CERTIFICATE

I, MEENAKSHI GHAI hereby certify that the work which is being presented in this thesis entitled **“PERFORMANCE OF FRACTIONAL RATE STBC CODES IN WIRELESS COMMUNICATIONS**” by me in partial fulfillment of requirements for the award of degree of Master of Engineering in Electronics and Communication from THAPAR INSTITUTE OF ENGG & TECH (Deemed University), PATIALA, is an authentic record of my own work carried under the supervision of Mr. RAJESH KHANNA and Mr. BALWANT SINGH at TIET, PATIALA.

The matter presented in this thesis has not been submitted in any other University or Institute for the award of Master of Engineering.

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This is certified that the above statement made by the candidate is correct to the best of my knowledge.

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ACKNOWLEDGEMENT

Words are often too less to reveal one's deep regards. An understanding of the work like this is never the outcome of the efforts of a single person. I take this opportunity to express my profound sense of gratitude and respect to all those who helped me through the duration of this thesis.

First, I would like to thank the Supreme Power, the GOD, who guided me to work on the right path of life. Without his grace, this would not have been possible. This work would not have been possible without the encouragement and able guidance of **'Mr. RAJESH KHANNA'**, Assistant Professor and **'Mr. BALWANT SINGH',** Sr. Lecturer, TIET, PATIALA. Their enthusiasm and optimism made this experience both rewarding and enjoyable. Most of the novel ideas and solutions found in this thesis are the result of our numerous stimulating discussions. His feedback and editorial comments were also invaluable for the writing of this thesis. I am grateful to **Head of the Department Dr. R. S. KALER** and **Dr. A.K. CHATTERJEE** for providing the facilities for the completion of thesis.

I take pride of my self being daughter of ideal great parents whose everlasting desire, sacrifice, affectionate blessing and help without which it would have not been possible for me to complete my studies.

At last, I would like to thank all the members and employees of Electronics and Communication Department, TIET Patiala whose love and affection made this possible.

(MEENAKSHI GHAI)

ABSTRACT

Challenges in modern wireless communication are high data rate, reduction of data transmission cost per bit etc. To overcome the low data rate problems in 3 G, space-time block coding is proposed in 4G. Space–time block coding, which is a new paradigm for transmitting data over fading channels using multiple transmit antennas.

In implementing space time block coding, data is encoded using a space–time block code and the encoded data is split into M_T streams which are simultaneously transmitted using M_R transmit antennas. The received signal at each receive antenna is a linear superposition of the M_T transmitted signals perturbed by noise. Maximum likelihood decoding is achieved in a simple way through decoupling of the signals transmitted from different antennas rather than joint detection. This uses the orthogonal structure of the space–time block code and gives a maximum-likelihood decoding algorithm, which is based only on linear processing at the receiver. Space–time block codes can be designed to achieve the maximum diversity order for a given number of transmit and receive antennas subject to the constraint of having a simple decoding algorithm. These codes achieve the maximum possible transmission rate for any number of transmit antennas using any arbitrary real constellation such as PAM. For an arbitrary complex constellation such as PSK and QAM, space–time block codes can be designed that achieve 1/2 of the maximum possible transmission rate for any number of transmit antennas. For the specific cases of two, three, and four transmit antennas, space–time block codes are designed that achieve, respectively, all, or 3/4 of maximum possible transmission rate using arbitrary complex constellations.

In this thesis rate 1 by 2 and rate 3 by 4 systems are studied under different fading environments using different modulations and their performances are compared. Finally, performance of different rate schemes using three and four number of transmit antennas is compared. The rate 3 by 4 code and rate 1 by 2 code for three and four antennas outperform rate 1 code using two transmit antennas. The performance gain is less as compared to the pervious case when numbers of receive antennas is increased.

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CHAPTER 1

~~INTRODUCTION~~

~~1.1 INTRODUCTION TO THE WIRELESS PROBLEM~~

~~Wireless communications has emerged as one of the largest sectors of the telecommunications, industry, evolving from a niche business in the last decade to one of the most promising areas for growth in the 21st century. For completely understanding the needs of modern wireless communications, evolution of various generations of mobile communication is studied next.~~

~~1.2 TIME-LINE FROM 1G TO 4G~~

~~The first generation (1G) cellular systems in the U.S., called the Advance Mobile Phone Service (AMPS), used FDMA with 30 KHz FM-modulated voice channels. The FCC initially allocated 40 MHz of spectrum to this system, which was increased to 50 MHz shortly after service introduction to support more users. This total bandwidth was divided into two 25 MHz bands, one for mobile-to-base station channels and the other for base station-to-mobile channels. The FCC divided these channels into two sets that were assigned to two different service providers in each city to encourage competition service in some of these areas, including some rural parts of the U.S. Thus, 1G wireless was analog and supported the first generation of analog cell phones with the speeds up to 2.4kbps [1].~~

~~The second generation (2G) digital systems called GSM which uses a combination of TDMA and slow frequency hopping with frequency-shift keying for the voice modulation. GSM systems provide data rates of up to 100 Kbps by aggregating all timeslots together for a single user. This enhancement is called GPRS. A more fundamental enhancement, Enhanced Data Services for GSM Evolution (EDGE), further increases data rates using a high-level modulation format combined with FEC coding.~~

~~The IS-54 and IS-136 systems currently provide data rates of 40-60 Kbps by aggregating time slots and using high-level modulation.~~

~~The third generation (3G) cellular systems are based on a wideband CDMA standard developed within the auspices of the International Telecommunications Union (ITU) .The standard, initially called International Mobile Telecommunications 2000 (IMT-2000), provides different data rates depending on mobility and location, from 384 Kbps for pedestrian use to 144 Kbps for vehicular use to 2 Mbps for indoor office use. 3G is not only provided the transmission speeds from 125kbps to 2Mbps, but also included many services, such as global roaming, superior voice quality and data always add on.~~

~~The fourth generation (4G) is a conceptual framework and a discussion point to address future needs of a high speed wireless network that can transmit multimedia and data to interface with wire-line backbone network perfectly just raised in 2002. The speeds of 4G can theoretically be promised up to 1Gbps.~~

~~The main distinguishing factors between 3G and 4G will be data rates, services, transmission ways, access technology to the Internet, the compatibility to interface with wire-line backbone network, quality of service and security. 4G should support at least 100 Mbps peak rates in full-mobility wide area coverage and 1Gbps in low-mobility local area coverage. The speeds of 3G can be up to 2Mbps, which is much slower than the speeds of 4G. For the service, 3G marketing is difficult to roam globally and interoperate across networks, yet 4G will be a global standard that provides global mobility and service portability so that service provider will no longer be limited by single-system .In other words, 4G should be able to provide very smooth global roaming ubiquitously with lower cost. Furthermore, 3G is based on a wide-area concept applying circuit and packet switching for transmission with limited access technology, such as WCDMA, CDMA and TD-SDMA~~

~~Fourth-generation (4G) wireless systems differ from third-generation (3G) as follows:~~

- ~~They entirely consist of packet-switched networks.~~
- ~~All network elements are digital.~~
- ~~Wide bandwidth is necessary to provide multimedia services like streaming video.~~
- ~~Network security is more important.~~

~~Thus to overcome the low data rate problem in 3G, in various fora and organizations for wireless research, such as the Wireless World Research Forum (WWRF) and International Telecommunication Union (ITU), there have been active discussions about systems beyond 3G to be deployed around 2010.In order to satisfy the above vision, requirements for the future wireless communications systems can be summarized as follows:~~

- ~~High data rate and reduction of data transmission cost per bit~~
- ~~IP-based network~~
- ~~Seamless connections~~
- ~~Service integration~~
- ~~Short delay in handover and packet transmission~~

~~Some key technologies needed to achieve this goal are~~

1. ~~Modulation and multiple access schemes~~
2. ~~Multiple antenna techniques (MIMO systems)~~
3. ~~Advanced Signal Processing Techniques~~
4. ~~Realistic Modeling of Fading Environment~~
5. ~~Adaptive Antennas~~
6. ~~Space Time Processing (STP) and coding (STC)~~
7. ~~Ultra wideband (UWB)~~
8. ~~Orthogonal frequency-division multiplexing (OFDM)~~

In this thesis the fractional rate STBC codes system are studied .To completely understand the performance of fractional rate schemes a brief introduction of MIMO systems is given next.

1.3 MULTIPLE INPUT MULTIPLE OUTPUT SYSTEMS (MIMO)

~~The Multiple-Input Multiple-Output (MIMO) techniques are widely proposed as the key technique to enhance the radio channel capacity of cellular systems. This technology can enhance the link quality by using diversity MIMO schemes and/or improve the spectrum efficiency by enabling multi-stream transmission. To transmit data in MIMO systems space-time coding is used to improve the performance.~~

Space-time coding involves use of multiple transmit and receive antennas, as illustrated in Figure 1.3. A typical communication system consists of a transmitter, a channel, and a receiver. Bits entering the space-time encoder serially are distributed to parallel sub-streams. Within each sub-stream, bits are mapped to signal waveforms, which are then emitted from the antenna corresponding to that sub-stream. The scheme used to map bits to signals is the called a space-time code. Signals transmitted simultaneously over each antenna interfere with each other as they propagate through the wireless channel. Meanwhile, the fading channel also distorts the signal waveforms. At the receiver, the distorted and superimposed waveforms detected by each receive antenna are used to estimate the original data bits [2].

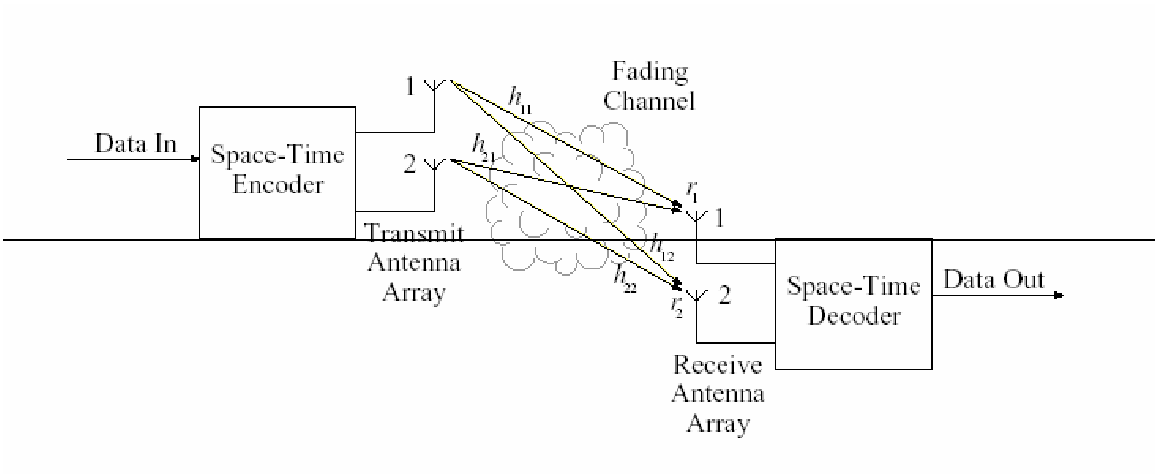


Figure-1.1: Typical Communication System Employing Space Time Coding

~~In a $M \times N$ MIMO system, Space-time codes are able to obtain a full diversity order of $M \times N$ with rate=1, where M is the numbers of transmit antennas and N is number of receive antennas. Space-time codes can be classified as:~~

- ~~Space-time trellis coding (STTC)- where the codes have a trellis description~~
- ~~Space-time block coding (STBC)- where a block description is used~~

~~Space-time block coding is the primarily discussed in this thesis by considering Alamouti scheme, which is rate 1 scheme and then moving on to the fractional rate schemes.~~

~~1.4 STATEMENT OF PROBLEM~~

~~STBC was introduced by Alamouti, which used two transmit antennas and one receive antenna and provided rate=1[6]. The performance of rate 1 code was studied under Rayleigh environment. The theory of space-time block codes was further developed by Tarokh, Jafarkhani and Calderbank [7]. They defined space-time block codes in terms of orthogonal code matrices. It was shown that full rate complex modulation orthogonal space-time block codes exist only for at most 2 antennas. In this thesis the work is extended further to study the fractional rate STBC for different modulation techniques under different fading environments.~~

~~1.8 OBJECTIVES OF THESIS~~

- ~~To study the rate 3 by 4 schemes using three antennas and four antennas.~~
- ~~To study the performance of rate 3 by 4 codes in Rayleigh fading environment using different modulation techniques.~~
- ~~To study the performance of rate 3 by 4 codes in Rician fading environment using different modulation techniques.~~
- ~~To study the performance of rate 3 by 4 codes in Nakagami fading environment using different modulation techniques.~~

- ~~To study the rate 1 by 2 schemes using three antennas and four antennas.~~
- ~~To study the performance of rate 1 by 2 codes in Rayleigh fading environment using different modulation techniques.~~
- ~~To study the performance of rate 1 by 2 codes in Rician fading environment using different modulation techniques.~~
- ~~To study the performance of rate 1 by 2 codes in Nakagami fading environment using different modulation techniques.~~
- ~~To compare the performances of rate 3 by 4 system under different fading environments i.e. Rayleigh, Rician and Nakagami.~~
- ~~To compare the performance of uncoded transmission with two, three and four antennas for different rate schemes.~~

~~1.9 THESIS ORGANISATION~~

- ~~Chapter 2 includes the literature survey about spatial diversity under different conditions i.e. channel unknown to the transmitter and channel known to the transmitter for MISO and MIMO systems. Briefly discussing about space time coding, orthogonal space time block codes are studied.~~
- ~~Chapter 3 includes performance of rate 3 by 4 and rate 1 by 2 schemes for different modulation schemes in RAYLEIGH fading channel. It discusses about the basic communication system model and RAYLEIGH fading channel. The various modulation techniques considered are BPSK, QPSK, 8-PSK, 4-QAM are also discussed. It also includes the MONTE CARLO SIMULATION basics for various modulations. The simulation results of BER/SER for RAYLEIGH fading using three and four antennas along with comparison of various modulations under the same channel are presented.~~
- ~~Chapter 4 includes performance of rate 3 by 4 and rate 1 by 2 schemes for different modulation schemes in RICIAN fading channel. It discusses about the RICIAN fading channel and simulation results of BER/SER for RICIAN fading using three and four antennas along with comparison of various modulations under the same channel.~~

- ~~Chapter 5 contains performance of rate 3 by 4 and rate 1 by 2 schemes for different modulation schemes in NAKAGAMI fading channel. It includes description about NAKAGAMI fading channel and simulation results of BER/SER for NAKAGAMI fading using three and four antennas along with comparison of various modulations under the same channel.~~
- ~~Chapter 6 contains performance comparison of uncoded transmission with two, three and four antennas using arbitrary constellations.~~
- ~~Chapter 7 includes conclusions and future scopes.~~

CHAPTER 2

LITERATURE SURVEY

2.1 INTRODUCTION

The next Generation Wireless Systems are expected to operate reliably in macro, micro and Pico cellular urban, suburban and rural indoor and outdoor environment and support not just high quality voice but also provide a high level of data services while maintaining a constant but high bit rate. This would entail planning for better quality and increased coverage and acceptable amount of data rates. Reliability of the Communication system is a major factor that would need to be considered in the design process. Sustaining the established network would necessitate the system to be more power and bandwidth efficient even in diverse environments while remaining affordable to contend against market competition.

This increased quality of service should be available not through the complex circuitry in the mobile receiver handset, but through the added cost-effective circuit enhancement at the base station. As of today, the capacity of wireless data communications is lagging behind demands due to unsatisfactory performance of the existing wireless networks, such as low data rates, low spectral efficiency and low quality of service. Fading makes tether less transmission a challenge when compared to fiber, coaxial cable, line-of-sight microwave or even satellite transmissions. Increasing the quality or reducing the effective error rate in a multipath-fading channel is extremely difficult. In additive white Gaussian noise (AWGN), using typical modulation and coding schemes, reducing the effective bit error rate (BER) from 10^{-2} to 10^{-3} may require only 1- or 2-dB higher signal to noise ratio (SNR).

The ways of mitigating this problem include Transmitter Power Control, which requires a good transmitter dynamic range and a perfect knowledge of the channel, which can only be estimated at best at the receiver. Other effective techniques are time and frequency diversity. Time interleaving, together with error correction coding, can provide diversity improvement. However, time interleaving results in large delays when the channel is slowly varying. Equivalently, spread spectrum techniques are ineffective when the coherence bandwidth of the channel is larger than the spreading bandwidth or, equivalently, where there is relatively small delay spread in the channel.

Diversity provides the receiver with multiple (ideally independent) looks at the same transmitted signal [3]. Each look constitutes a diversity branch. With an increase in the number of independent diversity branches, the probability that all branches are in a fade at the same time reduces sharply. Thus diversity techniques stabilize the wireless link leading to an improvement in link reliability or error rate. To mitigate the effects of fading, the following techniques are available:

1. Frequency Diversity - Transmission of signal on L different carriers (frequency separation should be at least equal to channel coherence bandwidth).
2. Time Diversity - Transmission of signal in L different time slots (time separation should be at least equal to channel coherence time).
3. Antenna Diversity: Spatial - Multiple receive antennas (antenna separation at least 10 wavelengths) and Polarization Diversity.
4. Bandwidth Expansion - Expansion of signal bandwidth to provide receiver with several independent fading signal paths (signal bandwidth expansion should be greater than coherence bandwidth).
5. Coding and Interleaving - Transmission of redundant information (i.e. forward error correction codes) and interleaving (interleaver should be longer than channel coherence time).

As in this thesis, spatial diversity is exploited to mitigate the effects of fading, is discussed in detail next.

2.2 SPATIAL DIVERSITY

Spatial diversity is an attractive alternative that does not sacrifice time or bandwidth, while also providing array gain or increased average received SNR [4]. The exact nature of the scheme that extracts spatial diversity depends on the antenna configuration (SIMO, MISO or MIMO). Spatial diversity is of two types:

1. Receive antenna diversity
2. Transmit antenna diversity

2.3. RECEIVE ANTENNA DIVERSITY

In this system single antenna is used at the transmitter and multiple antennas are used at the receiver (SIMO) channel. Receive diversity techniques are capable of extracting full diversity and array gain. The performance improvement is proportional to the number of receive antennas used. However, deploying multiple antennas at the terminal receiver is often not feasible due to cost or space limitations.

2.4. TRANSMIT ANTENNA DIVERSITY

Exploiting spatial diversity in systems with multiple antennas at the transmitter requires that the signal to be pre processed or pre-coded prior to the transmission. There has been increased interest in these techniques since the 1990s [12].

Transmit diversity can be leveraged in both the presence and absence of channel knowledge at the transmitter for MISO and MIMO systems, which are discussed in detail next.

2.4.1 MISO Systems: Channel Unknown To the Transmitter

Consider a simple but ingenious transmit diversity technique- the Alamouti scheme .In this technique, two different symbols s_1 and s_2 are transmitted simultaneously from antennas 1 and 2 respectively during the first symbol period, followed by signals $-s_2^*$ and s_1^* from antennas 1 and 2 respectively during the next symbol period.

Assuming that the channel remains constant over the two symbol periods and it is frequency flat. Therefore, $h = [h_1 \quad h_2]$ and the signals y_1 and y_2 received over the two symbol periods are given by

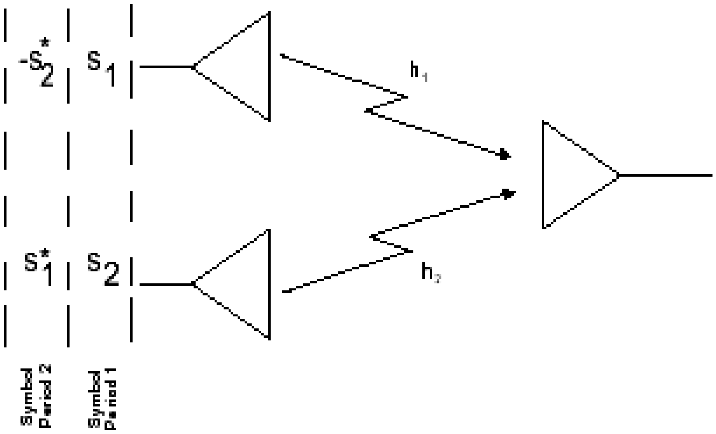


Figure 2.1: A Schematic of the Transmission Strategy in the Alamouti Scheme

$$y_1 = \sqrt{\frac{E_s}{2}} h_1 s_1 + \sqrt{\frac{E_s}{2}} h_2 s_2 + n_1 \tag{2.1}$$

$$y_2 = -\sqrt{\frac{E_s}{2}} h_1 s_2^* + \sqrt{\frac{E_s}{2}} h_2 s_1^* + n_2 \qquad (2.2)$$

Where n1 and n2 are noise with $\varepsilon\{|n_1|^2\} = \varepsilon\{|n_2|^2\} = N_0$ and $\frac{E_s}{2}$ is the average energy per symbol period per antenna. The receiver forms a rearranged signal vector y as follows:

$$\begin{aligned} \begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} &= \sqrt{\frac{E_s}{2}} \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \\ &= \sqrt{\frac{E_s}{2}} H_{eff} s + n \end{aligned} \qquad (2.3)$$

The average received SNR, η, per symbol is given by

$$\eta = \frac{\|h\|_F^2 \rho}{2} \qquad (2.4)$$

The Alamouti scheme extracts a diversity order of 2 (full M_T diversity), even in the absence of channel knowledge at the transmitter. A somewhat similar approach has been proposed for wideband CDMA systems and is now part of the CDMA 2000 standard. Since $\varepsilon\{\|h\|_F^2\} = 2$ for h=h_w, the average SNR at the receiver $\bar{\eta} = \rho$. Therefore, the absence of channel knowledge at the transmitter does not allow array gain. Transmit diversity techniques in the absence of channel knowledge at the transmitter may be designed to extract spatial diversity in systems with more than two transmit antennas.

