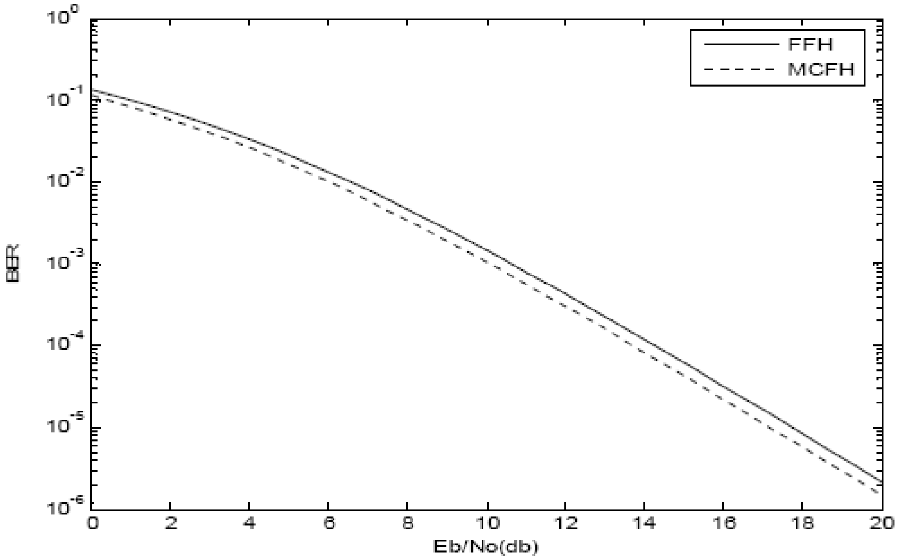

Figure 6.32. Diversity order = 3, Bit duration = 10^{-4} second, Delay spread =10^{-5} second, Doppler spread = 500Hz.

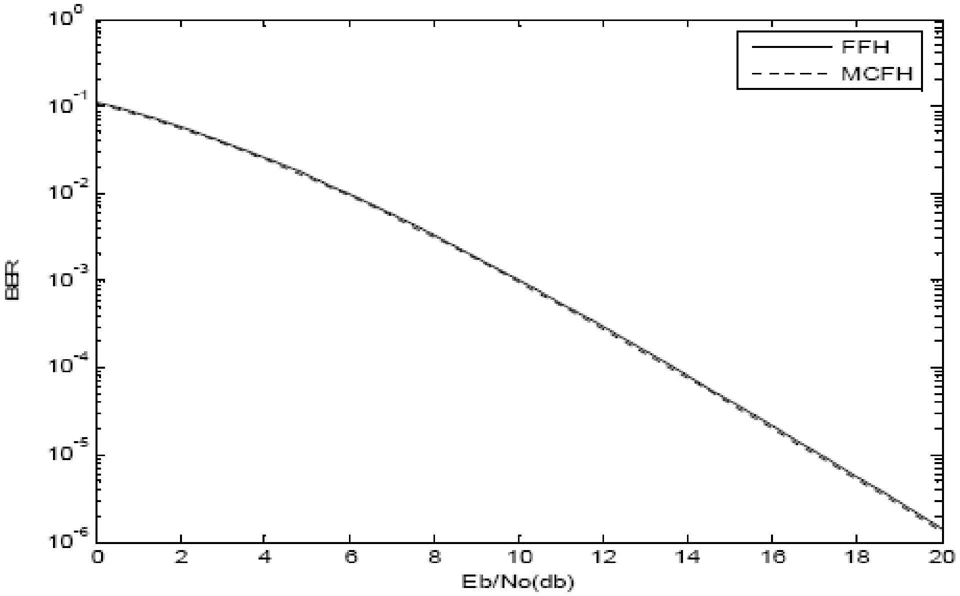

Figure 6.33. Diversity order = 3, Bit duration = 10^{-4} second, Delay spread =$3*10^{-6}$ second, Doppler spread = 1000Hz.

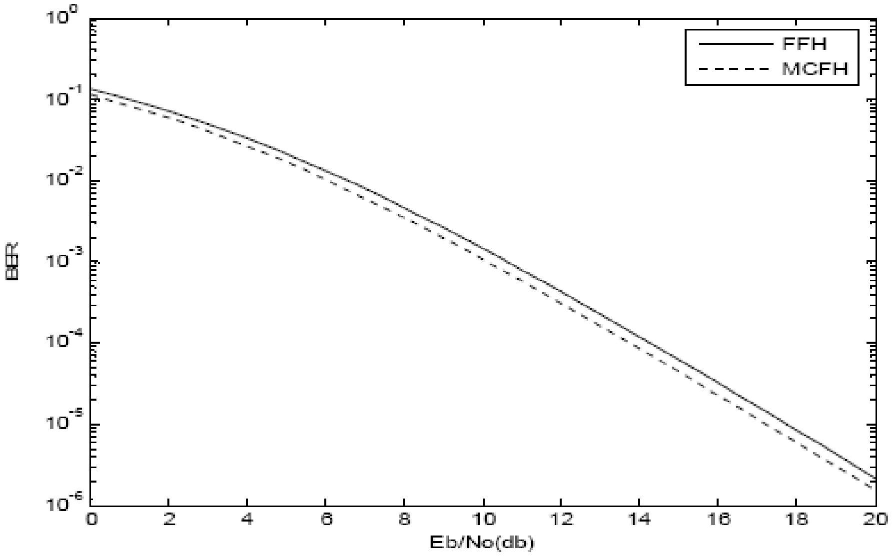

Figure 6.34. Diversity order = 3, Bit duration = 10^{-4} second, Delay spread =10^{-5} second, Doppler spread = 1000Hz.