2.4.2 MISO Systems: Channel Known to the Transmitter

Consider a MISO system with M_T transmit antennas and a frequency flat fading channel .the vector channel h is given by

$$h = [h_1 \ h_2 \ \ldots\ldots h_{M_T}] \qquad (2.5)$$

To exploit spatial diversity, the signal is transmitted from each transmit antenna after being weighted appropriately, so that the signals arrive in phase at the receive antenna and add coherently. The signal at the receiver is given by

$$y = \sqrt{\frac{E_s}{M_T}} hws + n \tag{2.6}$$

Where y is the received signal, w is a weight vector of dimension M_T*1 and n is noise. The weight vector must be chosen subject to $\|w\|_F^2 = M_T$ to ensure that the average total power of the transmitted signal is E_s. This scheme is known as transmit-maximal ratio combining. The SNR at the receiver η is given by

$$\eta = \|h\|_F^2 \rho \tag{2.7}$$

Hence, if perfect channel knowledge is available to the transmitter, transmit-MRC will deliver array gain and diversity gain.

2.4.3 MIMO Systems: Channel Unknown To the Transmitter

Consider a MIMO system with two transmits antennas and two receive antennas. The Alamouti scheme described may be used to extract diversity in such a system. Assuming that the channel remains constant over consecutive symbol periods. The signal received at the receive antenna array over consecutive symbol periods be y_1 and y_2 and is given by

$$y_1 = \sqrt{\frac{E_s}{2}} \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \tag{2.8}$$

$$y_2 = \sqrt{\frac{E_s}{2}} \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \end{bmatrix} \begin{bmatrix} -s_2^* \\ s_1^* \end{bmatrix} + \begin{bmatrix} n_3 \\ n_4 \end{bmatrix} \tag{2.9}$$

Where n_1, n_2, n_3, n_4 are uncorrelated noise samples with $\varepsilon\{|n_i|^2\} = N_0$. The received signal vector y may be expressed as

$$\begin{aligned} y &= \sqrt{\frac{E_s}{2}} \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \\ h_{1,2}^* & -h_{1,1}^* \\ h_{2,2}^* & -h_{2,1}^* \end{bmatrix} \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \\ n_4 \end{bmatrix} \\ &= \sqrt{\frac{E_s}{2}} H_{eff} s + n \end{aligned} \tag{2.10}$$

The average received SNR is given by

$$\eta = \frac{\|H\|_F^2 \rho}{2} \tag{2.11}$$

Therefore, the Alamouti scheme extracts order $M_T M_R$ diversity, though channel knowledge is not available at the transmitter. In the absence of channel knowledge at the transmitter, the Alamouti scheme is capable of extracting only receive array gain.

2.4.4 MIMO Systems: Channel Known to the Transmitter

Consider a system with M_R receives antennas and M_T transmits antennas. Here, as with transmit-MRC for MISO systems, the same signal is transmitted from all antennas in the transmit array with weight vector w. the received signal vector is given by

$$y = \sqrt{\frac{E_s}{M_T}} Hws + n \tag{2.12}$$

Where y is the $M_R \times 1$ received signal vector, H is the $M_R \times M_T$ channel transfer function, w is the $M_T \times 1$ complex weight vector and n is spatially white noise.

Array gain when the transmitter knows the channel is greater than or equal to the array gain when the channel is unknown. This scheme extracts a full diversity order of $M_T M_R$.

Coding can be used across space and time to maximize link performance. Broad goals are, to maximize link throughput and minimize error. These goals can be translated to supporting performance criteria such as the signaling rate (in bps/Hz or bits per transmission) , the diversity gain (or diversity order, which is the slope of the error vs. SNR curve), the coding gain(from code design that increases the effective SNR), and the array gain (from antenna combining that also increases the effective SNR). ST coding techniques that can extract diversity gain and coding gain is discussed next with the help of coding architecture.

2.5 GENERIC CODING ARCHITECTURE

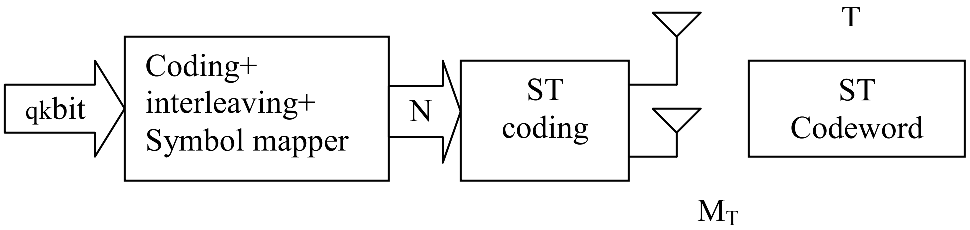


Figure- 2.2: Coding Architecture

A general coding architecture for transmission over multiple antennas is described here. Consider figure 2.2 in which a block of qk bits is input to a block that performs the functions of temporal coding, interleaving and symbol mapping. In the process q (N-K) parity bits are added and N symbols are output. 2^q is the modulation order. The N symbols are now input to a ST coder that adds an additional $M_T T$-N parity symbols and packs the resulting M_T T symbols into an $M_T \times T$ frame of length T. The block/frame is then transmitted over T symbol periods and is referred to as ST Codeword. The signaling (data) rate on the channel is qK/T bits/transmission and should not exceed the channel capacity. Signaling rate is given by,

$$\frac{qK}{T} = q\left(\frac{qK}{qN}\right)\left(\frac{N}{T}\right) \tag{2.13}$$

$$= q\, r_t\, r_s$$

where r_t=qK/qN is the temporal code rate of the outer encoder and r_s=N/T is the spatial code rate defined as the average number of independent symbols (constructed from the input symbols) transmitted from the M_T antennas over T symbols periods. When all transmit antennas send one symbol per symbol period we get $r_s=1$.On the other hand, in spatial multiplexing, M_T independent symbols per symbol period are sending to get $r_s=M_T$. Depending on the choice of ST coding, the spatial rate r_s varies between 0 to M_T.

ST codewords can be broadly classified as:

- rate ≥ 1 ST coding
- rate ≤ 1 ST coding

1. ST diversity coding (rate ≥ 1)

ST hybrid code similar in nature to the linear dispersion framework proposed by Hassibi and Hochwald offers spatial rates ranging from 1 to M_T that explicitly includes both capacity efficiency and diversity/coding gain metrics [16].

2. ST diversity coding (rate ≤ 1)

Diversity modulation, or space-time coding, uses specially designed codeword that maximize the diversity advantage or reliability of the transmitted information. In fading channels, such codes maximize the diversity gain at the expense of a loss in capacity. Major goals in space time coding are (a) to improve error performance, which implies the maximum diversity gain; and (b) to increase coding gain, which depends on the minimum distance of the code; (c) to increase the array gain, which is upper bounded by number of receive antennas. ST diversity coding with channel knowledge is considered here. There are two forms of ST diversity coding:

1. ST trellis coding (STTC) – where the codes have a trellis description
2. ST block coding (STBC)- where a block description is used

2.5.1 Space-Time Trellis Coding

STTC are an extension of conventional trellis codes to multi-antenna systems. These codes may be designed to extract diversity gain and coding gain. Each STTC can be described using a trellis. The number of nodes in the trellis diagram corresponds to the number of states in the trellis. Each node has A groups of symbols to the left (A being the constellation size), with each group consisting of MT entries. Each group corresponds to the output for a given input symbol. The M_T entries in each group correspond to the symbols to be transmitted from M_T antennas [5].

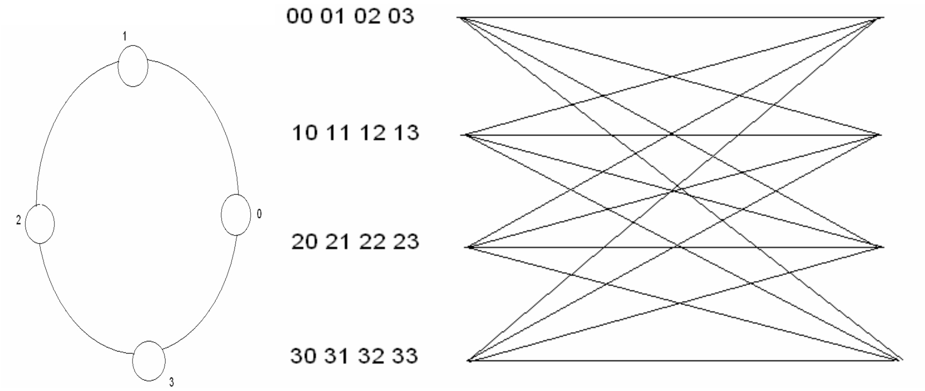


Figure 2.3: Trellis Diagram For A 4-QAM, Four State Trellis Code for M_T=2 with A Rate of 2 Bps/Hz

Figure 2.3 shows the trellis diagram for a simple 4=QAM, four state trellis code, for M_T=2 with rate 2 bps/Hz. The trellis has four nodes corresponding to four states. There are four groups of symbols at the left of every node since there are four possible inputs (4-Qam constellation). Each group has two entries corresponding to the symbols to be output trough the two transmit antennas. For example, 02 (third entry for first node) correspond to symbols 2 and 0 being output from antennas 1 and 2 respectively, when the input is the third symbol. The output 0,1,2 and 3 are mapped to data symbols 1,j, -1 and –j respectively. The encoder is required to be in the zero state at the beginning and at the end of each frame (block). Beginning in state 0, if the incoming two bits are 10, the encoder outputs a 2 on antenna 1 and a 0 on antenna 2 and changes state-to-state 2.

Space-time trellis coding is a recent proposal that combines signal processing at the receiver with coding technique appropriate to multiple antennas. Specific space-time trellis codes designed for 2-4 antennas perform extremely well in slow fading environments (typical to indoor transmission) and come close to the outage capacity computed by Telatar and independently by Foschini and Gans. However, when the numbers of transmit antennas is fixed, the decoding complexity of space-time trellis codes (measured by the number of trellis states in the decoder) increases exponentially with the transmission rate.

2.5.2 Space-Time Block Coding

Space-time coding, a new paradigm for communication over multiple fading channels using multiple transmit antennas. Data is encoded using a space-time block code and the encoded data is split into n streams which are simultaneously transmitted using n transmit antennas. The received signal at each receive antenna is a linear superposition of the n transmitted signals perturbed by noise. Maximum-likelihood decoding is achieved in a simple way through decoupling of the signals transmitted from different antennas rather than joint detection. Space-time block codes are designed to achieve the maximum diversity order for a given number of transmit and receive antennas subject to the constraint of having a simple decoding algorithm.

2.6 ORTHOGONAL SPACE-TIME BLOCK CODING (OSTBC)

Orthogonal STBC can be explained by Alamouti scheme [6]. The Alamouti scheme transmits symbols s_1 and s_2 from antennas 1 and 2 respectively, during the first symbol period, followed by $-s_2^*$ and s_1^* from antennas 1 and 2 respectively during the following symbol period. Hence, the transmitted ST codeword may be expressed as

$$S = \begin{bmatrix} s_1 & -s_2^* \\ s_2 & s_1^* \end{bmatrix} \tag{2.14}$$

It is easy to verify that the codeword difference matrix between any pair of codeword, say $S^{(i)}$ and $S^{(j)}$, is of the form

$$E_{i,j} = \begin{bmatrix} e_1 & -e_2^* \\ e_2 & e_1^* \end{bmatrix} \tag{2.15}$$

$E_{i,j}$ is an orthogonal matrix with two non-zero eigen values (rank 2) of equal magnitude.

The Alamouti scheme therefore delivers full $2M_R$ order diversity, where MR is the number of the receive antennas .the structure of the transmitted signal is such that the effective channel is rendered orthogonal regardless of the channel realization, thus decoupling the otherwise complex vector ML detection problem in to the simpler scalar detection problems. The receiver output is given by

$$y_i = \sqrt{\frac{E_s}{2}} \|H\|_F^2 s_i + n_i , \qquad i = 1,2 \tag{2.16}$$

Where y_i is the scalar processed received signal corresponding to the transmitted symbol s_i and n_i is noise with variance $\|H\|_F^2 N_0$.

ST code construction for Alamouti type schemes ($M_T=2$) can b generalized using orthogonal designs for $M_T>2$. Orthogonal ST code words for real constellation may be designed for systems using any number of transmit antennas using the solution to the Hurwitz-Radon problem. An example of an orthogonal design for $M_T=4$ is

$$S=\begin{bmatrix} s_1 & -s_2 & -s_3 & -s_4 \\ s_2 & s_1 & s_4 & -s_3 \\ s_3 & -s_4 & s_1 & s_2 \\ s_4 & s_3 & -s_2 & s_1 \end{bmatrix} \tag{2.17}$$

Where symbols s_1, s_2, s_3 and s_4 are all drawn from a real constellation. The difference between two codeword, say $S^{(i)}$ and $S^{(j)}$, is an orthogonal matrix $E_{i,j}$ .the spatial rate for the ST codes is 1.

In case of complex constellations, Tarokh et al.,1999b showed that orthogonal design with spatial rate 1 does not exist for systems with more than two transmit antennas. The Alamouti scheme is rates 1 design for systems with two transmit antennas. Orthogonal designs for rates less than or equal to ½ exists for systems with any number of transmit antennas.

Orthogonal space-time block codes with rates greater than ½ can exists for systems with three or four transmit antennas. One such code with rate =3/4 for three and four transmit antennas has been proposed in space-time block codes from orthogonal designs by Vahid Tarokh et al. Higher order quasi-orthogonal St codes have been proposed by Papadias and Foschini. Though OSTBC are attractive due to their low implementation and decoding complexity, they will be outperformed by STTC. However, OSTBC concatenated with the standard AWGN codes can outperform some of the best-known STTC (with the same transmit power and signaling rate) in terms of error performance.

The performance of rate 3 by 4 and rate 1 by 2 code under rayleigh fading is discussed next and their SNR performance is compared.

CHAPTER 4

PERFORMANCE OF FRACTIONAL RATE CODES IN RICIAN FADING ENVIRONMENT

The basic wireless communication system model consisting of encoder, channel and the receiver discussed in section 3.1 is used for RICIAN fading also. Here also the space-time encoder, encodes the incoming data bit stream and with the help of transmitting antennas transmits the signal. At the receiver, signal is decoded.

The only difference is in nature of the channel, which is RICIAN in this case. Depending on the nature of the radio propagation environment, there are different channel models describing the statistical behavior of the multipath-fading envelope.

4.1 Rician 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 Rician. In such a situation, random multipath components arriving at different angles are superimposed on a stationary dominant signal [10]. At the output of an envelope detector, this has the effect of adding a dc component to the random multipath. For a multipath fading channel containing a specular or LOS component, the complex envelope of the received signal can be given by the Rician distribution,

$$p(r) = \begin{cases} \frac{r}{\sigma^2} e^{-\frac{(r^2 + A^2)}{2\sigma^2}} I_0\left(\frac{Ar}{\sigma^2}\right) & \text{for } (A \geq 0, r \geq 0) \\ 0 & \text{for } (r < 0) \end{cases} \tag{4.1}$$

where *A* denotes the peak amplitude of the dominant or LOS signal and I0(.) is the zeroth order modified Bessel function of the first kind. The Rician distribution is often described in terms of a parameter *K* called Rician factor, which is defined as the ratio between the deterministic signal power and the variance of the multipath.

The description for various modulation techniques i.e.: BPSK, QPSK, 8PSK and M-4-QAM, their corresponding constellation diagrams remain the same as discussed in section 3.3. Also the MONTE CARLO SIMULATION STEPS for RAYLEIGH fading are similar for RICIAN fading too expect for generation of Rician fade channel.

4.2 SIMULATION RESULTS OF RATE 3 BY 4 SCHEMES

4.2.1 Simulation results of BER for RICIAN FADING in DIFFERENT MODULATION TECHNIQUES using THREE TRANSMIT ANTENNAS

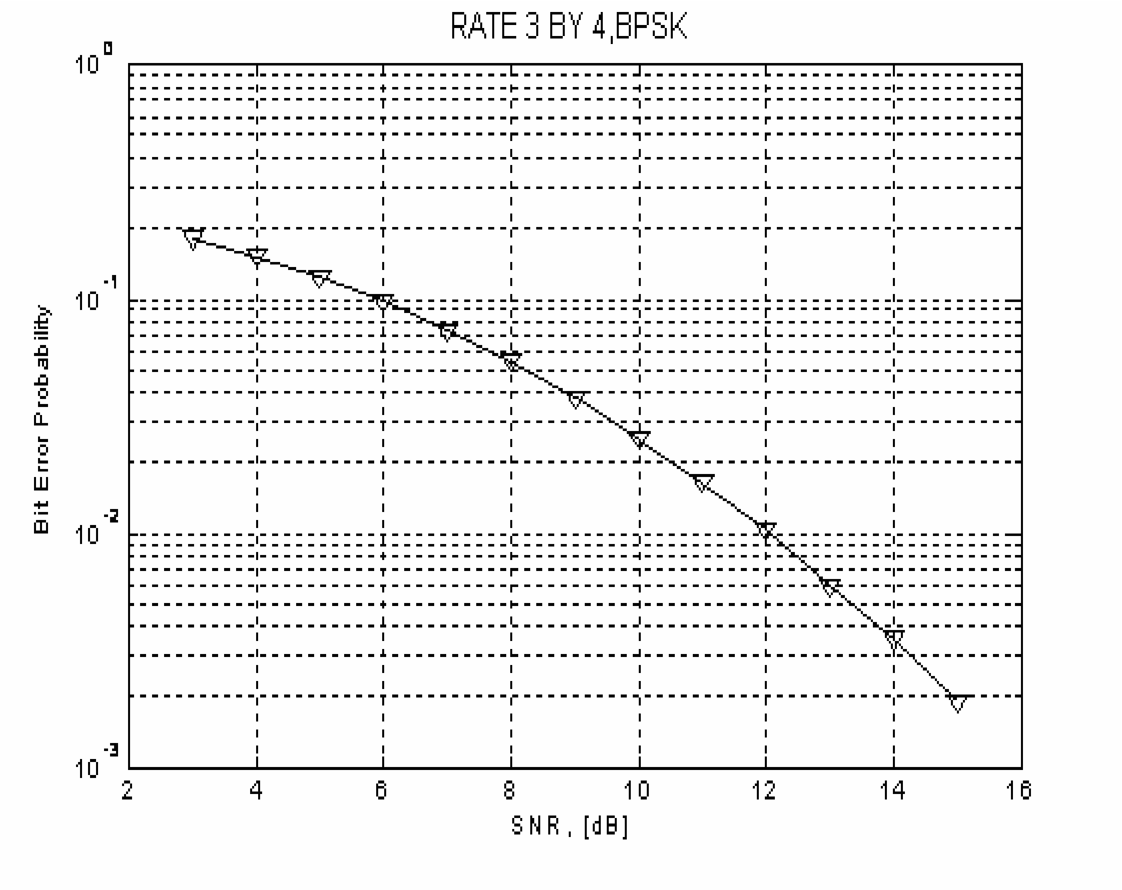


Figure-4.1: BER error performance of BPSK for RICIAN fading for rate 3 by 4 (3 Transmitting Antennas)

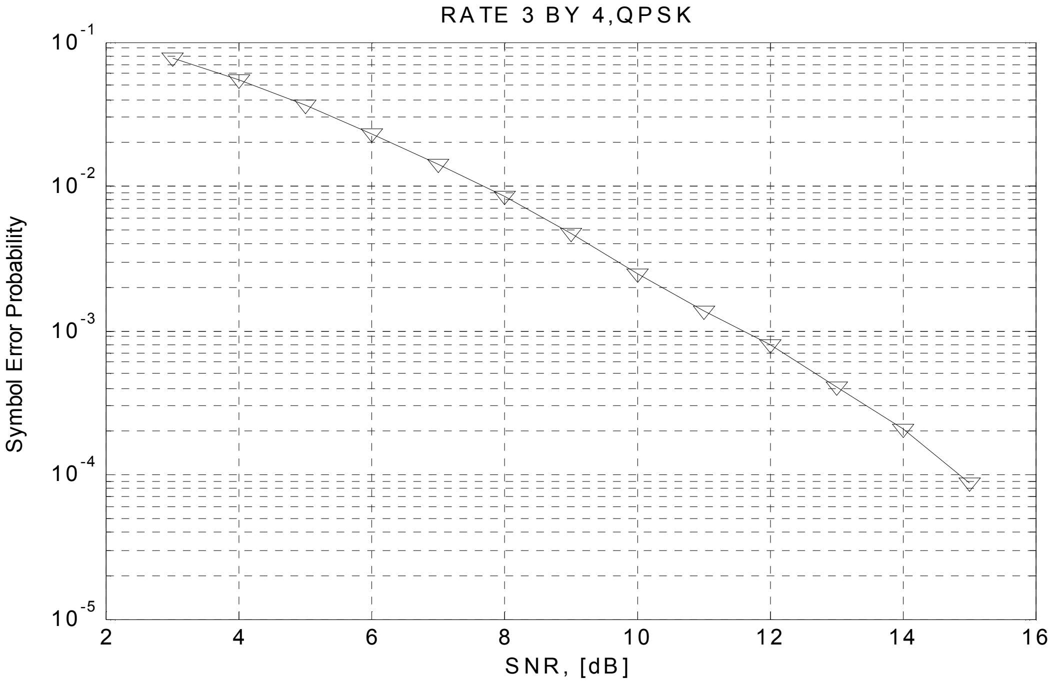


Figure-4.2: BER error performance of QPSK for RICIAN fading for rate 3 by 4 (3 Transmitting Antennas)