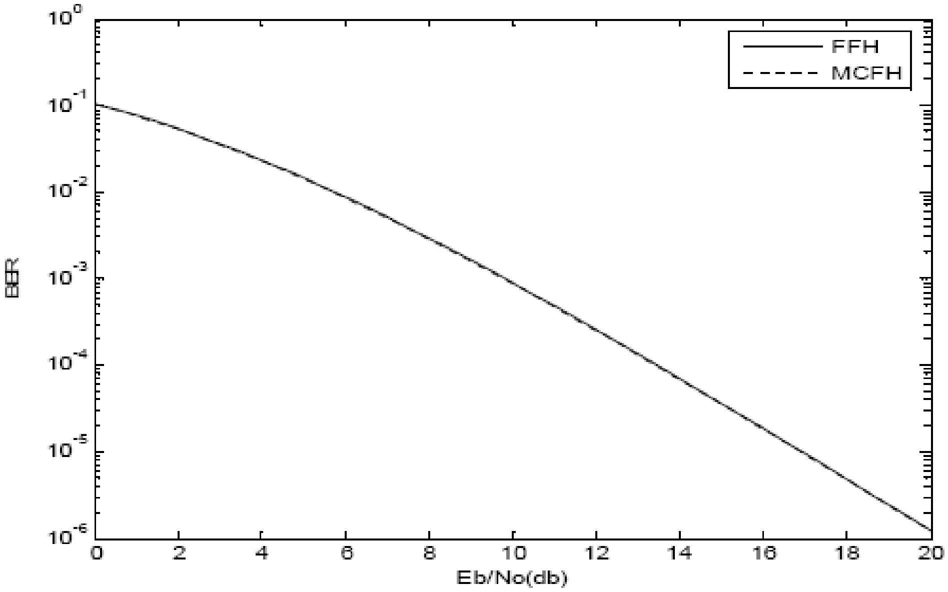

Figure 6.35. Diversity order = 3, Bit duration = 10^{-6} second, Delay spread =$3*10^{-9}$ second, Doppler spread = 100Hz.

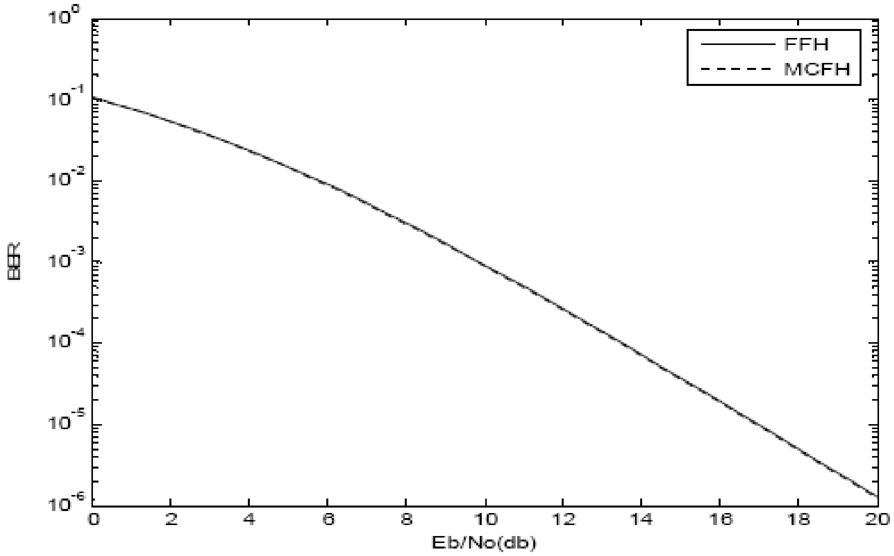

Figure 6.36. Diversity order = 3, Bit duration = 10^{-6} second, Delay spread =10^{-8} second, Doppler spread = 100Hz.

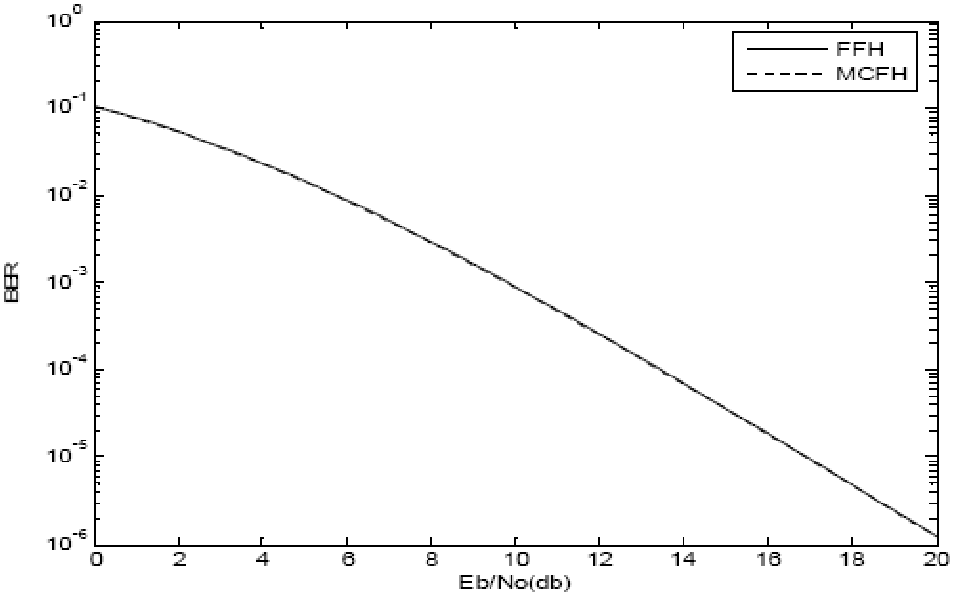

Figure 6.37. Diversity order = 3, Bit duration = 10^{-6} second, Delay spread =$3*10^{-9}$ second, Doppler spread = 1000Hz.

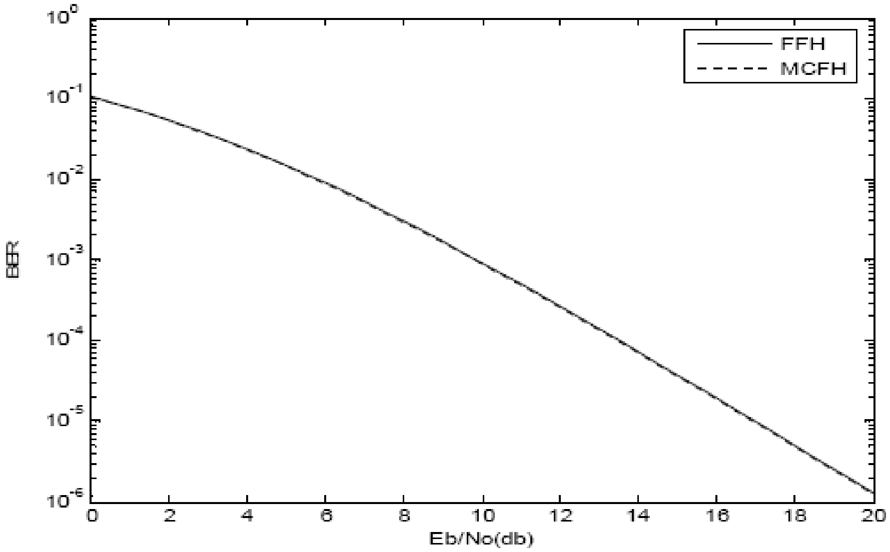

Figure 6.38. Diversity order = 3, Bit duration = 10^{-6} second, Delay spread =10^{-8} second, Doppler spread = 1000Hz.

Figure 6.29 is for differential binary phase shift keying (DBPSK) modulation technique in rayleigh fading channel. In this bit error rate for both techniques i.e fast frequency hopping and multi-carrier frequency hopping technique is same only very less variations are there. However on increasing delay spread variation is more visible as in figure 6.30.

Figure 6.41-6.44 represents the plot of bit error rate and maximum delay spread. It is clear from plots that on increasing maximum delay spread bit error rate increases.

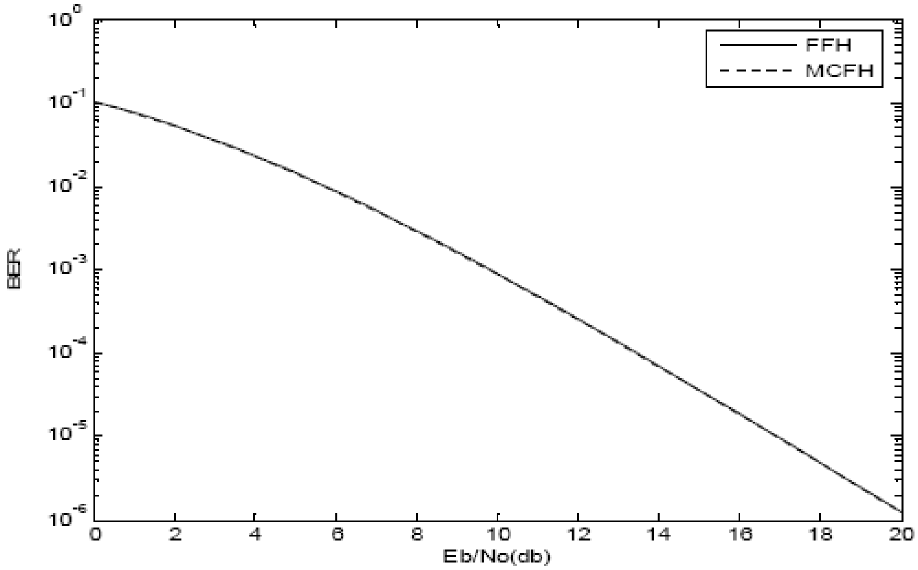

Figure 6.39. Diversity order = 3, Bit duration = 10^{-6} second, Delay spread =$3*10^{-9}$ second, Doppler spread = 10000Hz.