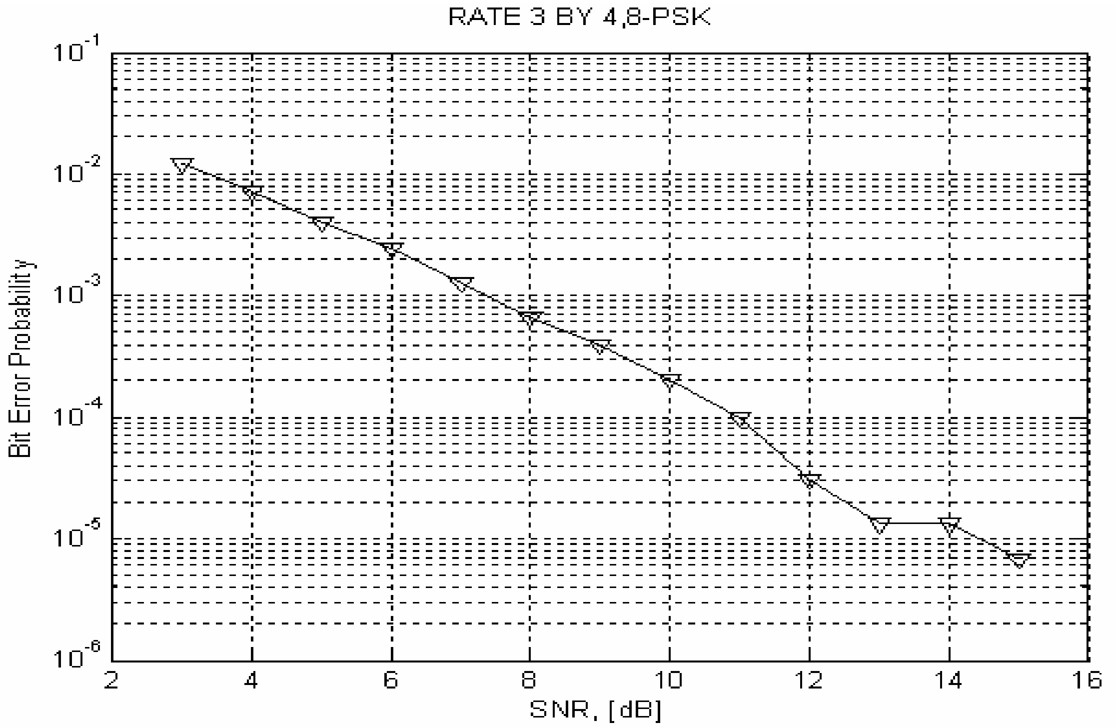


Figure-4.3: BER error performance of 8-PSK for RICIAN fading for rate 3 by 4 (3 Transmitting Antennas)

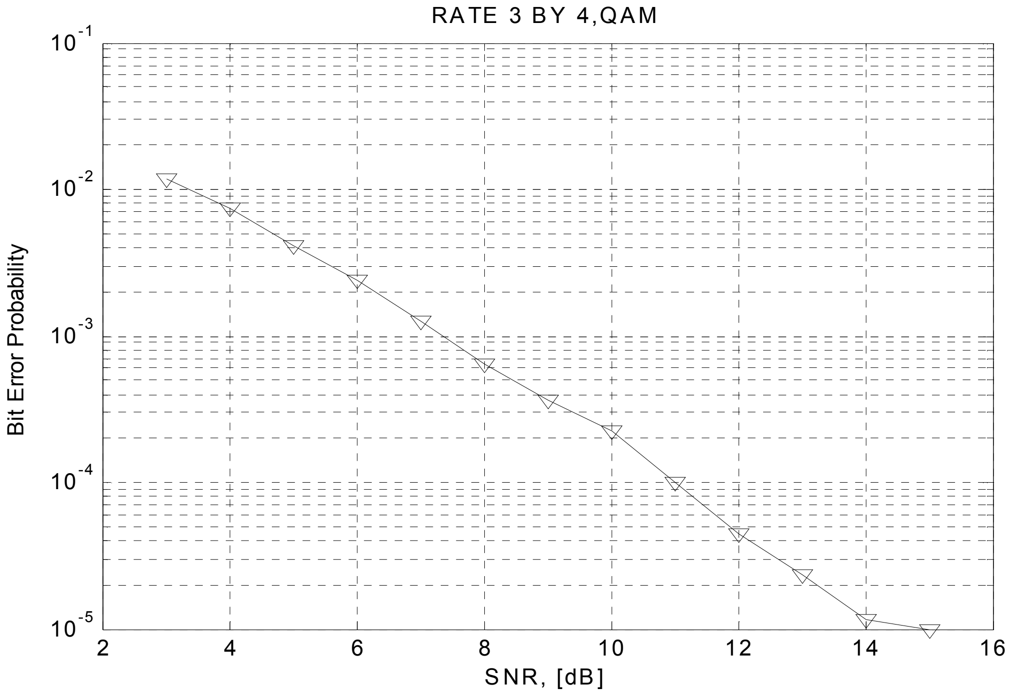


Figure-4.4: BER error performance of 4-QAM for RICIAN fading for rate 3 by 4 (3 Transmitting Antennas)

4.2.1.1 SNR Comparison of Various Modulations under Rician Fading.

Table-4.1: SNR performance under RICIAN fading at BER 10^{-2} for rate 3 by 4 (3 Transmitting Antennas)

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	12dB
QPSK	8 dB
8-PSK	3.2dB
4-QAM	3.5 dB

Table-4.1 shows that at the bit error rate of 10^{-2} 8-PSK modulation technique gives about 8.8 dB gain over the use of BPSK under RICIAN fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK. Also, gain difference between QAM and QPSK is 4.5.

4.2.2 Simulation results of BER for RICIAN FADING in DIFFERENT MODULATION TECHNIQUES using FOUR TRANSMIT ANTENNAS

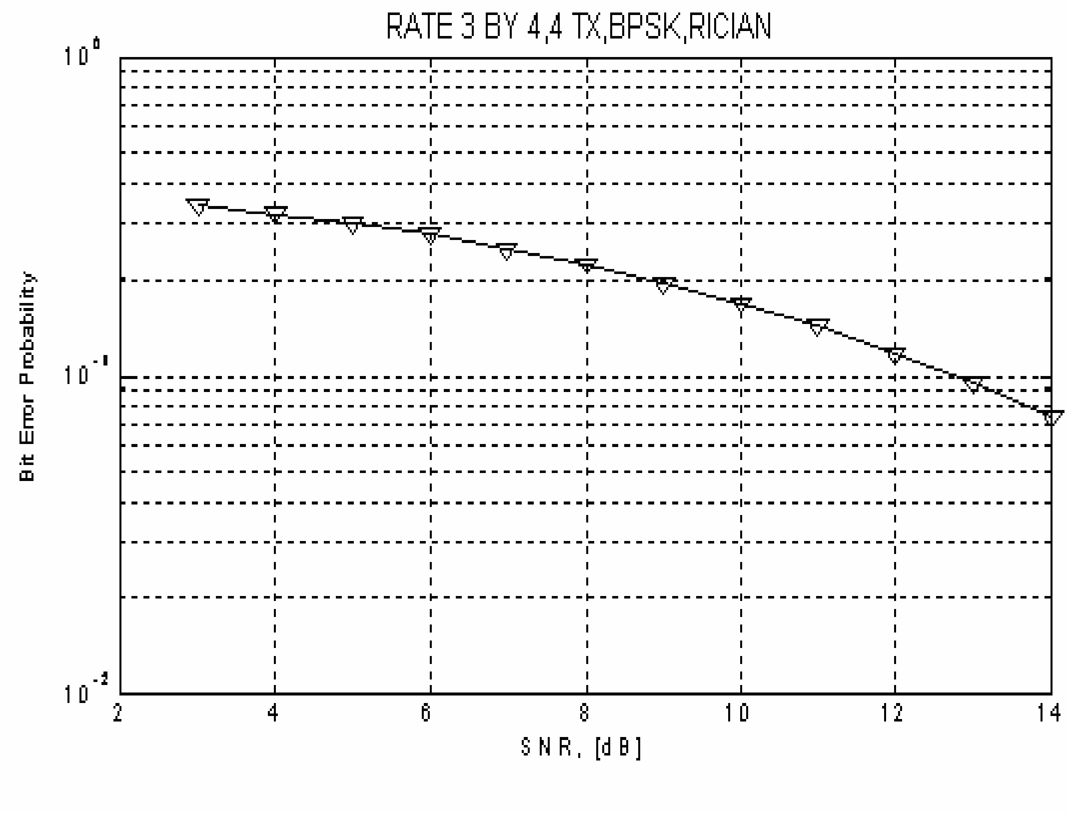


Figure-4.5: BER error performance of BPSK for RICIAN fading for rate 3 by 4 (4 Transmitting Antennas)

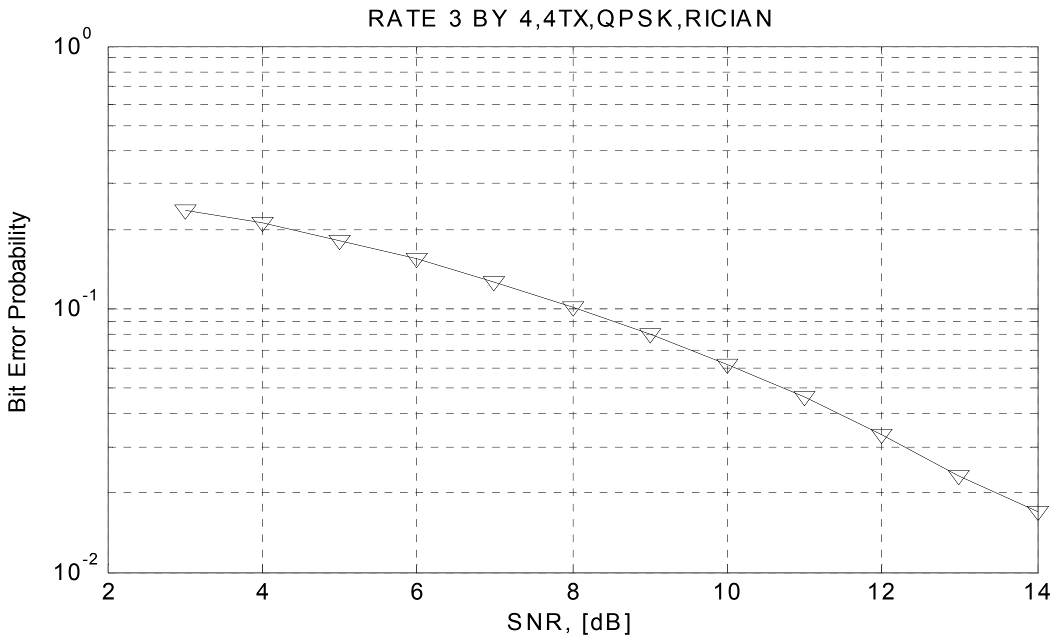


Figure-4.6: BER error performance of QPSK for RICIAN fading for rate 3 by 4 (4 Transmitting Antennas)

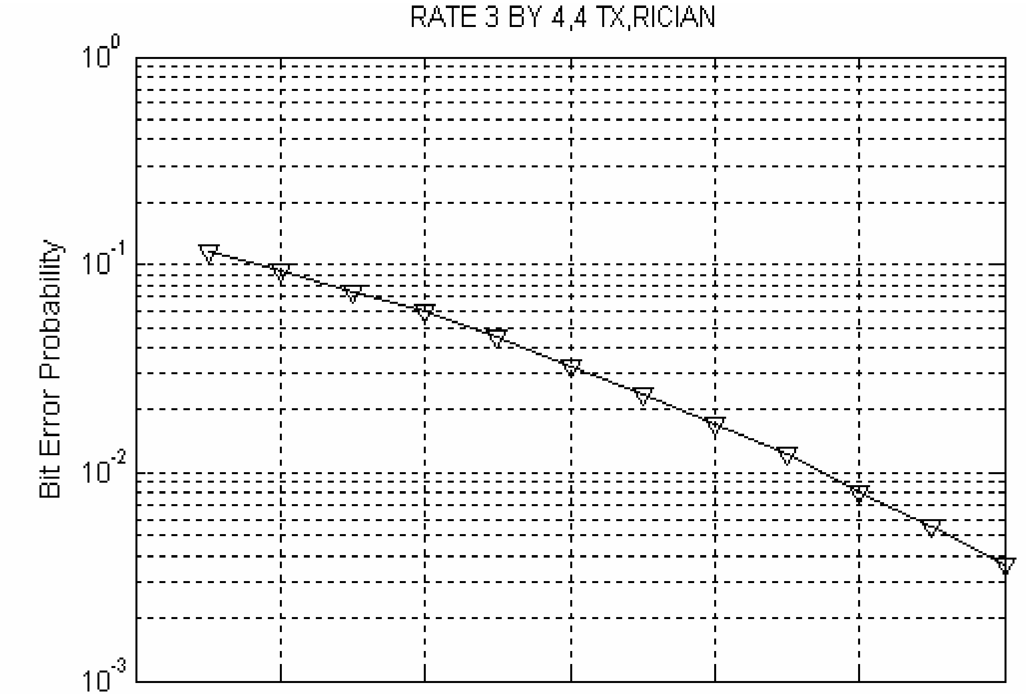


Figure-4.7: BER error performance of 8-PSK for RICIAN fading for rate 3 by 4 (4 Transmitting Antennas)

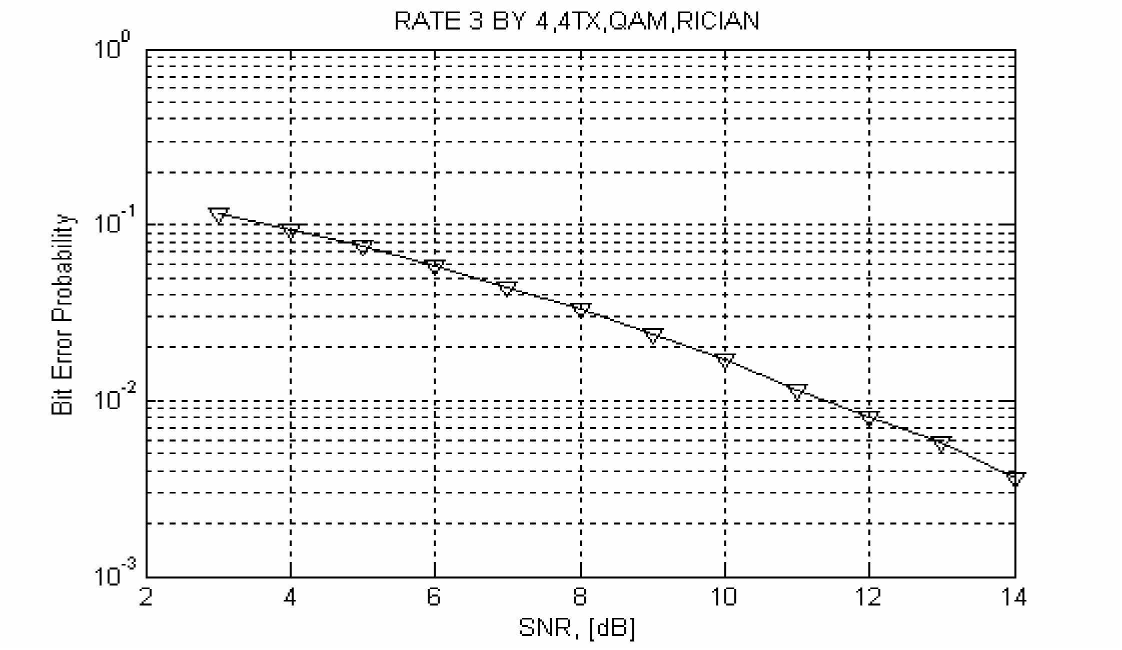


Figure-4.8: BER error performance of 4-QAM for RICIAN fading for rate 3 by 4 (4 Transmitting Antennas)

4.2.2.1 SNR Comparison of Various Modulations under Rician Fading.

Table-4.2: SNR performance under RICIAN fading at BER 10^{-1} for rate 3 by 4 (4 Transmitting Antennas)

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	13dB
QPSK	8 dB
8-PSK	3.5 dB
4-QAM	4 dB

Table-4.2 shows that at the bit error rate of 10^{-1} 8-PSK modulation technique gives about 9.5 dB gain over the use of BPSK under RICIAN fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK. The performance of QPSK and QAM comparable at bit error rate of 10^{-2} with difference in gain of 0.5 dB.

4.2.3 Simulation results of SER for RICIAN FADING in DIFFERENT MODULATION TECHNIQUES using THREE TRANSMIT ANTENNAS

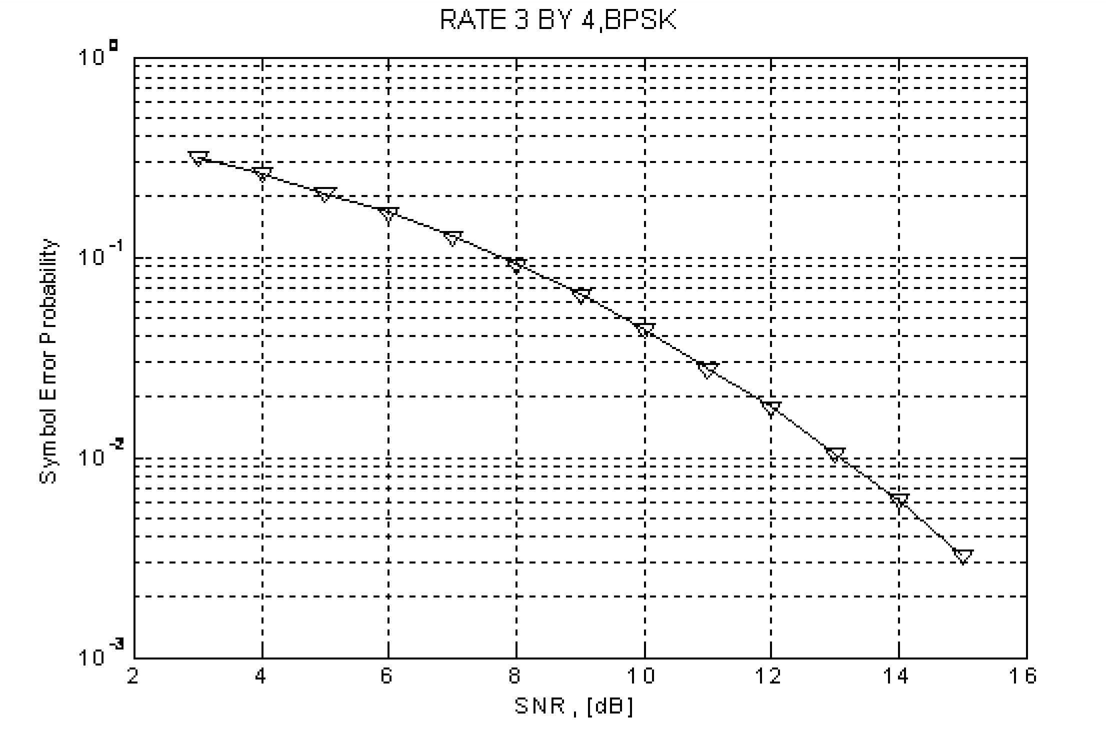


Figure-4.9: SER performance of BPSK under RICIAN fading for rate 3 by 4 (3 Transmitting Antennas)

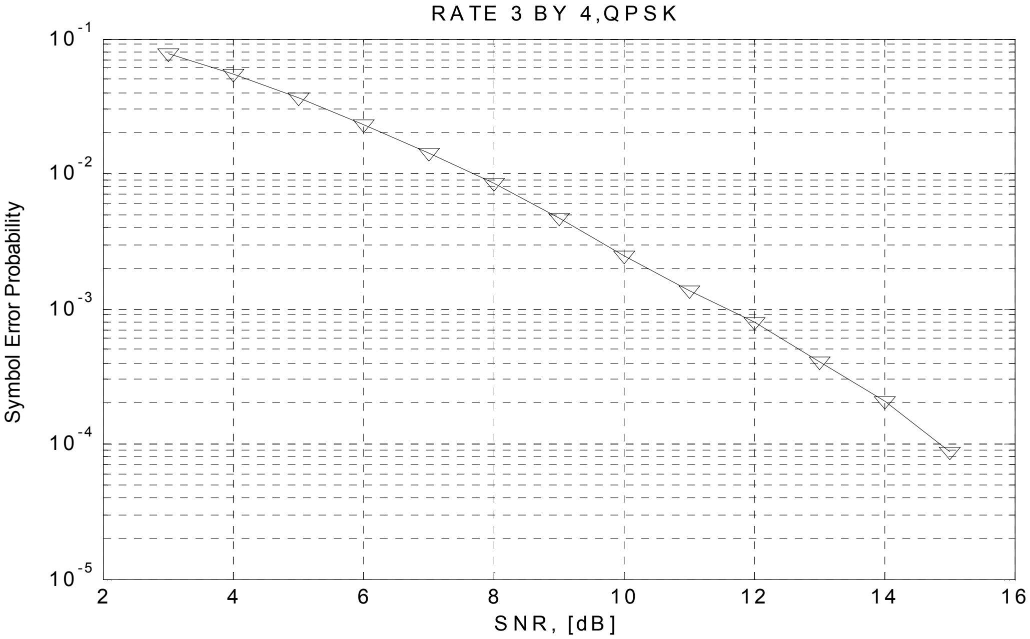


Figure-4.10: SER performance of QPSK under RICIAN fading for rate 3 by 4 (3 Transmitting Antennas)