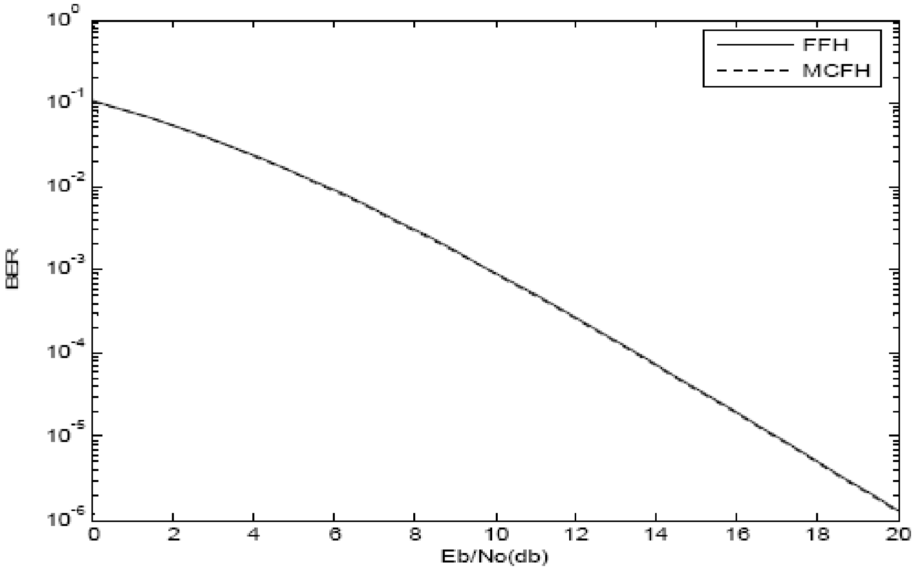

Figure 6.40. Diversity order = 3, Bit duration = 10^{-6} second, Delay spread =10^{-8} second, Doppler spread = 10000Hz.

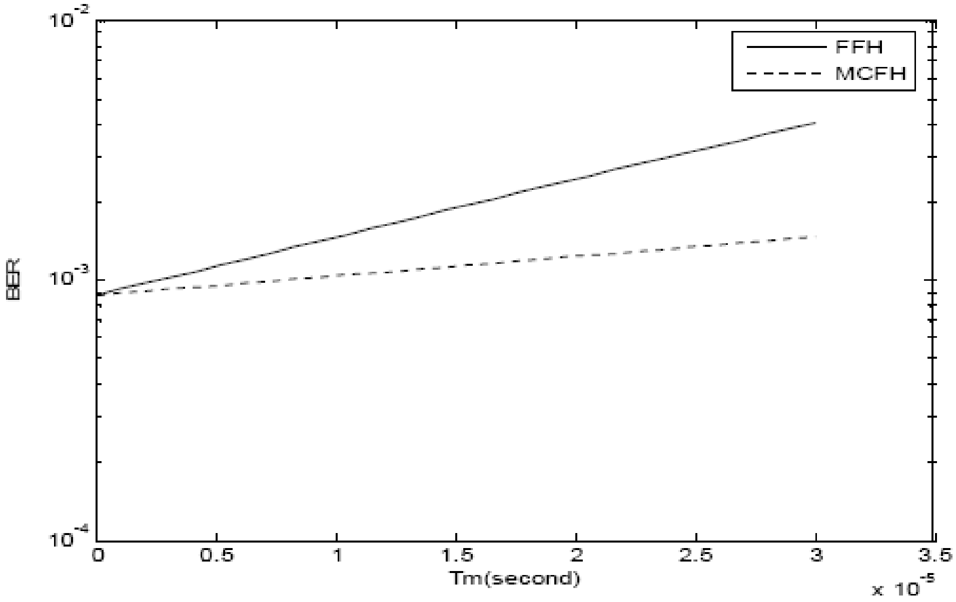

Figure 6.41. Diversity order = 3, Bit duration = 10^{-4} second, Doppler spread = 50Hz, E_b/N_0 = 10db.

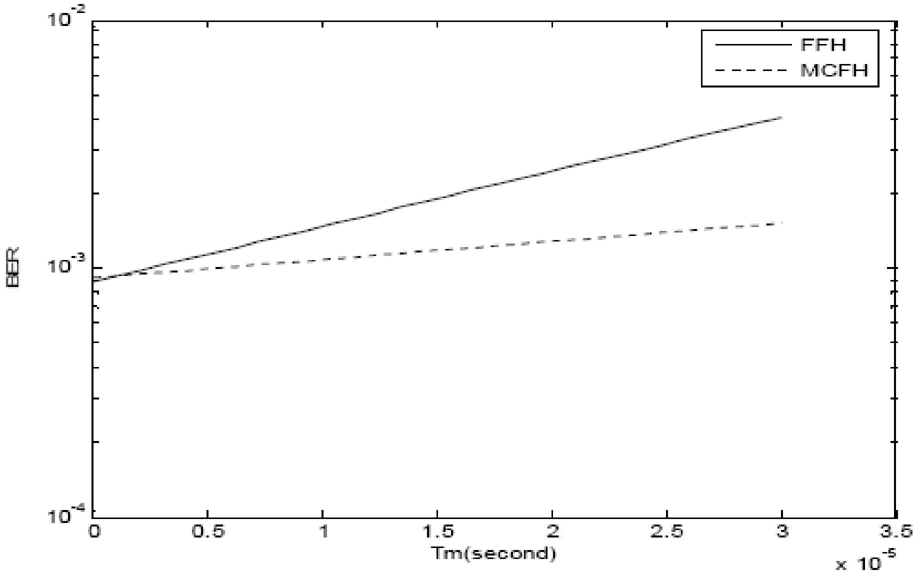

Figure 6.42. Diversity order = 3, Bit duration = 10^{-4} second, Doppler spread = 1000Hz, E_b/N_0 = 10db.

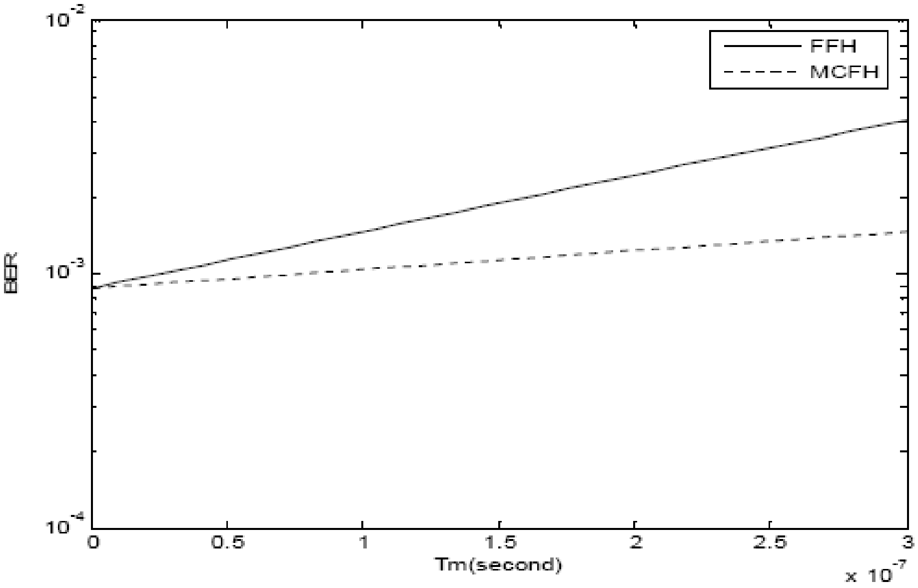

Figure 6.43. Diversity order = 3, Bit duration = 10^{-6} second, Doppler spread = 100Hz, E_b/N_0 = 10db.

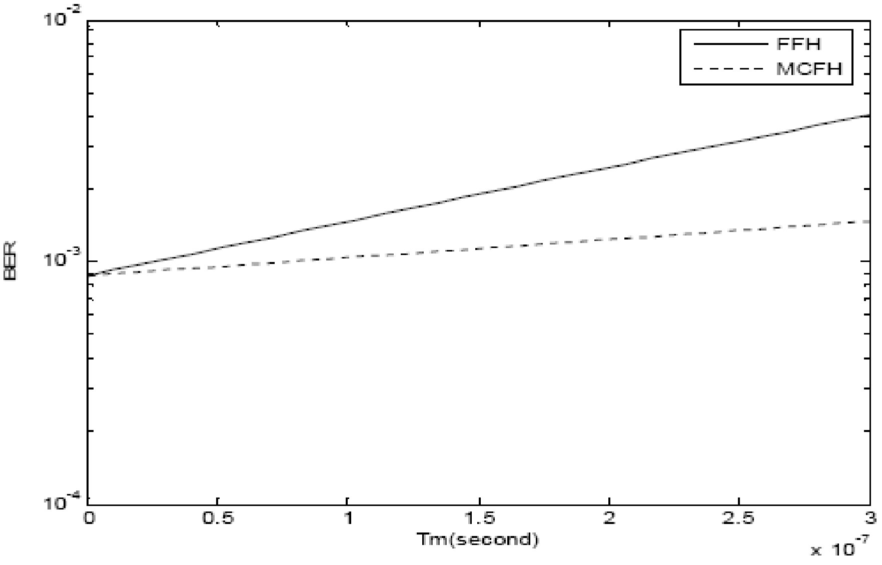

Figure 6.44. Diversity order = 3, Bit duration = 10^{-6} second, Doppler spread = 5000Hz, E_b/N_0 = 10db.

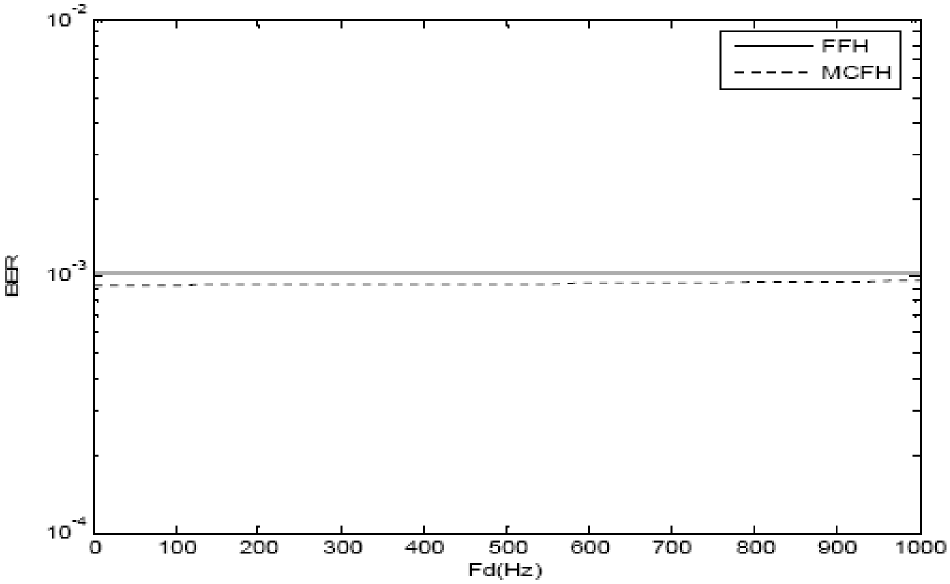

Figure 6.45. Diversity order = 3, Bit duration = 10^{-4} second, Delay spread = $3*10^{-6}$ second,
E_b/N_0 = 10db.