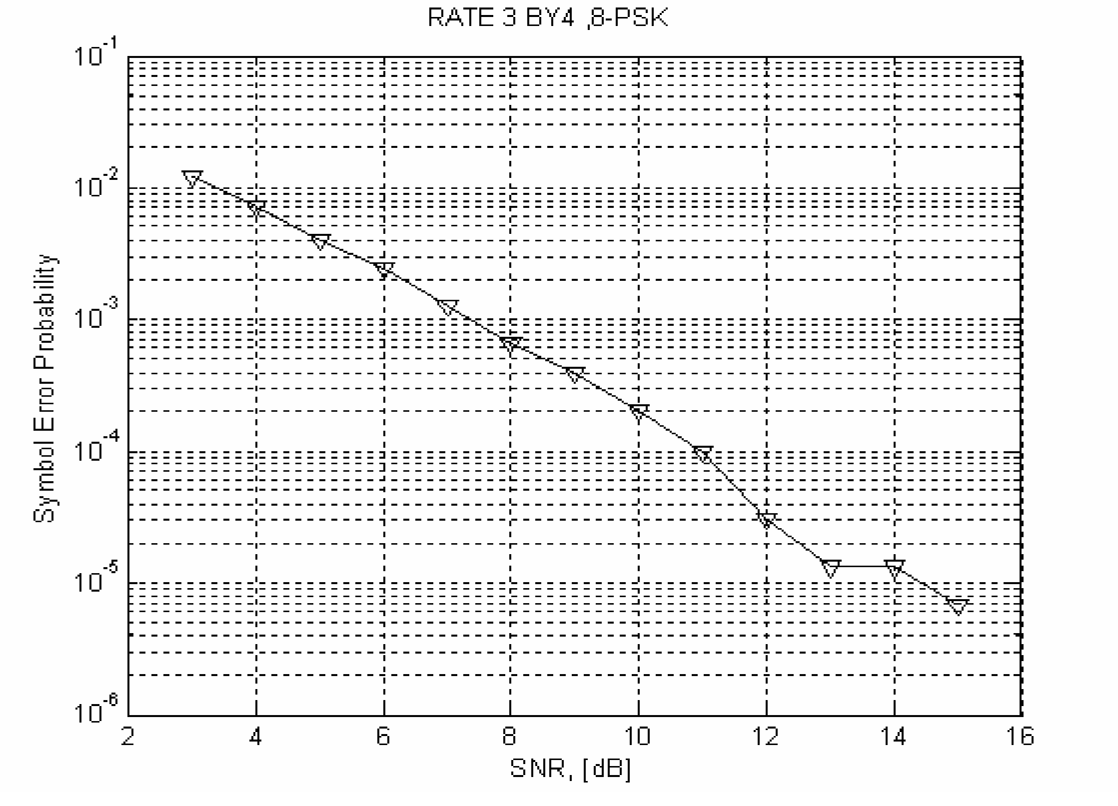


Figure-4.11: SER performance of 8-PSK under RICIAN fading for rate 3 by 4 (3 Transmitting Antennas)

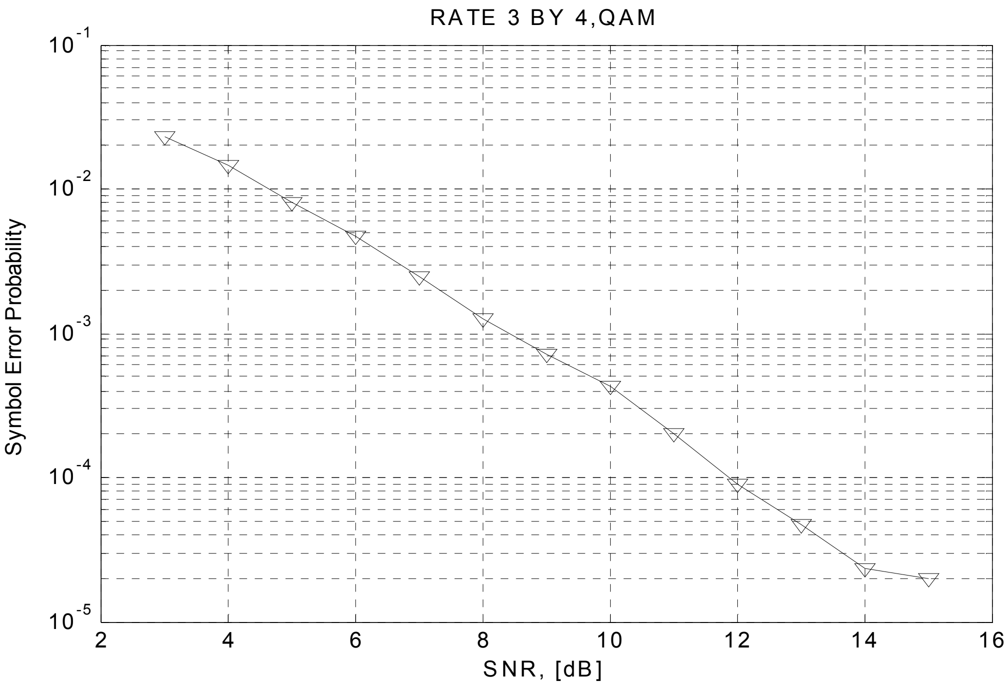


Figure-4.12: SER performance of 4-QAM under RICIAN fading for rate 3 by 4 (3 Transmitting Antennas)

4.2.3.1 SNR Comparison Of Various Modulations Under Rician Fading.

Table-4.3: SNR performance under RICIAN fading at SER of 10^{-2}dB for rate 3 by 4 (3 Transmitting Antennas)

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	8 dB
QPSK	7.5 dB
8-PSK	3.5 dB
4-QAM	5 dB

Table-4.3 shows that at the symbol error rate of 10^{-2} 8-PSK-modulation technique gives about 4.5 dB gain over the use of BPSK under RICIAN fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK. Difference in gain performance of QPSK and 4-QAM is about 2.5 dB.

4.2.4 Simulation results of SER for RICIAN FADING in DIFFERENT MODULATION TECHNIQUES using FOUR TRANSMIT ANTENNAS

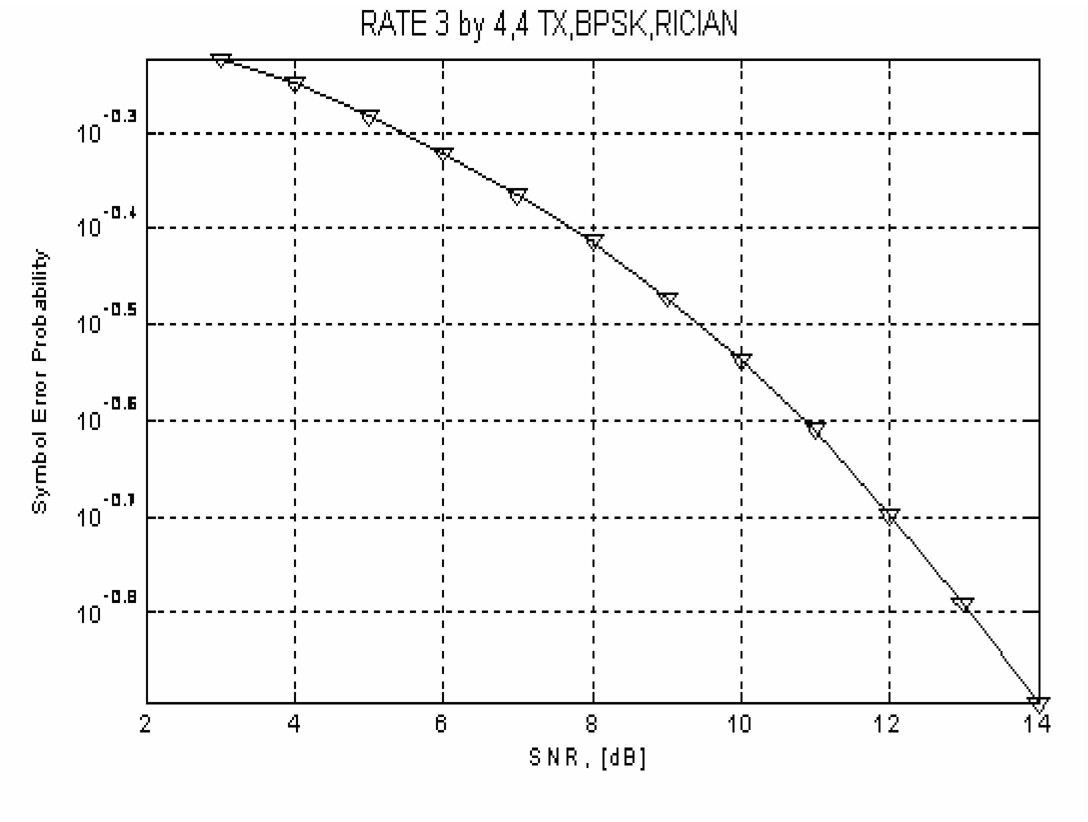


Figure-4.13: SER error performance of BPSK for RICIAN fading for rate 3 by 4 (4 Transmitting Antennas)

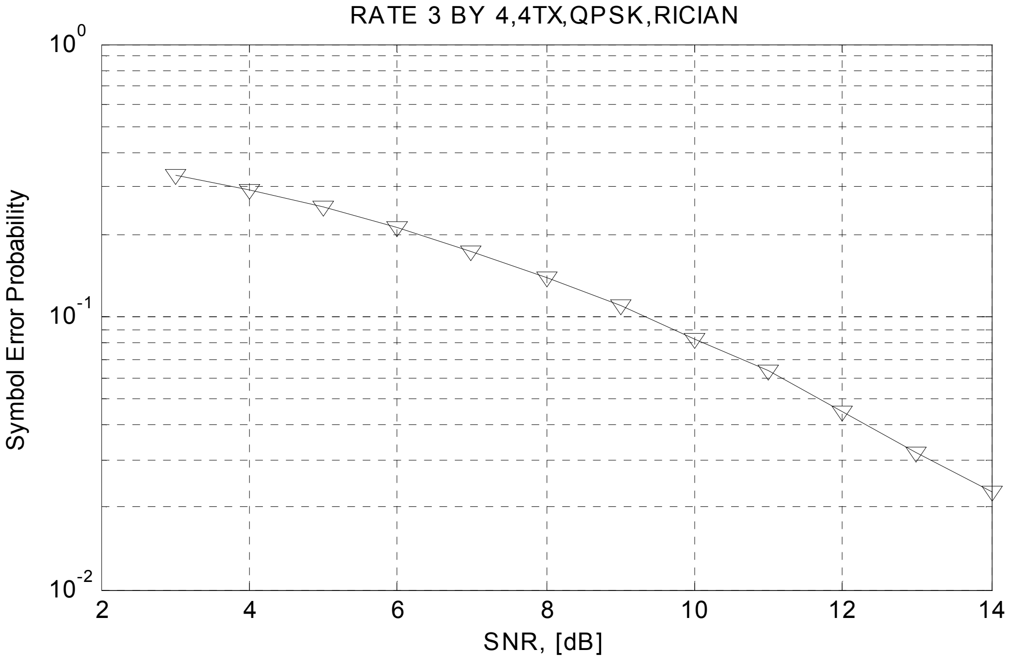


Figure-4.14: SER error performance of QPSK for RICIAN fading for rate 3 by 4 (4 Transmitting Antennas)

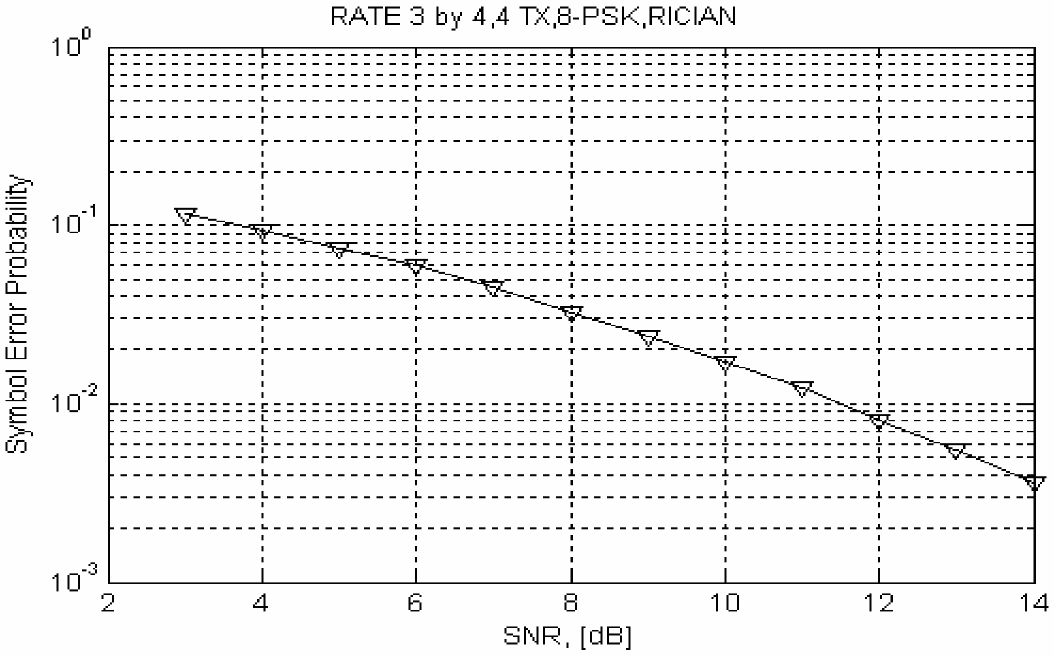


Figure-4.15: SER error performance of 8-PSK for RICIAN fading for rate 3 by 4 (4 Transmitting Antennas)

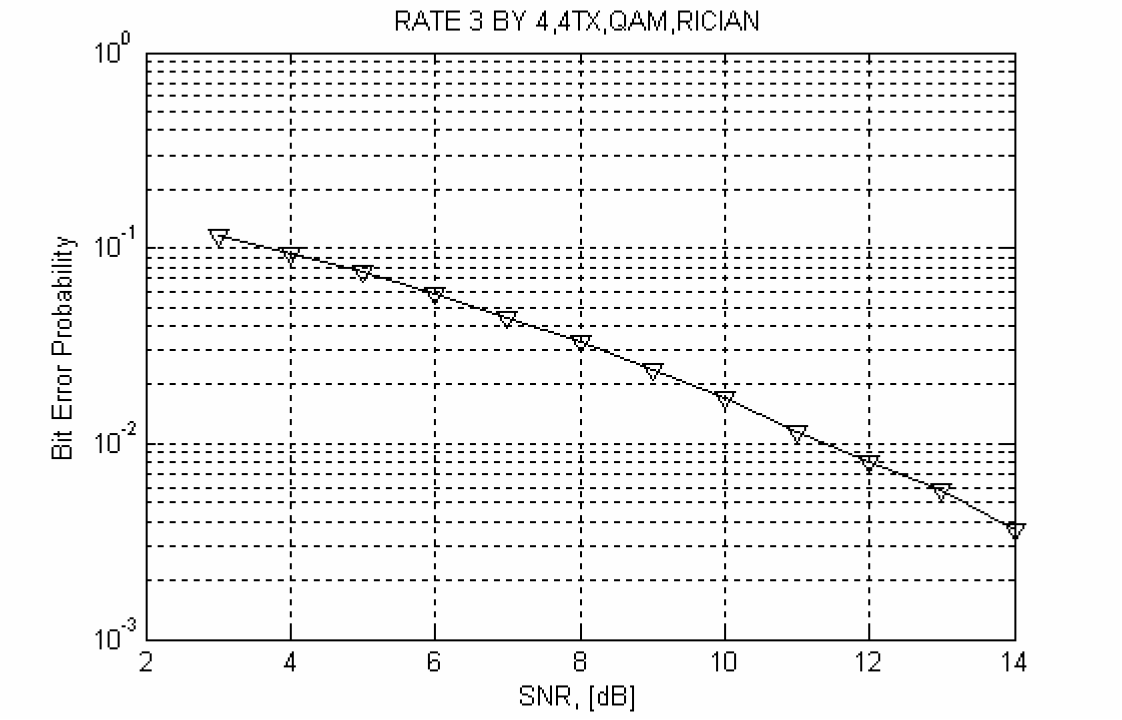


Figure-4.16: SER error performance of 4-QAM for RICIAN fading for rate 3 by 4 (4 Transmitting Antennas)

4.2.4.1 SNR Comparison of Various Modulations under Rician Fading.

Table-4.4: SNR performance under RICIAN fading at SER 10^{-2} for rate 3 by 4 (4 Transmitting Antennas)

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	16 dB
QPSK	9 dB
8-PSK	3.5 dB
4-QAM	3.5 dB

Table-4.4 shows that at the symbol error rate of 10^{-2} 8-PSK-modulation technique gives about 12.5 dB gain over the use of BPSK under RICIAN fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK. The performance of QPSK and 4-QAM is comparable at bit error rate of $10^{-2.}$.

4.3 SIMULATION RESULTS OF RATE 1 BY 2 SCHEMES

4.3.1 Simulation results of BER for RICIAN FADING in DIFFERENT MODULATION TECHNIQUES using THREE TRANSMIT ANTENNAS

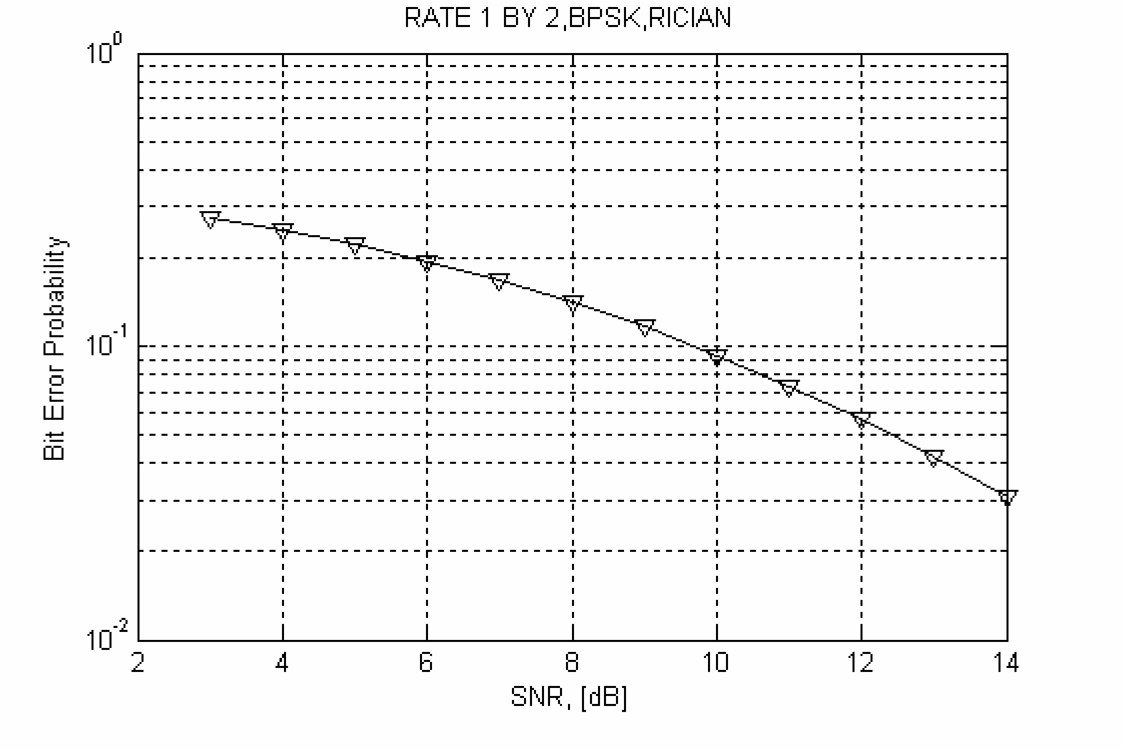


Figure-4.17: BER error performance of BPSK for RICIAN fading for rate 1 by 2 for 3 transmit antennas

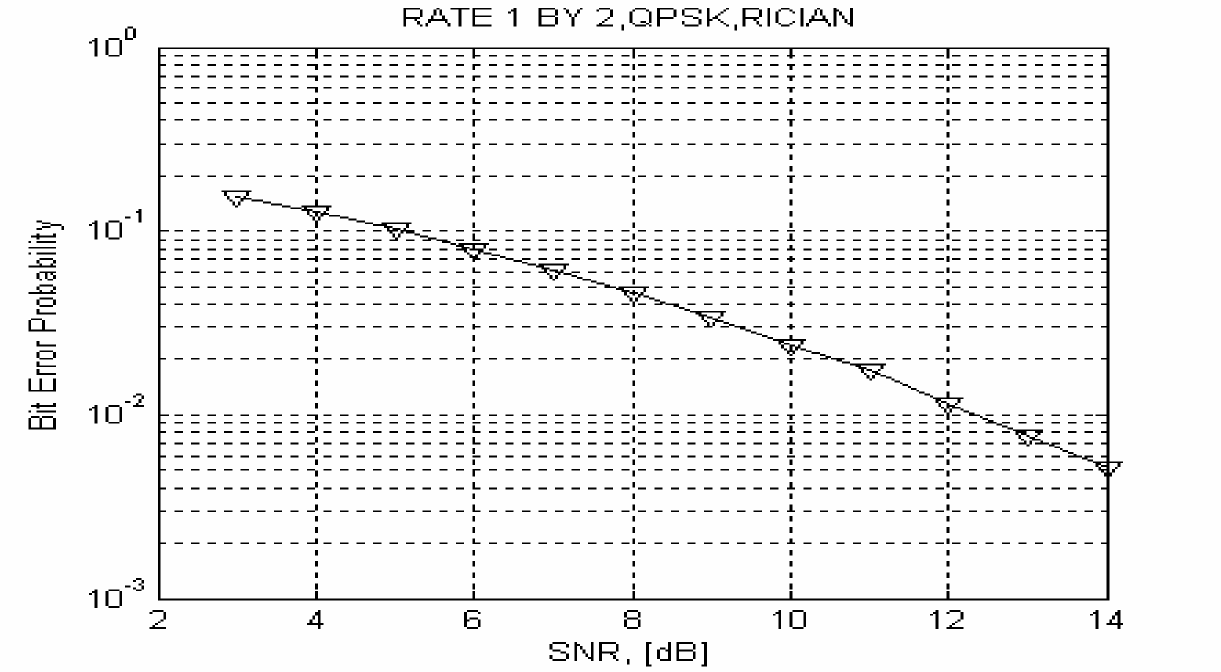


Figure-4.18: BER error performance of QPSK for RICIAN fading for rate 1 by 2 for 3 transmit antennas