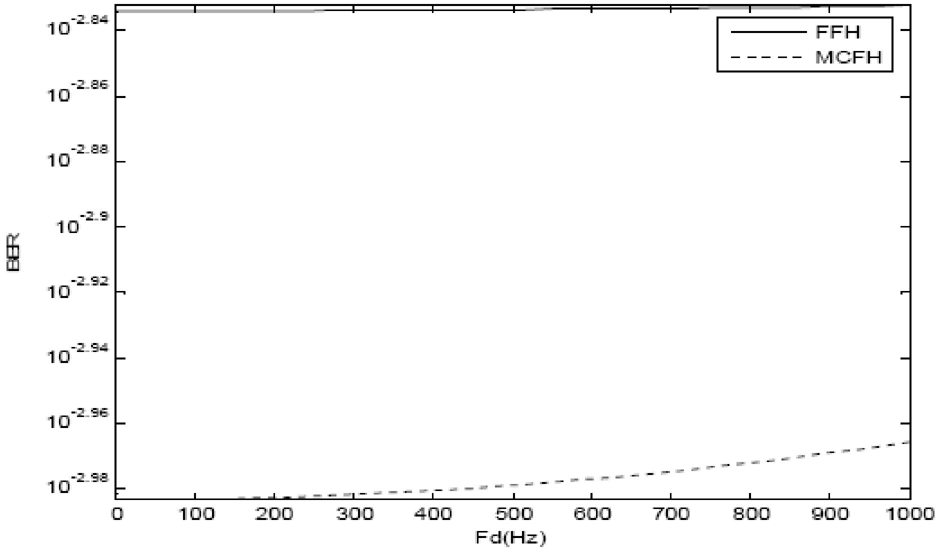

Figure 6.46. Diversity order = 3, Bit duration = 10^{-4} second, Delay spread = 10^{-5} second,
E_b/N_0 = 10db.

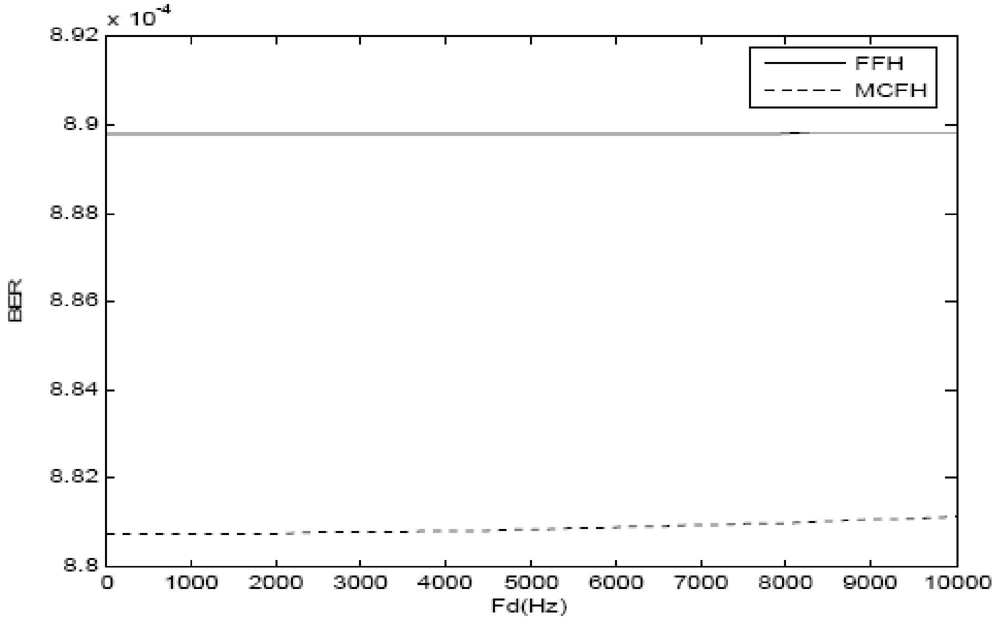

Figure 6.47. Diversity order = 3, Bit duration = 10^{-6} second, Delay spread = $3*10^{-9}$ second, E_b/N_0 = 10db.

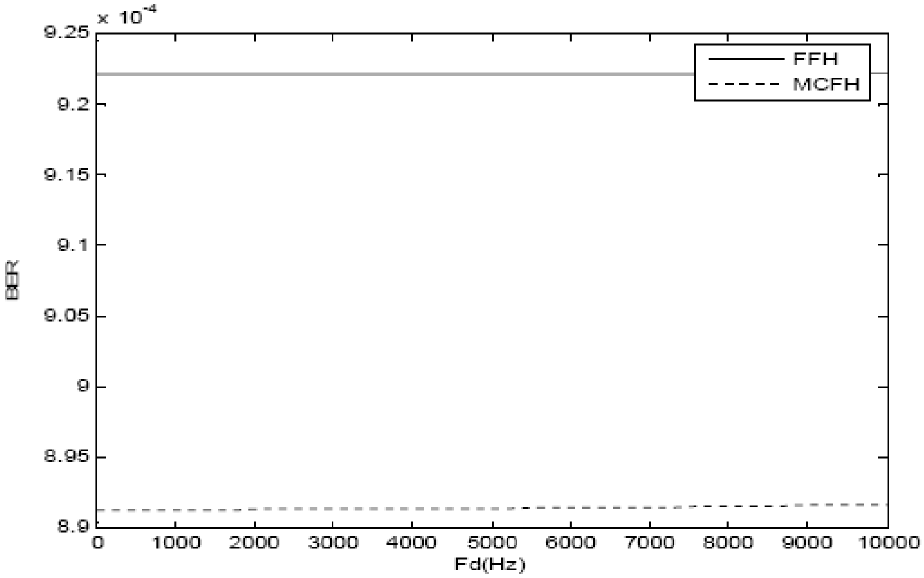

Figure 6.48. Diversity order = 3, Bit duration = 10^{-6} second, Delay spread = 10^{-8} second, E_b/N_0 = 10db.