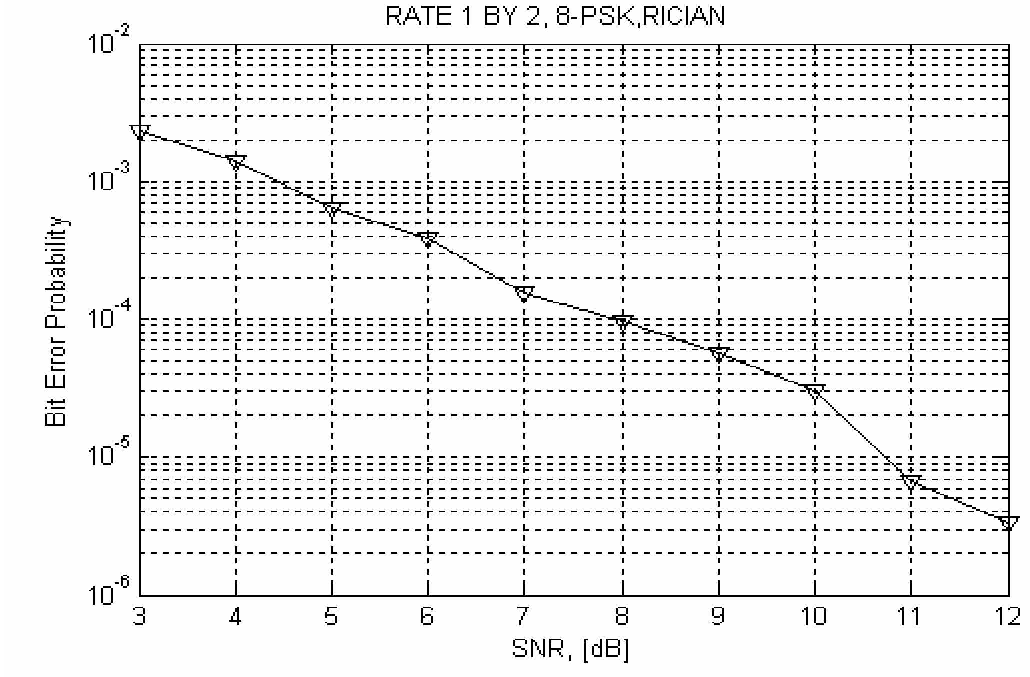


Figure-4.19: BER error performance of 8-PSK for RICIAN fading for rate 1 by 2 for 3 transmit antennas

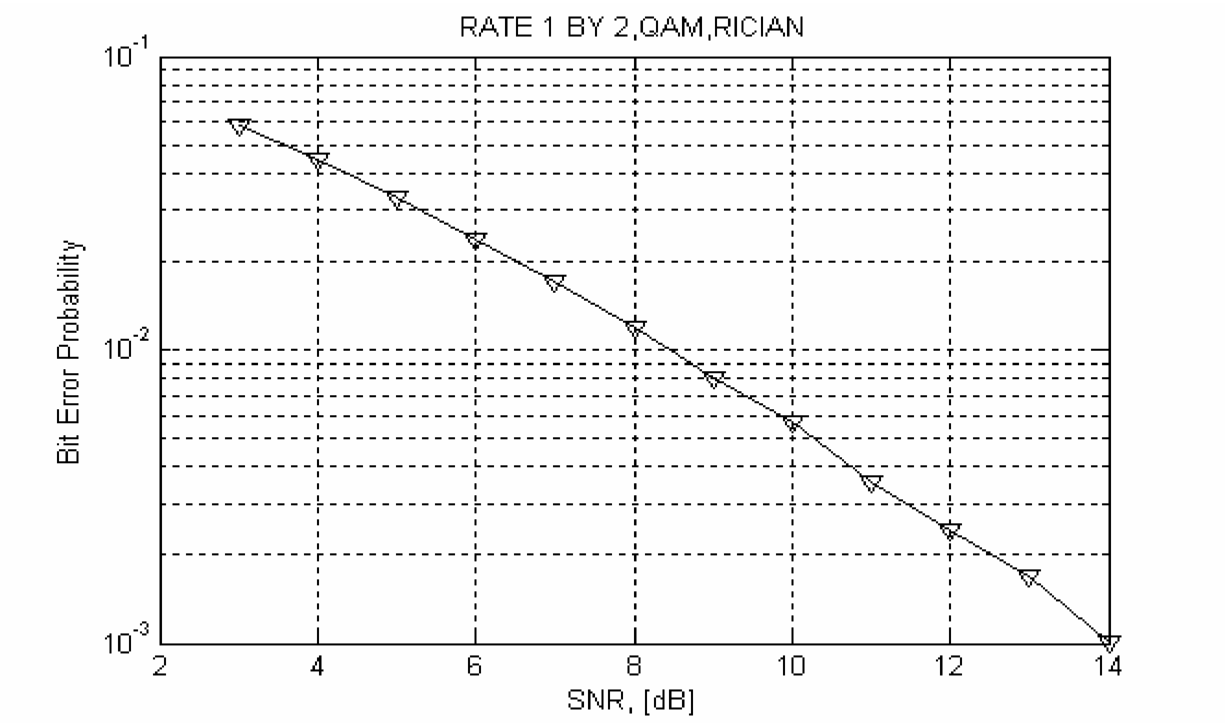


Figure-4.20: BER error performance of 4-QAM for RICIAN fading for rate 1 by 2 for 3 transmit antennas

4.3.1.1 SNR Comparison of Various Modulations under Rician Fading.

Table-4.5: SNR performance under RICIAN fading at BER 10^{-2} for rate 1 by 2 for 3 transmit antennas

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	16dB
QPSK	12 dB
8-PSK	2.5 dB
4-4-QAM	8.5 dB

Table-4.5 shows that at the bit error rate of 10^{-2} 8-PSK modulation technique gives about 13.5dB gain over the use of BPSK under RICIAN fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK. Also,4-QAMgives about 3.5 dB gain as compared to QPSK.

4.3.2 Simulation results of BER for RICIAN FADING in DIFFERENT MODULATION TECHNIQUES using FOUR TRANSMIT ANTENNAS

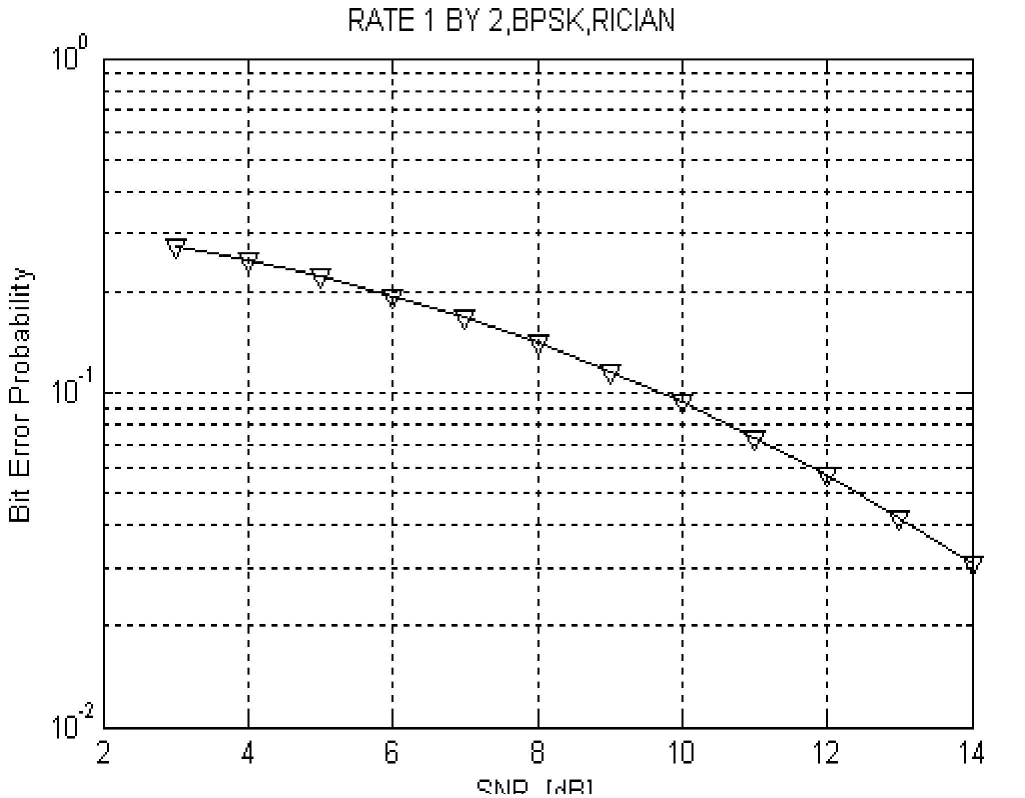


Figure-4.21: BER error performance of BPSK for RICIAN fading for rate 1 by 2 for 4 transmit antennas

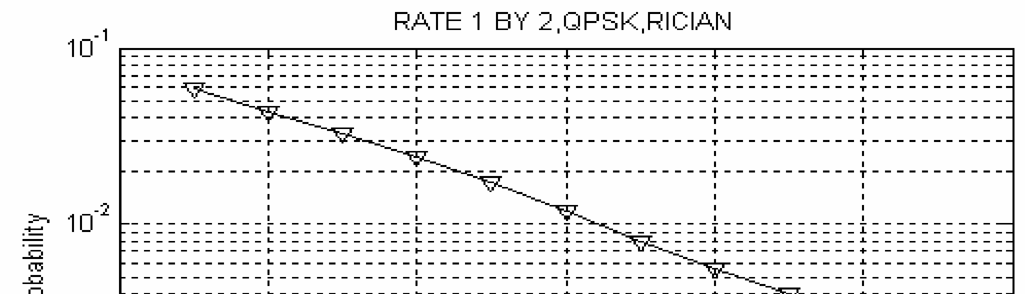


Figure-4.22: BER error performance of QPSK for RICIAN fading for rate 1 by 2 for 4 transmit antennas

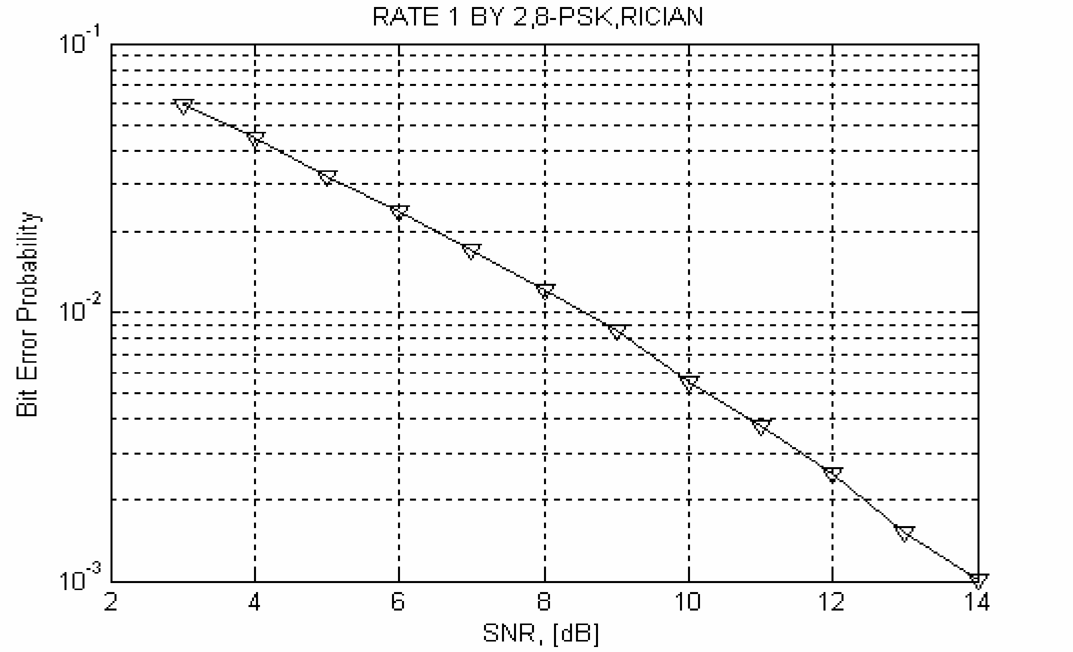


Figure-4.23: BER error performance of 8-PSK for RICIAN fading for rate 1 by 2 for 4 transmit antennas

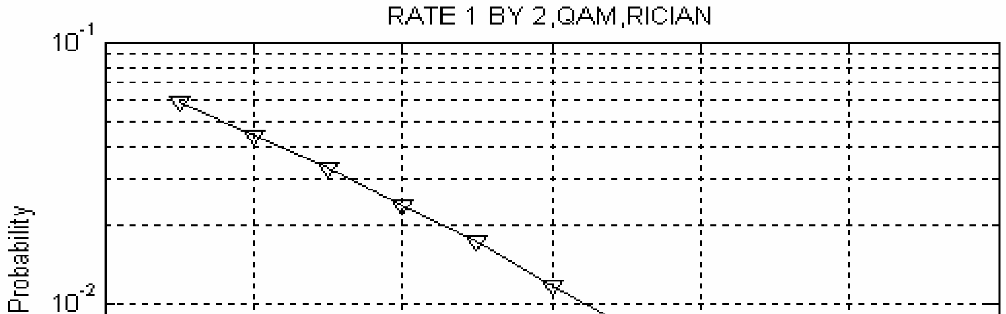


Figure-4.24: BER error performance of 4-QAM for RICIAN fading for rate 1 by 2 for 4 transmit antennas

4.3.2.1 SNR Comparison of Various Modulations under Rayleigh Fading.

Table-4.6: SNR performance under RAYLEIGH fading at BER 10^{-2} for rate 1 by 2 for 4 transmit antennas

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	16dB
QPSK	8 dB
8-PSK	8.5 dB
4-4-QAM	8.5 dB

Table-4.6 shows that at the bit error rate of 10^{-2} 8-PSK modulation technique gives about 7.5 dB gain over the use of BPSK under RAYLEIGH fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK. The performance of QPSK and QAM comparable at bit error rate of 10^{-2}.

4.3.3 Simulation results of SER for RICIAN FADING in DIFFERENT MODULATION TECHNIQUES using THREE TRANSMIT ANTENNAS

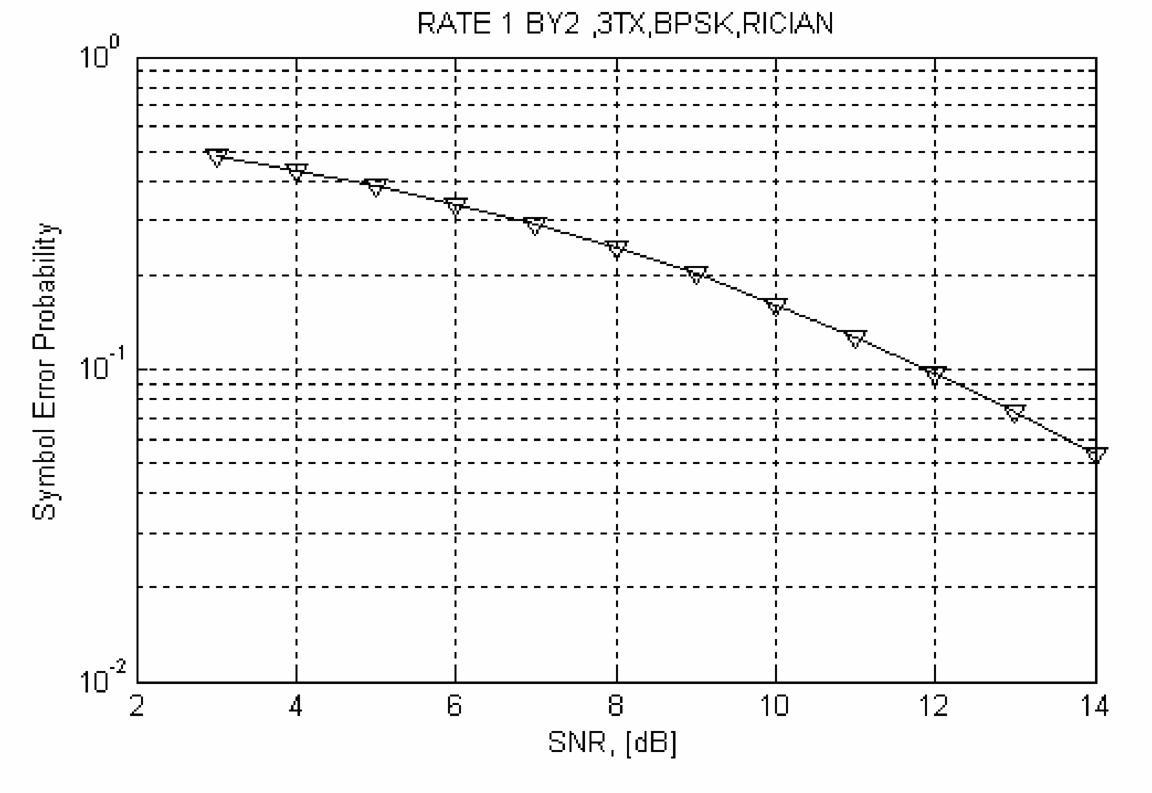


Figure-4.25: SER performance of BPSK under RICIAN fading for rate 3 by 4 (3 Transmitting Antennas)

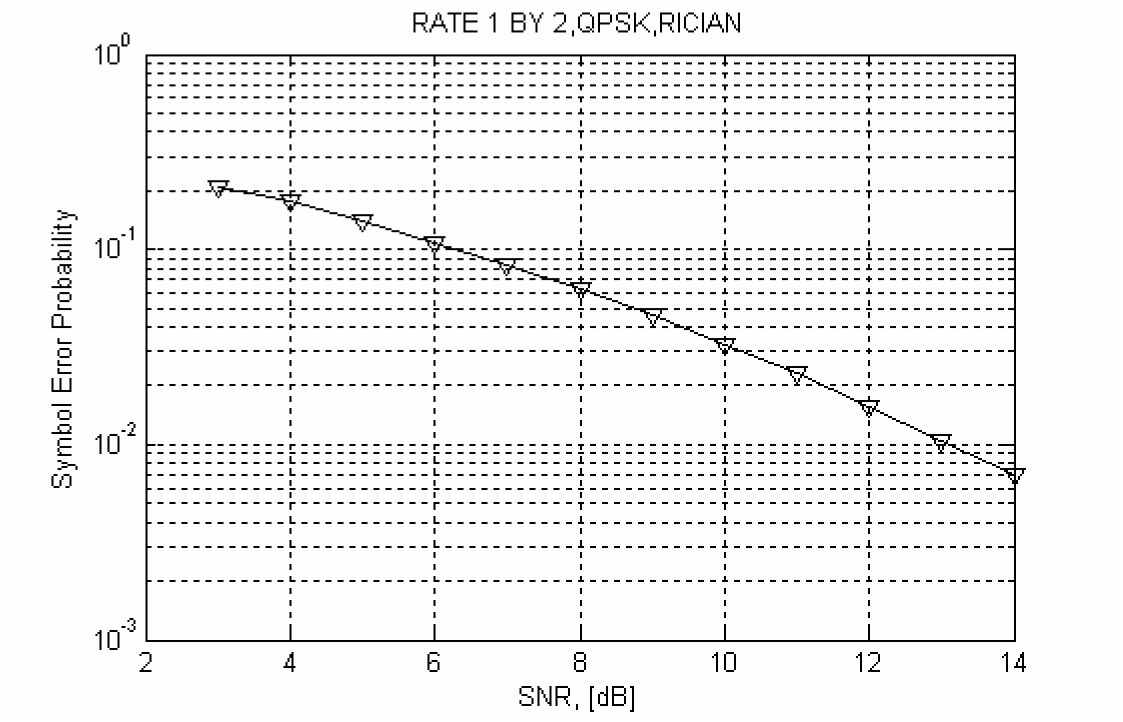


Figure-4.26: SER performance of QPSK under RICIAN fading for rate 3 by 4 (3 Transmitting Antennas)