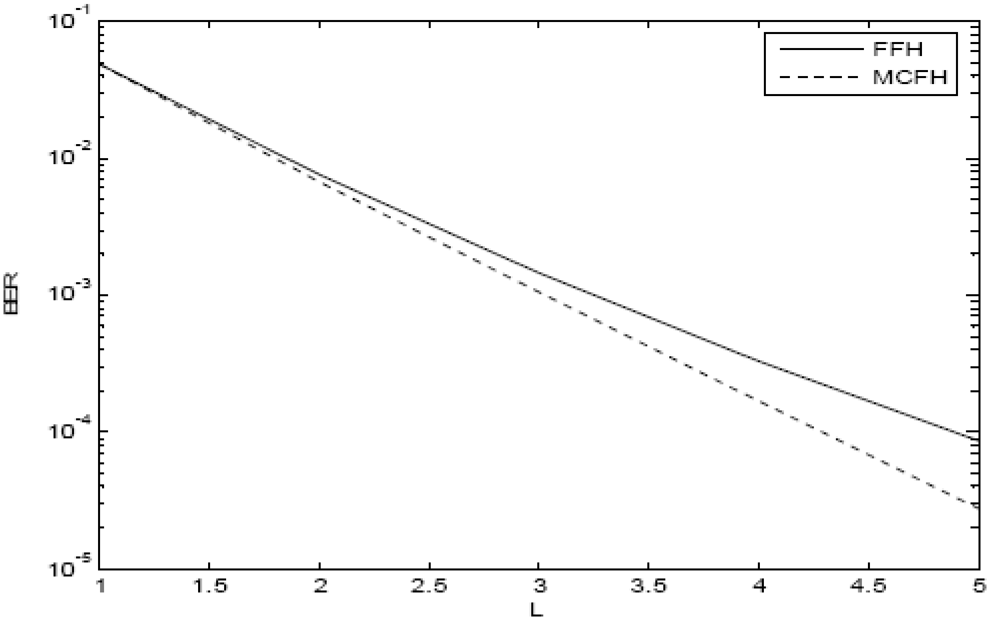

Figure 6.49. Bit duration = 10^{-4} second, Doppler spread =10Hz, E_b/N_0 = 10db, Delay spread = 10^{-5} second.

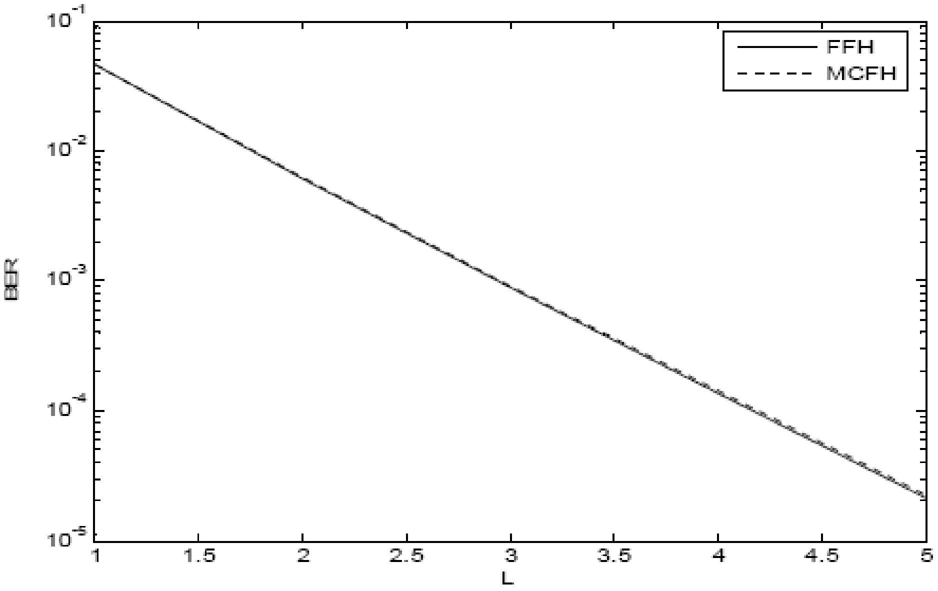

Figure 6.50. Bit duration = 10^{-4} second, Doppler spread =1000Hz, E_b/N_0 = 10db, Delay spread = 10^{-8} second.