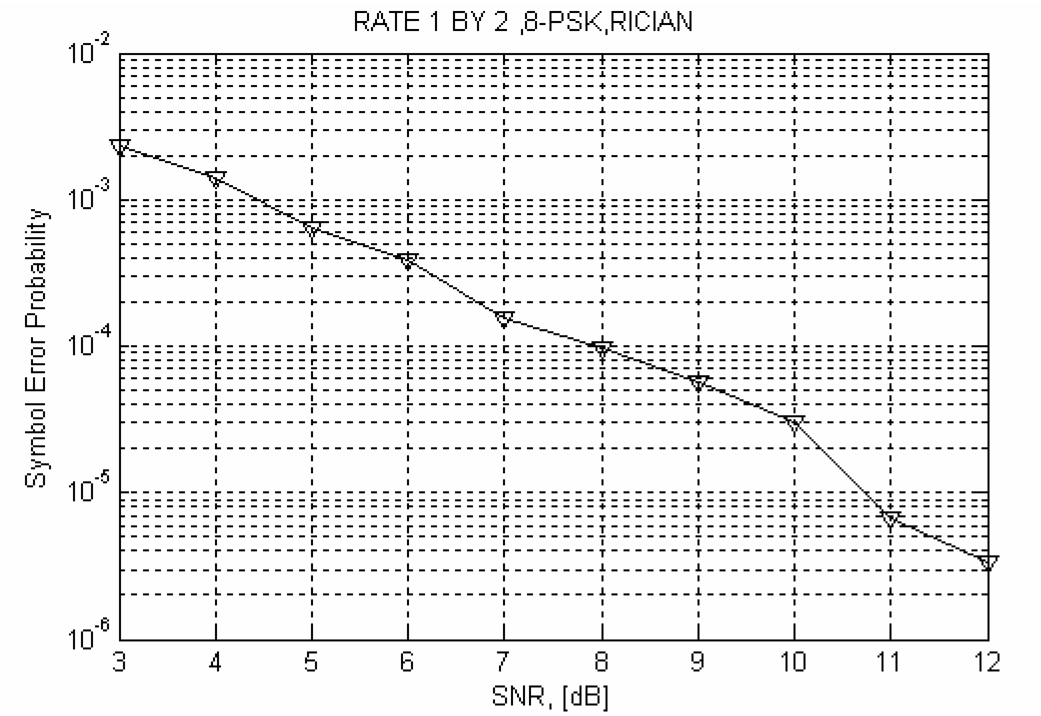


Figure-4.27: SER performance of 8-PSK under RICIAN fading for rate 3 by 4 (3 Transmitting Antennas)

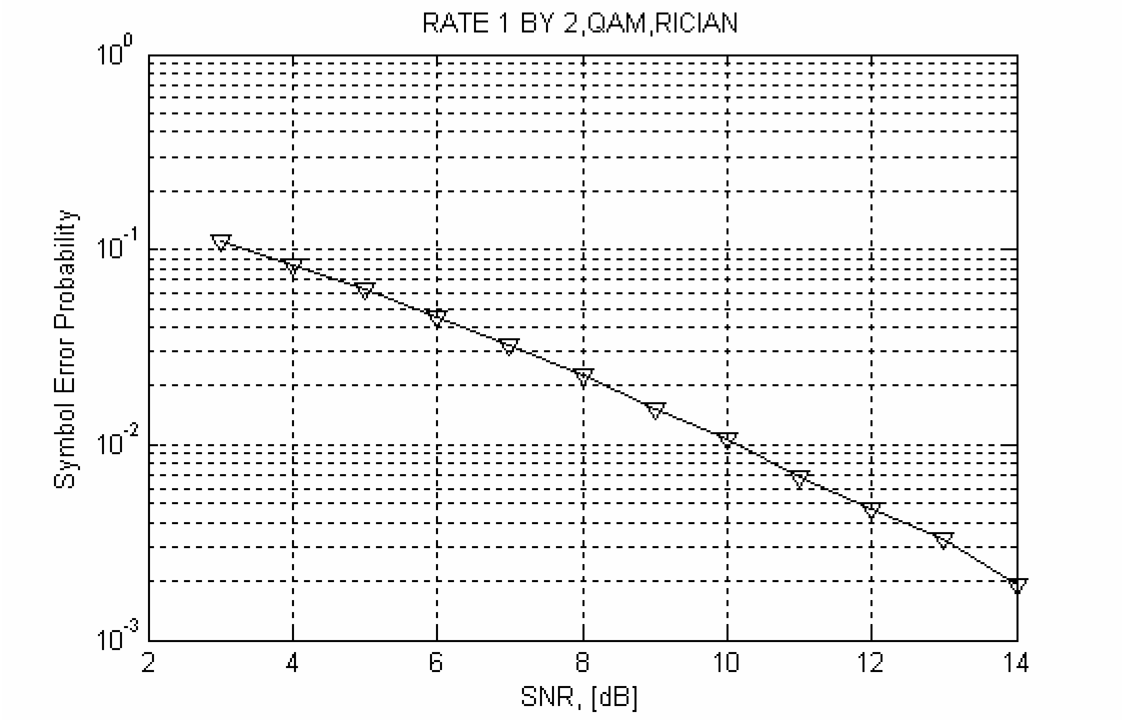


Figure-4.28: SER performance of QAM under RICIAN fading for rate 3 by 4 (3 Transmitting Antennas)

4.3.3.1 SNR COMPARISON OF VARIOUS MODULATIONS UNDER RICIAN FADING

Table-4.7: SNR performance under RICIAN fading at SER of 10^{-2}dB for rate 3 by 4 and 3 Transmitting Antennas

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	16 dB
QPSK	13 dB
8-PSK	2.5 dB
4-QAM	10 dB

Table-4.2.3 shows that at the symbol error rate of 10^{-2} 8-PSK modulation technique gives about 13.5 dB gain over the use of BPSK under RICIAN fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK. Difference in gain performance of QPSK and 4-QAM is about 3 dB.

4.3.4 Simulation results of SER for RICIAN FADING in DIFFERENT MODULATION TECHNIQUES using FOUR TRANSMIT ANTENNAS

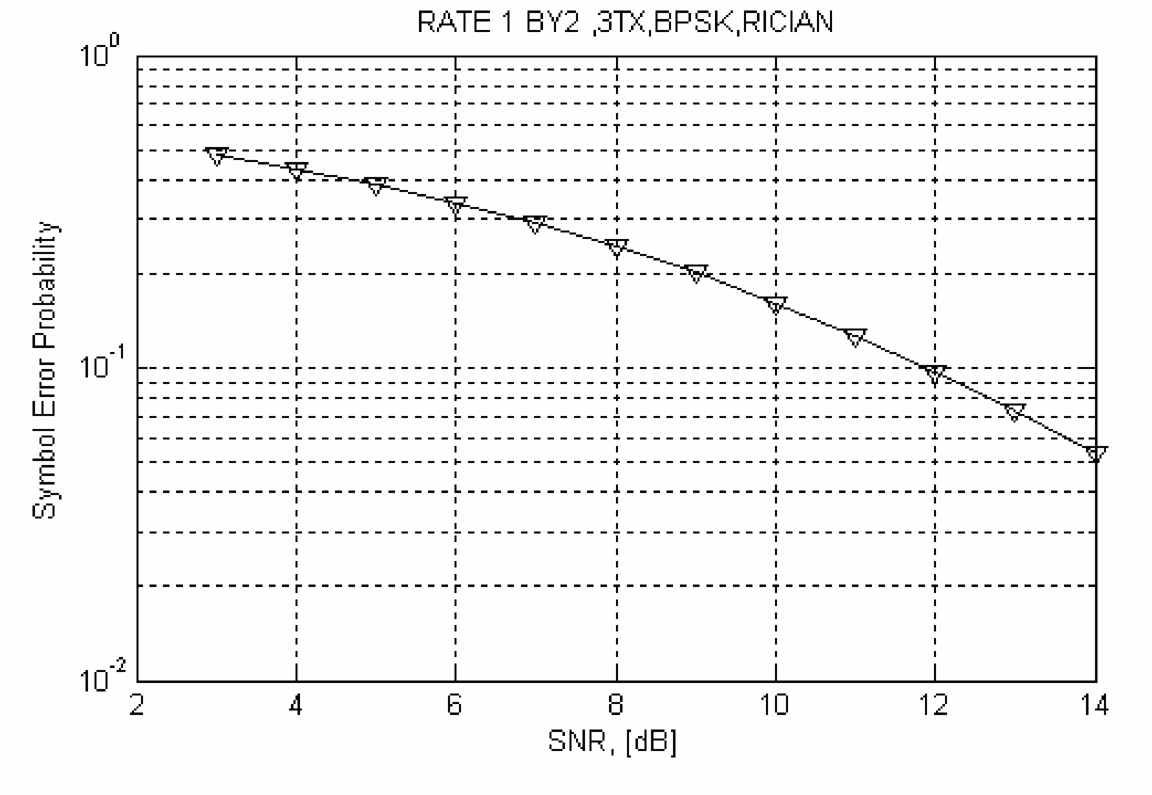


Figure-4.29: SER performance of BPSK under RICIAN fading for rate 3 by 4 (4 Transmitting Antennas)

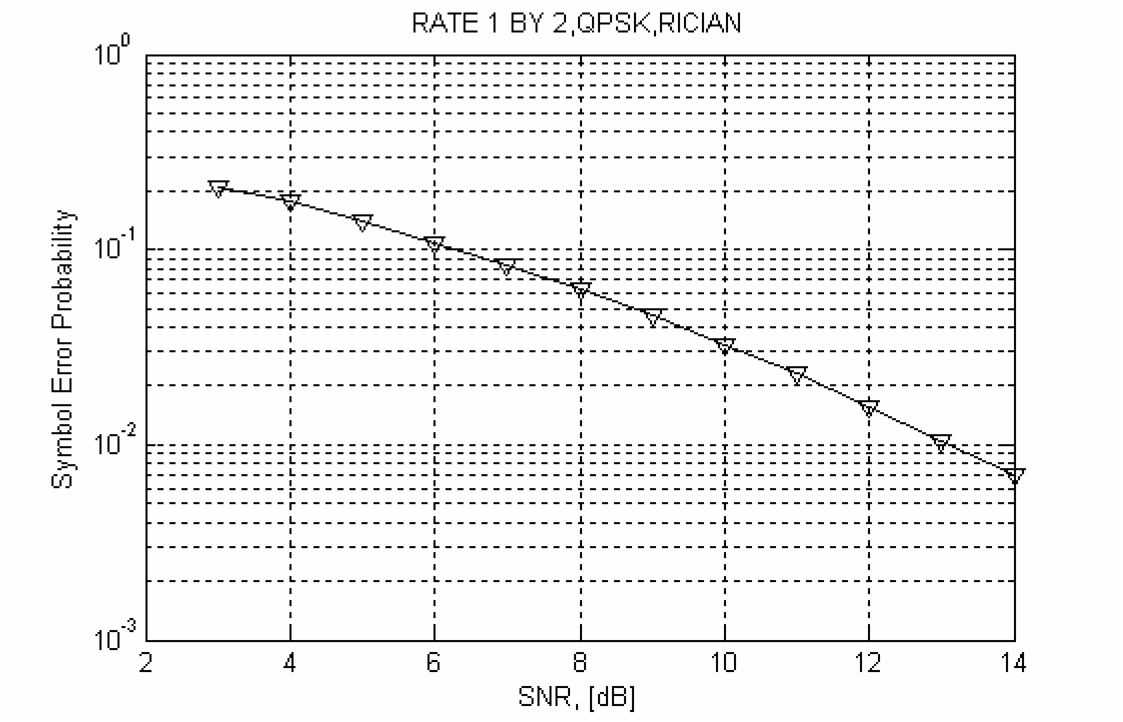


Figure-4.30: SER performance of QPSK under RICIAN fading for rate 3 by 4 (4 Transmitting Antennas)

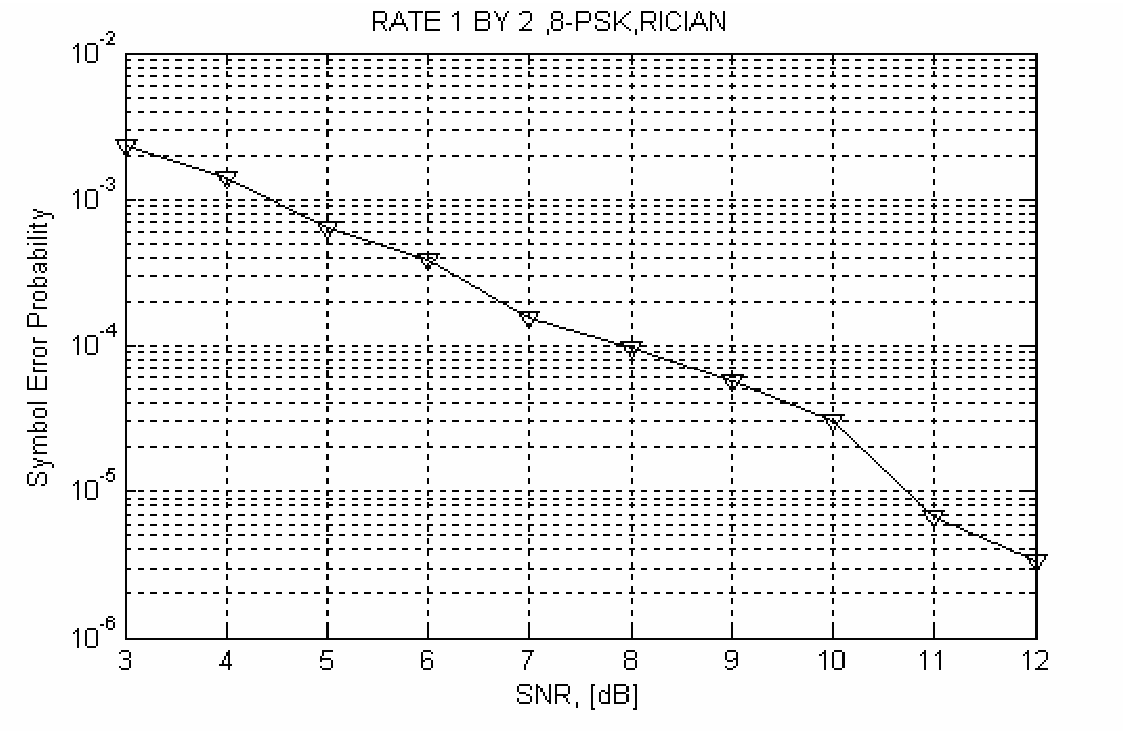


Figure-4.31: SER performance of 8-PSK under RICIAN fading for rate 3 by 4 (4 Transmitting Antennas)

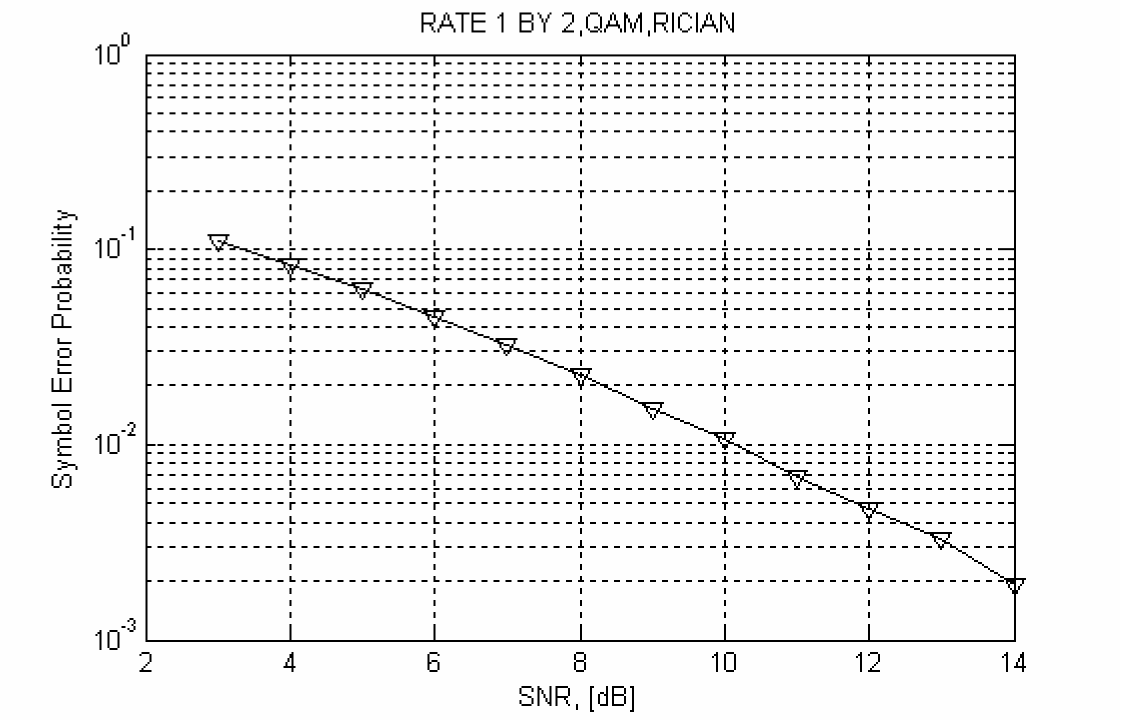


Figure-4.32: SER performance of 4-QAM under RICIAN fading for rate 3 by 4 (4 Transmitting Antennas)

4.3.4.1 SNR COMPARISON OF VARIOUS MODULATIONS UNDER RICIAN FADING.

Table-4.8: SNR performance under RICIAN fading at SER of 10^{-2}dB for rate 3 by 4 (4 Transmitting Antennas)

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	16 dB
QPSK	12.5 dB
8-PSK	2.5 dB
4-QAM	10 dB

Table-4.2.3 shows that at the symbol error rate of 10^{-2} 8-PSK modulation technique gives about 13.5 dB gain over the use of BPSK under RICIAN fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK. Difference in gain performance of QPSK and 4-QAM is about 2.5 dB.

CHAPTER 5

PERFORMANCE OF FRACTIONAL RATE CODES IN NAKAGAMI FADING ENVIRONMENT

The communication system model for rate 3 by 4and rate 1 by 2 system under NAKAGAMI fading also consists of space time encoder, channel involved and the receiver as discussed in chapter 3.The basic functioning of the encoder and the receiver is the same. The only difference is in the nature of channel involved which NAKAGAMI is in this case.

5.1 NAKAGAMI FADING CHANNEL

The Nakagami distribution is selected to fit empirical data and is known to provide a close match to some experimental data than the Rayleigh, Rician or log-normal distributions. The Nakagami distribution is often used to model multipath fading as it can model fading conditions that are either more or less severe than Rayleigh fading. When m=1, Nakagami distribution becomes the Rayleigh distribution, when m=1/2 it becomes a one-sided Gaussian distribution and when $m \to \infty$ the distribution becomes an impulse (no fading). Even Rice distribution can be closely approximated using Nakagami parameter *m* via the relationship $m = (K+1)^2/(2K+1)$.

Considering a receiver with M diversity branches, let the received instantaneous signal A_k at the k_{th} branch be characterized by the Nakagami distribution. The Nakagami distribution describes the received envelope $z(t) = r(t)$ by a central chi-square distribution with *m* degrees of freedom,

$$p(A_k) = \frac{2}{\Gamma(m_k)} \cdot \left(\frac{m_k}{\Omega_k}\right)^{m_k} \cdot A_k^{2m_k - 1} . e^{-\frac{m_k}{\Omega_k} A_k^2} \quad , \quad k = 1,2,....M \qquad 3.12.3.1$$

Where $\Gamma(.)$ is the Gamma function, $\Omega_k = \overline{A_k^2}$ is the average power on k_{th} branch, m_k is the fading parameter. In joint domain processing, the samples in both the spatial domain and the temporal domain are processed simultaneously. The processor in this case computes the overall combiner coefficients/weight vectors by processing signals jointly in both the spatial and the temporal domains [11].

The description of various modulations i.e.: BPSK, QPSK, 8-PSK and 8-QAM are similar to the one discussed in section 3.3. The MONTE CARLO SIMULATIONS STEPS for NAKAGAMI fading are similar to the one for RAYLEIGH fading given in section 3.4.