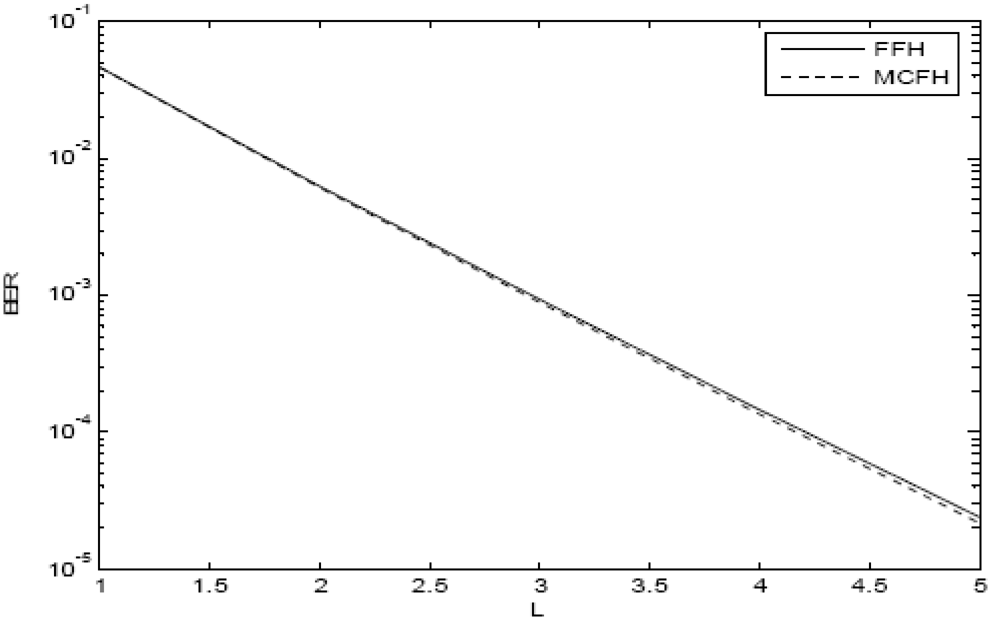

Figure 6.51. Bit duration = 10^{-6} second, Doppler spread =10Hz, E_b/N_0 = 10db, Delay spread = 10^{-8} second.

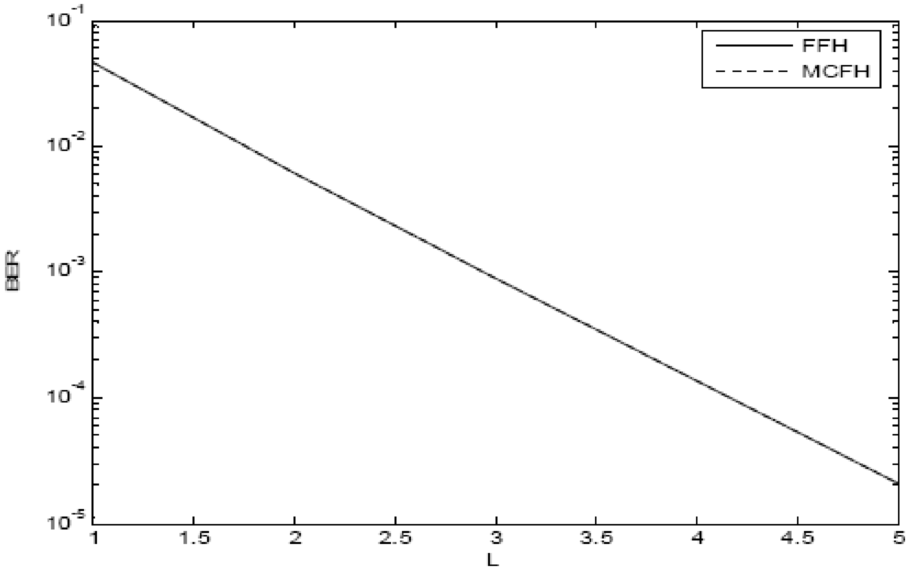

Figure 6.52. Bit duration = 10^{-6} second, Doppler spread =10000Hz, E_b/N_0 = 10db, Delay spread = 10^{-11} second.

Bit error rate is monotonically increasing function of ratio of maximum delay spread (T_m) to hopping period. Bit duration taken is 10^{-4} and 10^{-6} second, which approximate the minimum and maximum limit of WLAN, PAN, Bluetooth systems. Figure 6.43 shows variation of MCFH and FFH with delay spread from which it can be easily stated that FFH is better than MCFH if time spreading is very poor and doppler spread is very severe. Figure 6.45-6.48 shows that gain of MCFH over FFH increases with doppler spread and it can be stated that effect of delay spread is more severe than doppler spread in both frequency hopping spread spectrum systems. Figure 6.49-6.52 shows the variation of BER of FFH and MCFH systems with diversity order and it is found that with increase in diversity order bit error rate decreases.

CONCLUSION

- Multicarrier frequency hopping (MCFH) spread spectrum system outperforms fast frequency hopping (FFH) spread spectrum system in slow frequency selective, fast frequency selective and slow frequency non –selective fading channels.

- Fast frequency hopping (FFH) spread spectrum system outperforms multicarrier frequency hopping (MCFH) spread spectrum system in fast frequency non-selective fading channels.

- Effect of delay spread is more severe than doppler spread in both frequency hopping spread spectrum systems.

- Multicarrier frequency hopping (MCFH) spread spectrum system is better than fast frequency hopping (FFH) spread spectrum system for IEEE 802.11 (WLAN) and IEEE 802.15 (Bluetooth, PAN) up to 9 db

- Improvement in performance by increasing the value of diversity order and ricean factor is more in multicarrier frequency hopping spread spectrum system than fast frequency hopping spread spectrum system.

FUTURE SCOPE

- Performance of fast frequency (FFH) and multi carrier frequency hopping (MCFH) spread spectrum systems can be compared for high order modulation techniques i.e. MFSK and DFSK with more than two phases.

- Frequency hopping techniques can provide a better means for reception of radio signals which are immune to a wide variety of jamming techniques and will provide complete immunity to certain comman interference or jamming signals usually encountered in tactical military operations.

- Wireless community is on the verge of the standardization of fourth generation (4G) systems. The development of frequency hopping techniques can enables different systems comprising 4G such as adaptive wideband code divison multiple access (WCDMA), adaptive time divison multiple access (ATDMA), multi-carrier (OFDMA) and ultra wide band (UWB) receiver elements.

- Performance of fast frequency hopping (FFH) and multicarrier frequency hopping (MCFH) spread spectrum systems can be compared in Nakagami fading channel.

- The hopping techniques can be used for testing of voice VLANs.

- In this thesis single user performance is evaluated for both systems, multi user performances can be evaluated and compared for two systems.

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