5.2 SIMULATION RESULTS OF RATE 3 BY 4 SCHEMES

5.2.1 Simulation results of BER for NAKAGAMI FADING in DIFFERENT MODULATION TECHNIQUES using THREE TRANSMIT ANTENNAS

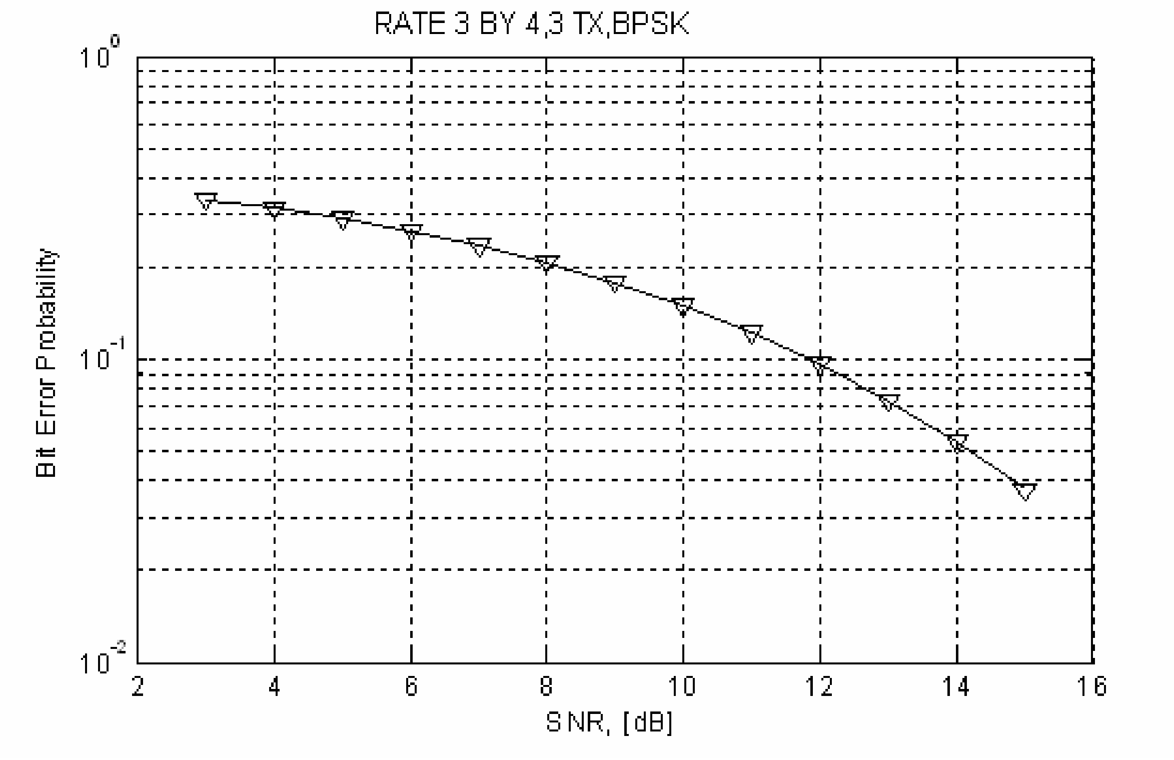


Figure-5.1: BER error performance of BPSK for NAKAGAMI fading for rate 3 by 4 (3 Transmitting Antennas)

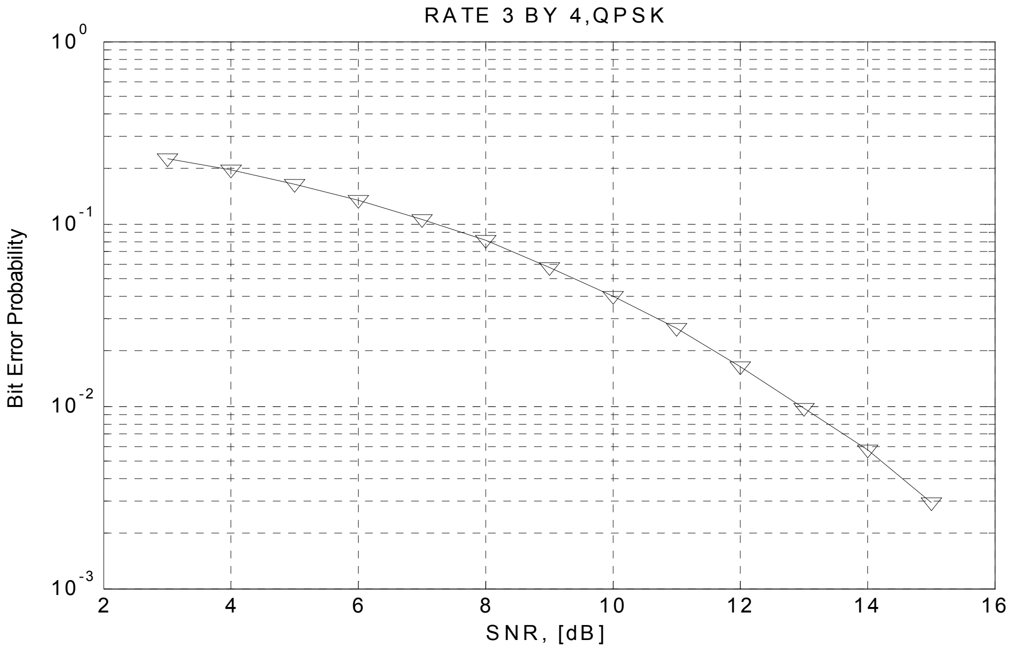


Figure-5.2: BER error performance of QPSK for NAKAGAMI fading for rate 3 by 4(3 Transmitting Antennas)

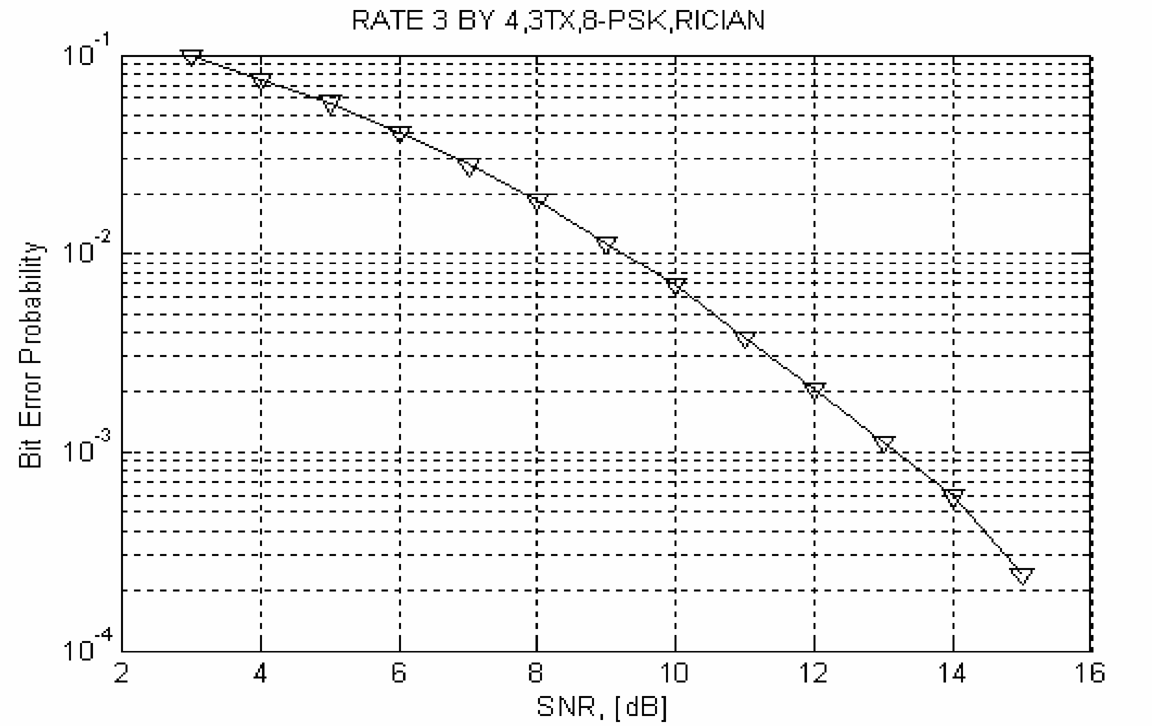


Figure-5.3: BER error performance of 8-PSK for NAKAGAMI fading for rate 3 by 4 (3 Transmitting Antennas)

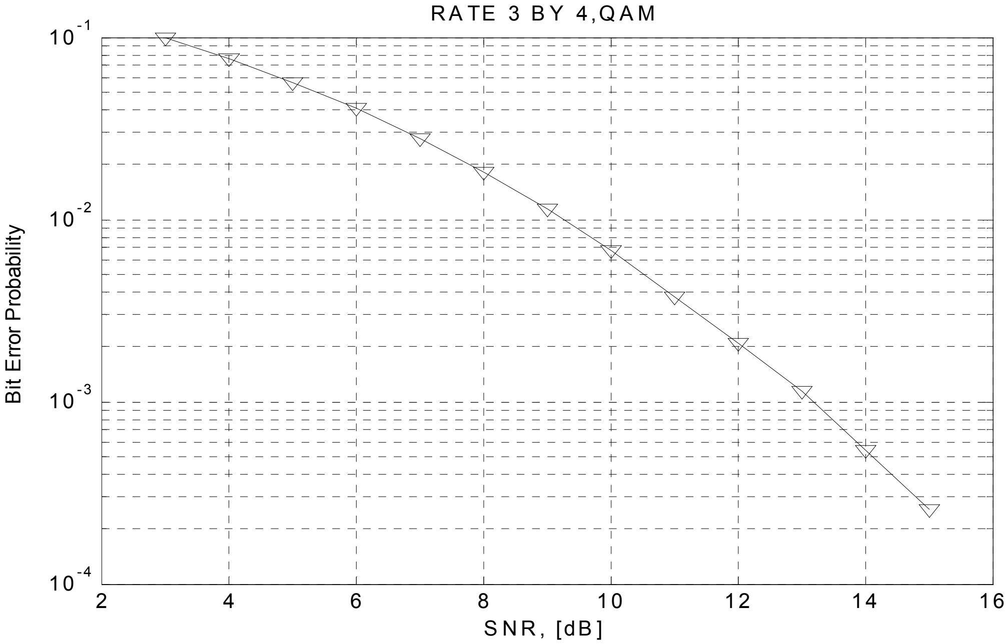


Figure-5.4: BER error performance of 4-QAM for NAKAGAMI fading for rate 3 by 4 (3 Transmitting Antennas)

5.2.1.1 SNR Comparison of Various Modulations under NAKAGAMI Fading.

Table-5.1: SNR performance under NAKAGAMI fading at BER 10^{-2}.

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	16dB
QPSK	13 dB
8-PSK	9 dB
4-QAM	9 dB

Table-5.1 shows that at the bit error rate of 10^{-2} 8-PSK modulation technique gives about 7 dB gain over the use of BPSK under NAKAGAMI fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK 4-QAM also gives good performance as compared to other modulation techniques.

5.2.2 Simulation results of BER for NAKAGAMI FADING in DIFFERENT MODULATION TECHNIQUES using FOUR TRANSMIT ANTENNAS

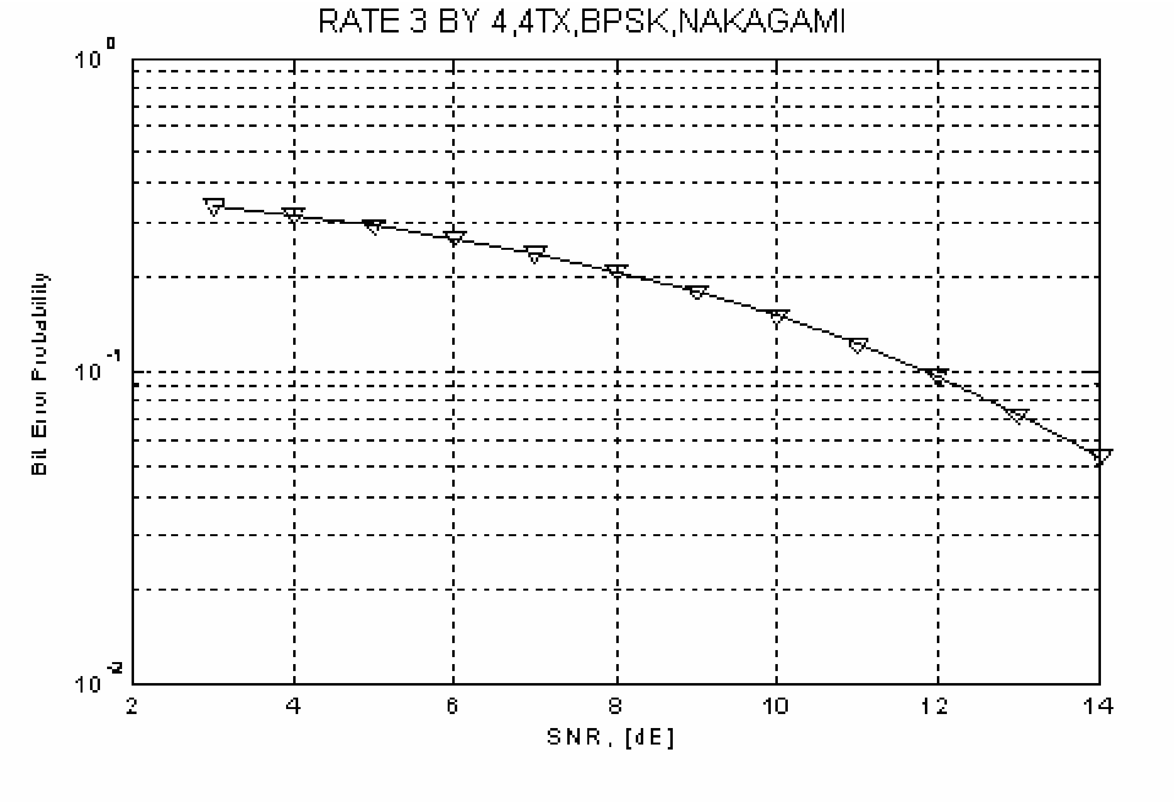


Figure-5.5: BER error performance of BPSK for NAKAGAMI fading for rate 3 by 4 (4 Transmitting Antennas)

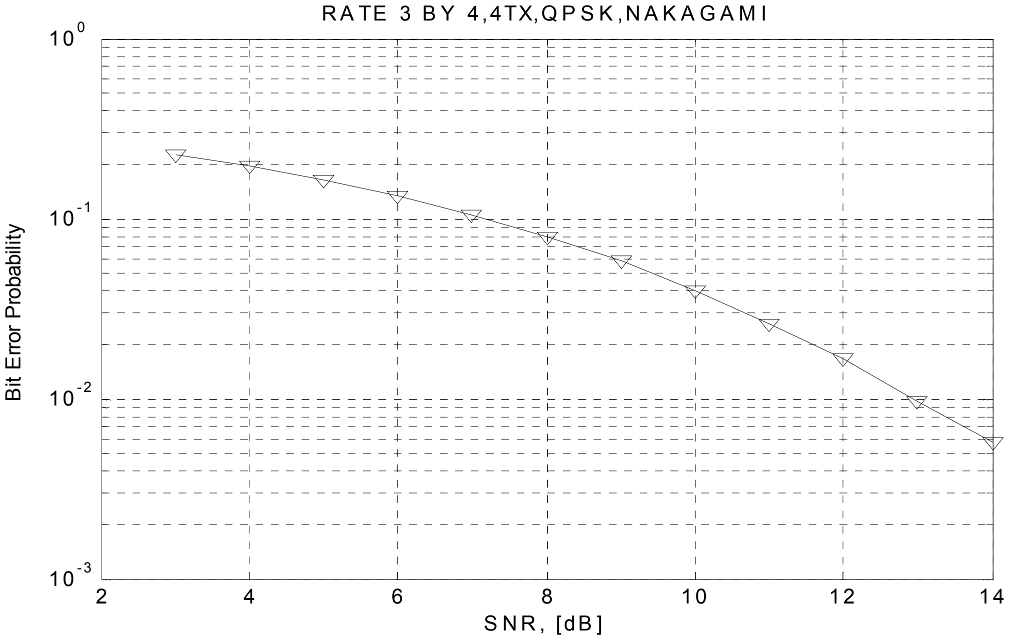


Figure-5.6: BER error performance of QPSK for NAKAGAMI fading for rate 3 by 4 (4 Transmitting Antennas)

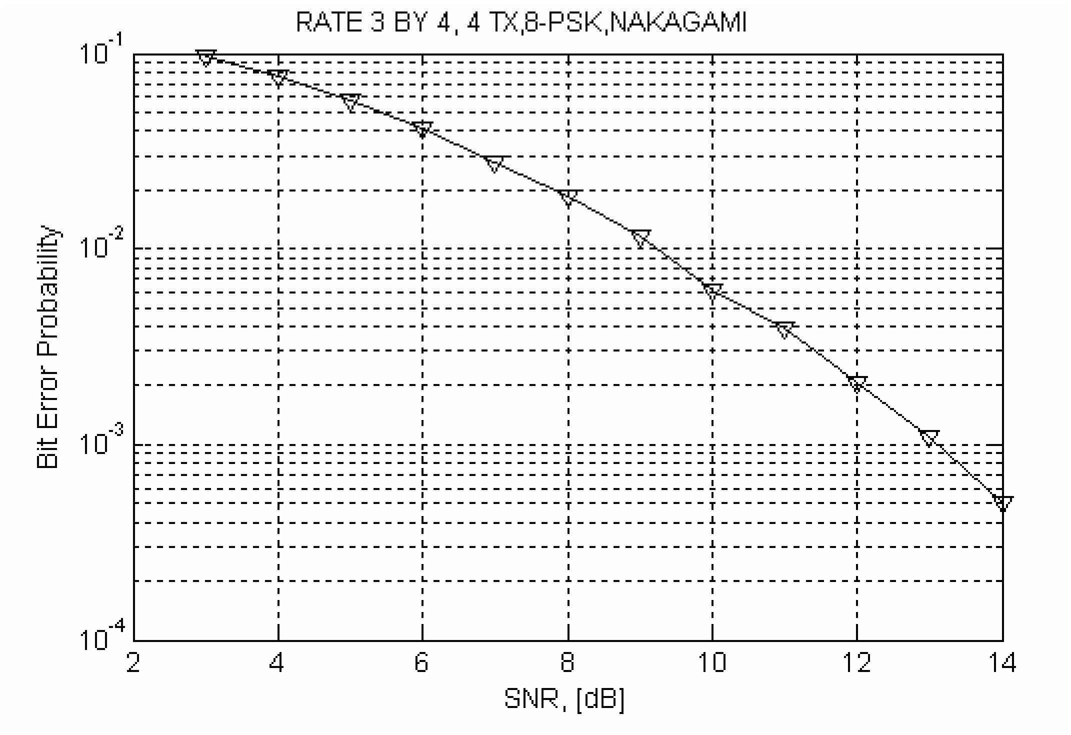


Figure-5.7: Figure-3.4.2.4: BER error performance of 8-PSK for NAKAGAMI fading for rate 3 by 4 (4 Transmitting Antennas)

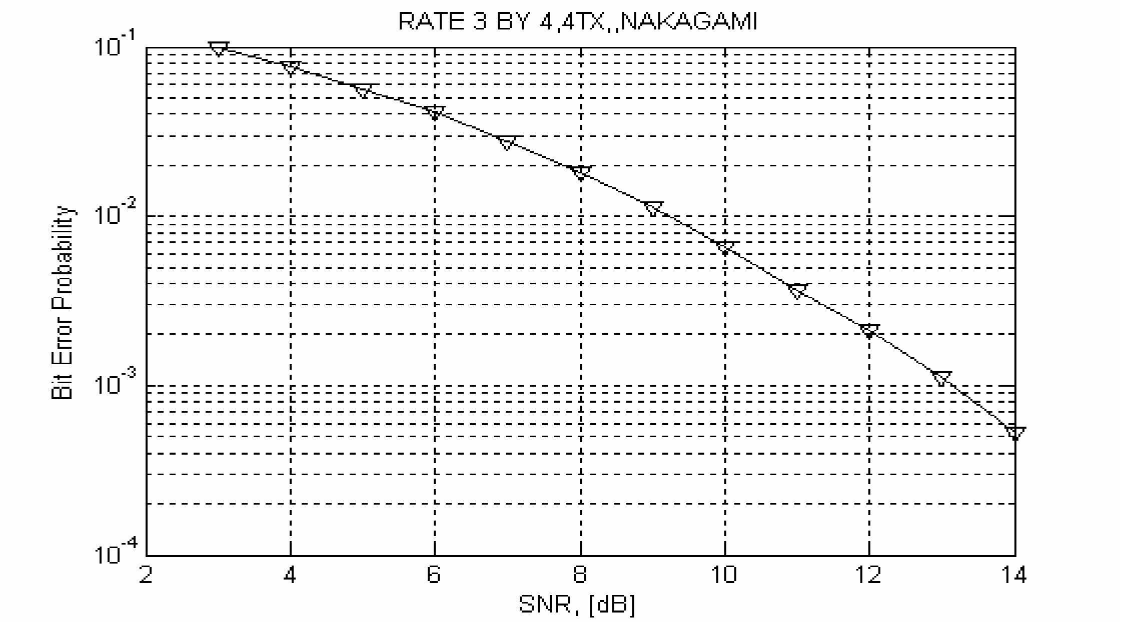


Figure-5.8: BER error performance of 4-QAM for NAKAGAMI fading for rate 3 by 4 (4 Transmitting Antennas)

5.2.2.1 SNR Comparison of Various Modulations under Nakagami Fading.

Table-5.2: SNR performance under NAKAGAMI fading at BER 10^{-2}.

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	16dB
QPSK	13 dB
8-PSK	9 dB
4-QAM	9 dB

Table-5.2 shows that at the bit error rate of 10^{-2} 8-PSK modulation technique gives about 7 dB gains over the use of BPSK under NAKAGAMI fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK 4-QAM also gives good performance as compared to other modulation techniques.

5.2.3 Simulation results of SER for NAKAGAMI FADING in DIFFERENT MODULATION TECHNIQUES using THREE TRANSMIT ANTENNAS

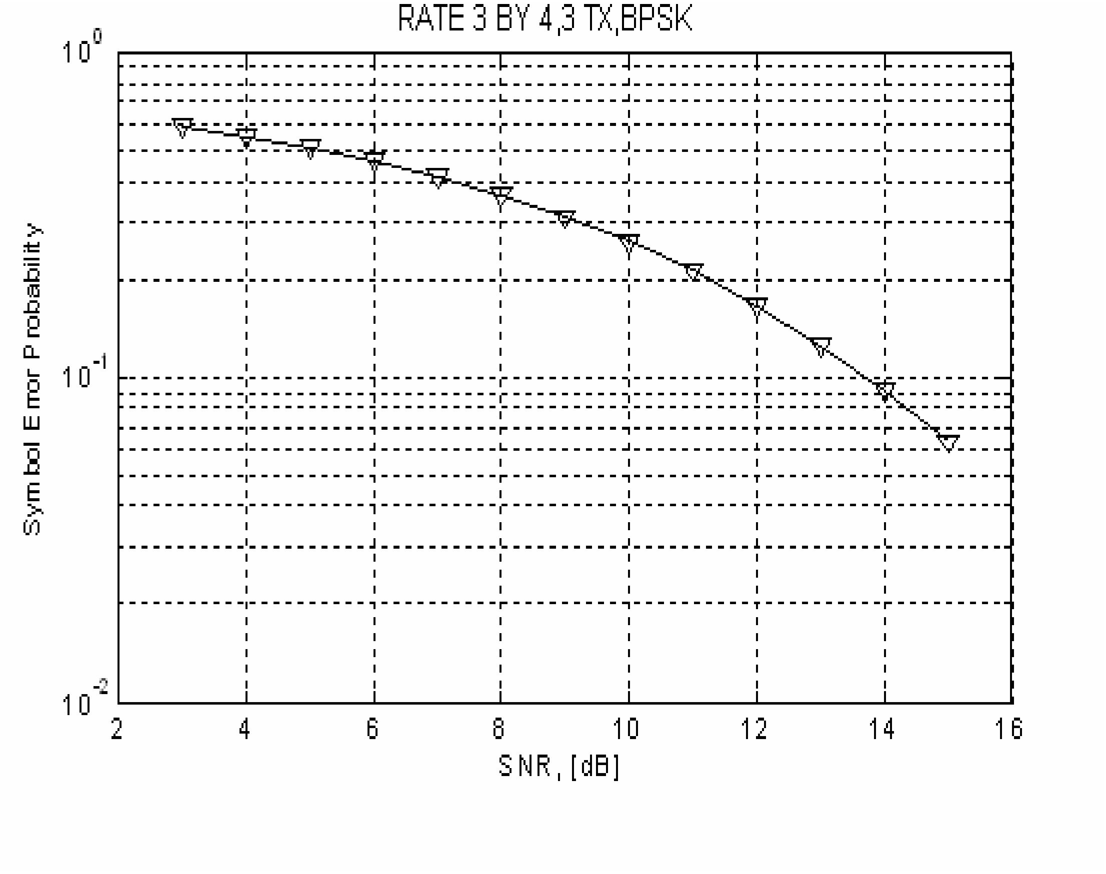


Figure-5.9: SER error performance of BPSK for NAKAGAMI fading for rate 3 by 4 (3 Transmitting Antennas)

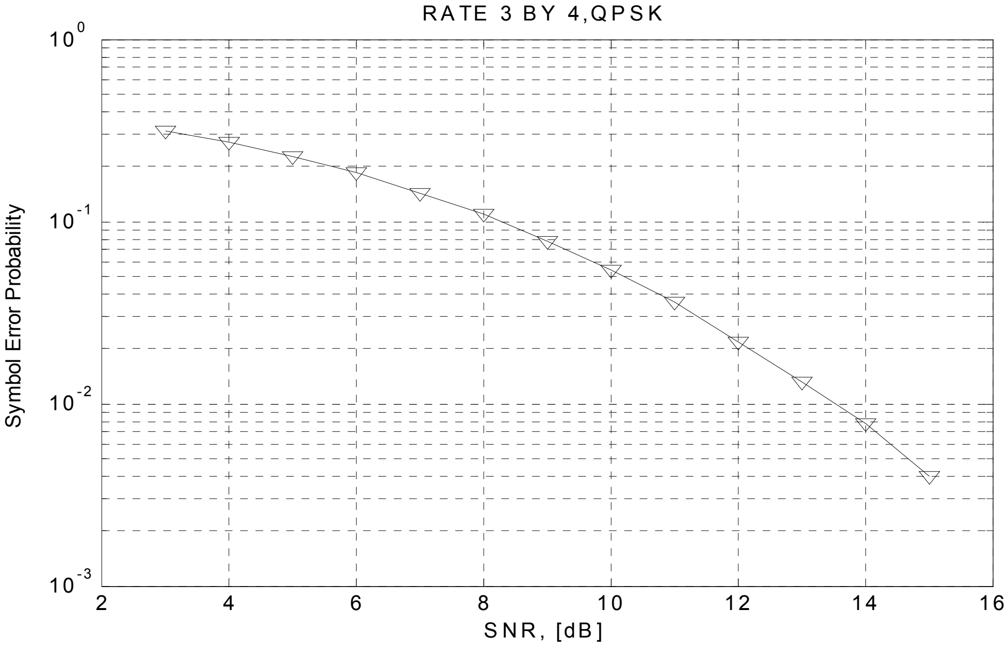


Figure-5.10: SER error performance of QPSK for NAKAGAMI fading for rate 3 by 4(3 Transmitting Antennas)

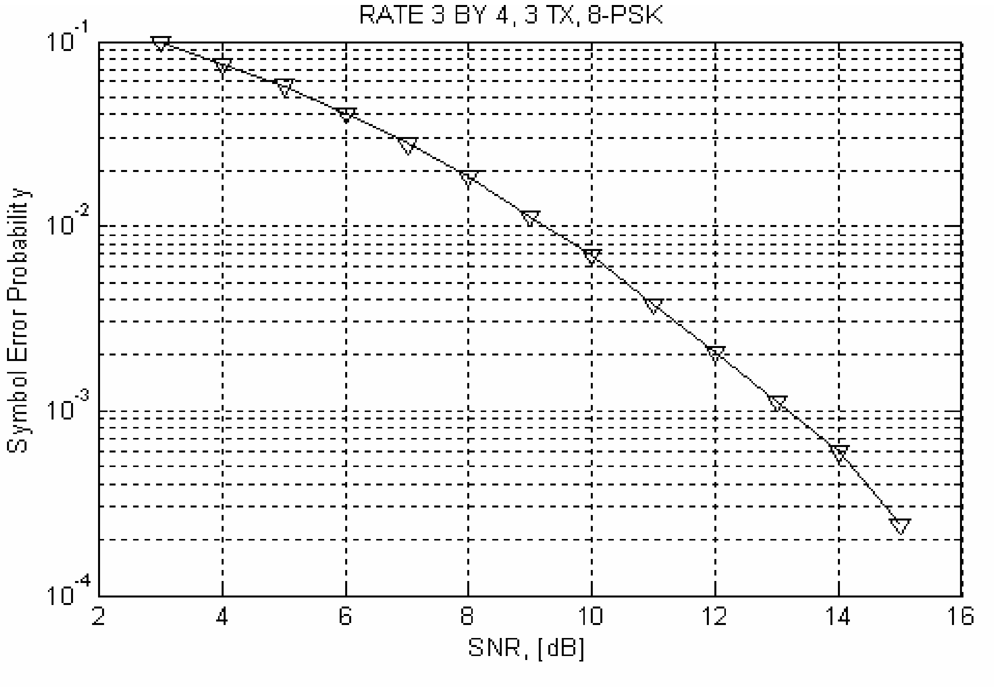


Figure-5.11: SER error performance of 8-PSK for NAKAGAMI fading for rate 3 by 4 (3 Transmitting Antennas)

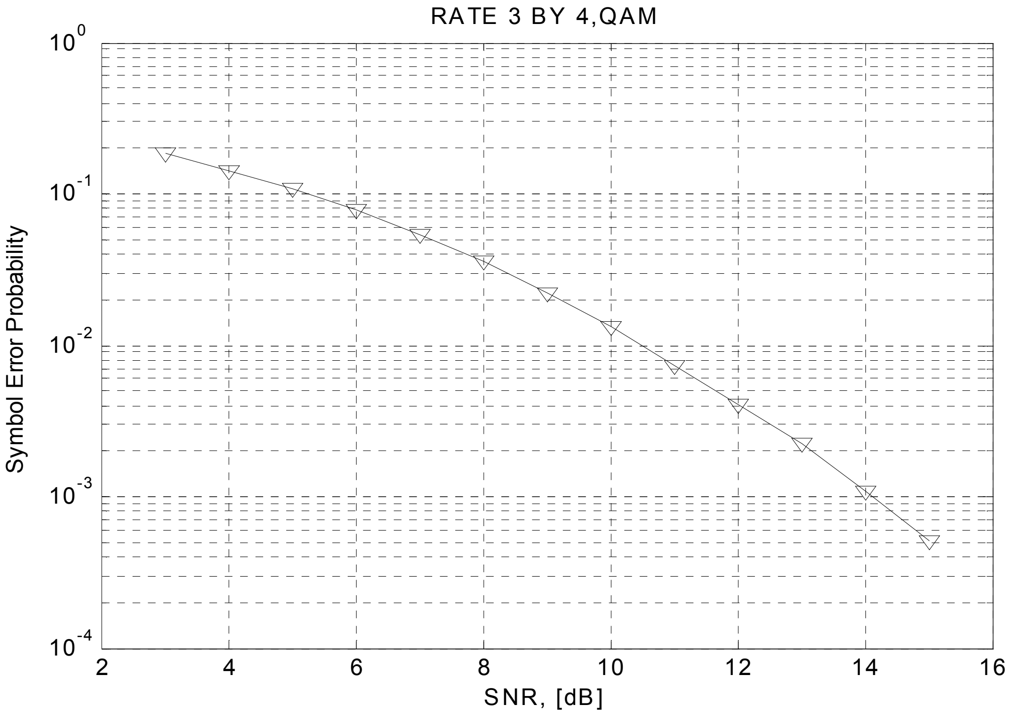


Figure-5.12: SER error performance of 4-QAM for NAKAGAMI fading for rate 3 by 4 (3 Transmitting Antennas)

5.2.3.1 SNR Comparison of Various Modulations under NAKAGAMI Fading

Table-5.3: SNR performance under NAKAGAMI fading at SER 10^{-2}

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	18 dB
QPSK	13.5 dB
8-PSK	8.5 dB
4-QAM	10.5 dB

Table-5.3 shows that at the symbol error rate of 10^{-2} 8-PSK modulation technique gives about 9.5 dB gain over the use of BPSK under NAKAGAMI fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK 4-QAM also gives good performance as compared to other modulation techniques.

5.2.4 Simulation results of SER for NAKAGAMI FADING in DIFFERENT MODULATION TECHNIQUES using FOUR TRANSMIT ANTENNAS

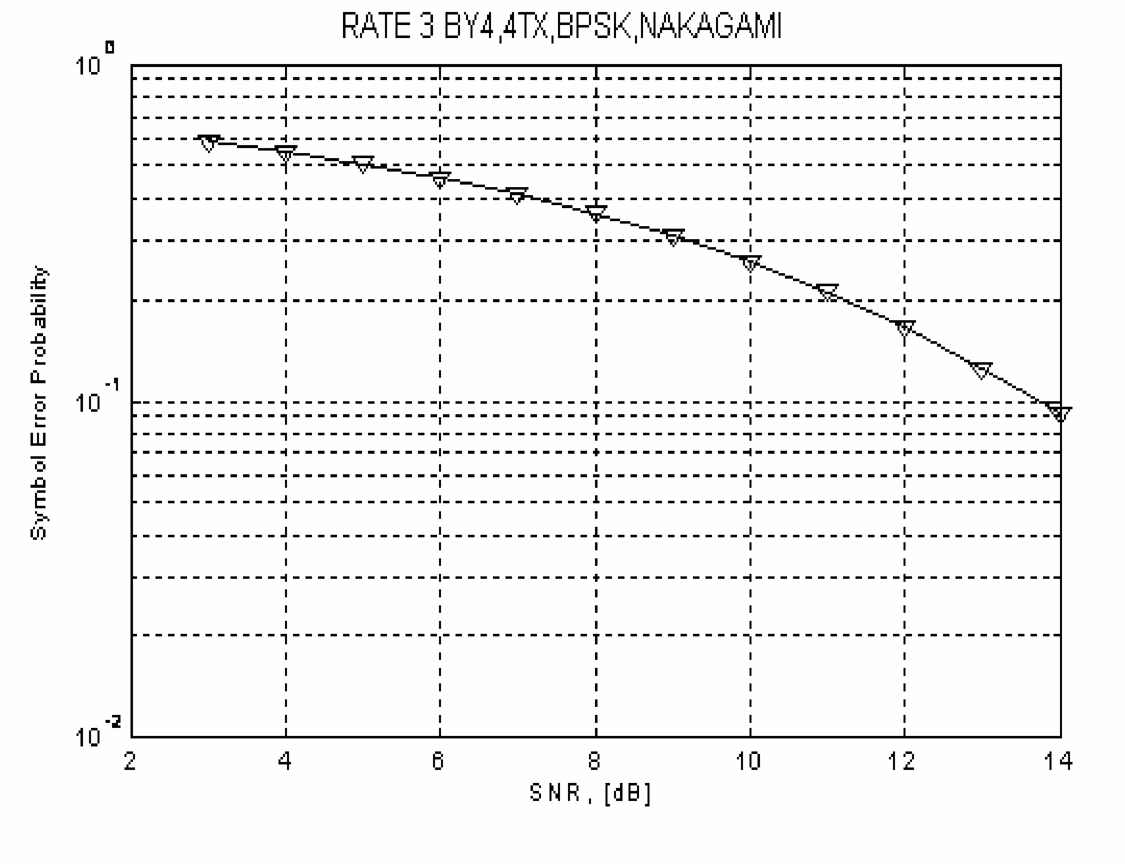


Figure-5.13: SER error performance of BPSK for NAKAGAMI fading for rate 3 by 4 (4 Transmitting Antennas)

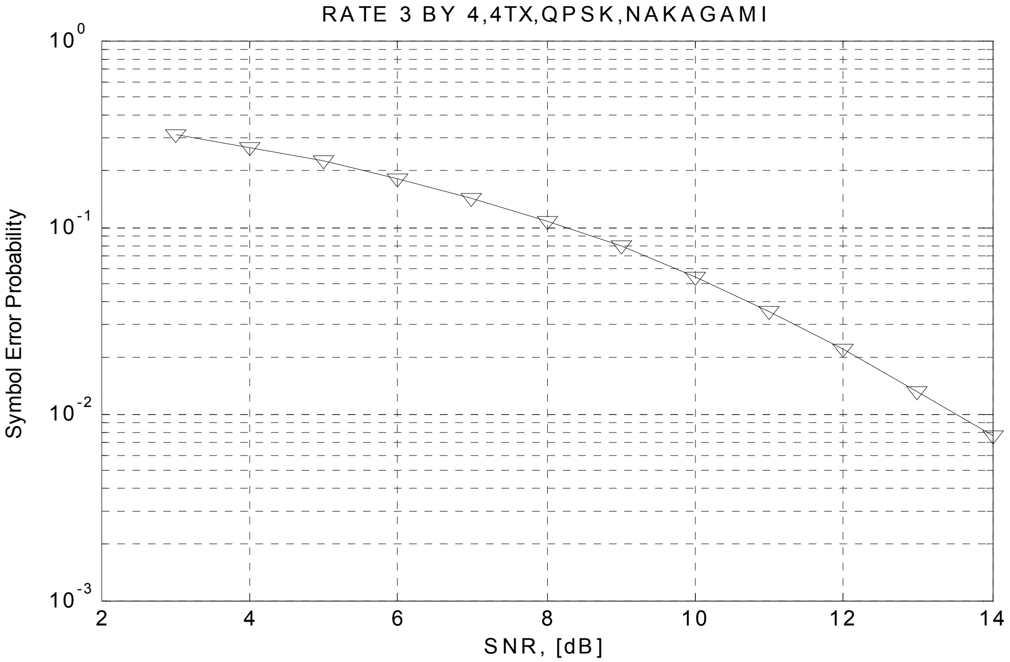


Figure-5.14: SER error performance of QPSK for NAKAGAMI fading for rate 3 by 4 (4 Transmitting Antennas)

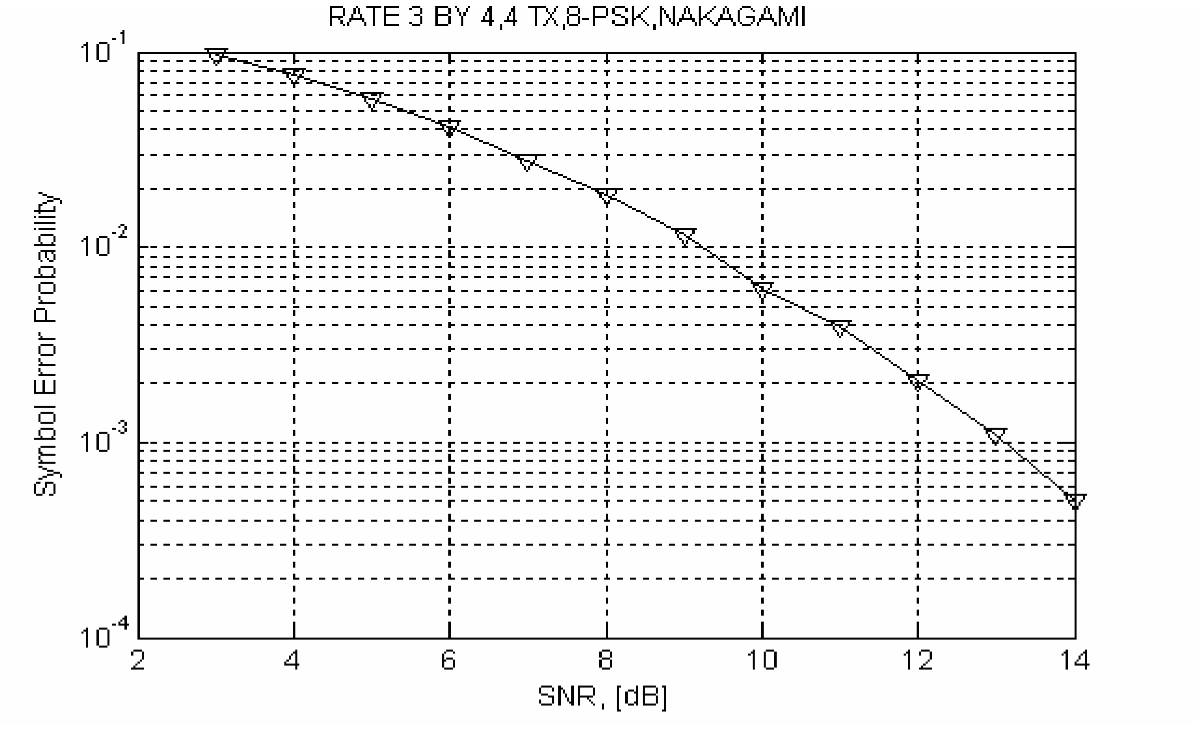


Figure-5.15: SER error performance of 8-PSK for NAKAGAMI fading for rate 3 by 4 (4 Transmitting Antennas)

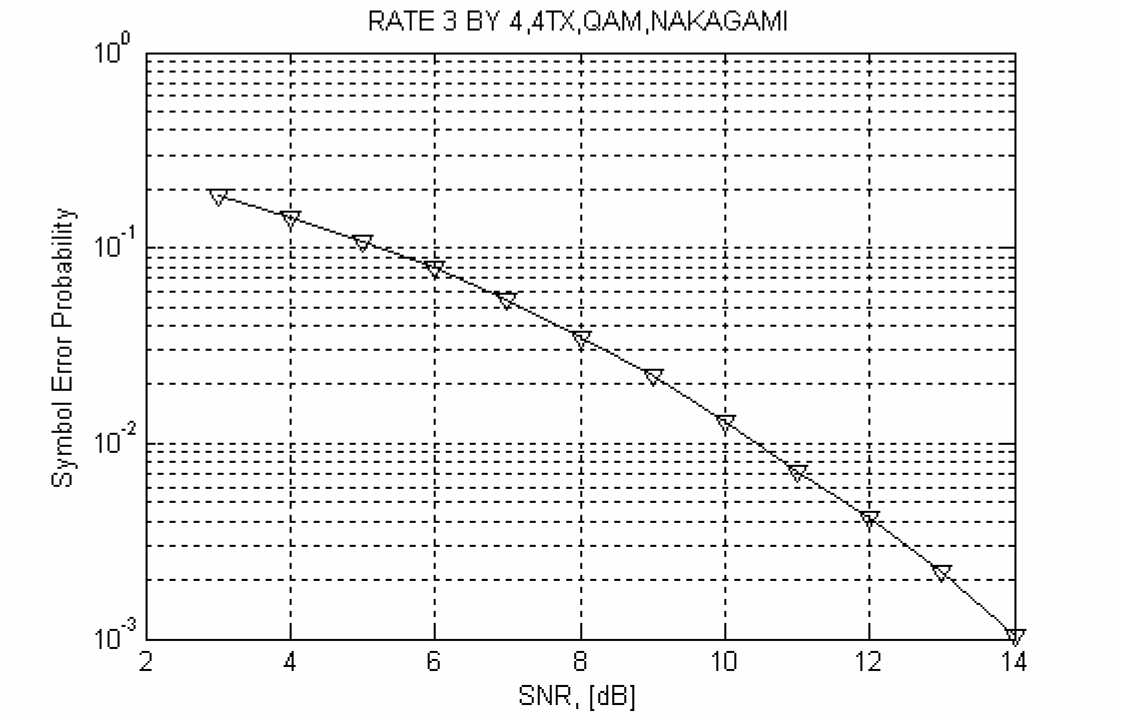


Figure-5.16: SER error performance of 4-QAM for NAKAGAMI fading for rate 3 by 4 (4 Transmitting Antennas)

5.2.4.1 SNR Comparison of Various Modulations under NAKAGAMI Fading

Table-5.4: SNR performance under NAKAGAMI fading at SER 10^{-2}

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	18dB
QPSK	13.5 dB
8-PSK	9 dB
4-QAM	10.5 dB

Table-5.4 shows that at the symbol error rate of 10^{-2} 8-PSK modulation technique gives about 9 dB gain over the use of BPSK under NAKAGAMI fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK. 4-QAM also gives good performance as compared to other modulation techniques.

5.3 SIMULATION RESULTS OF RATE 1 BY 2 SCHEMES

5.3.1 Simulation results of BER for NAKAGAMI FADING in DIFFERENT MODULATION TECHNIQUES using THREE TRANSMIT ANTENNAS

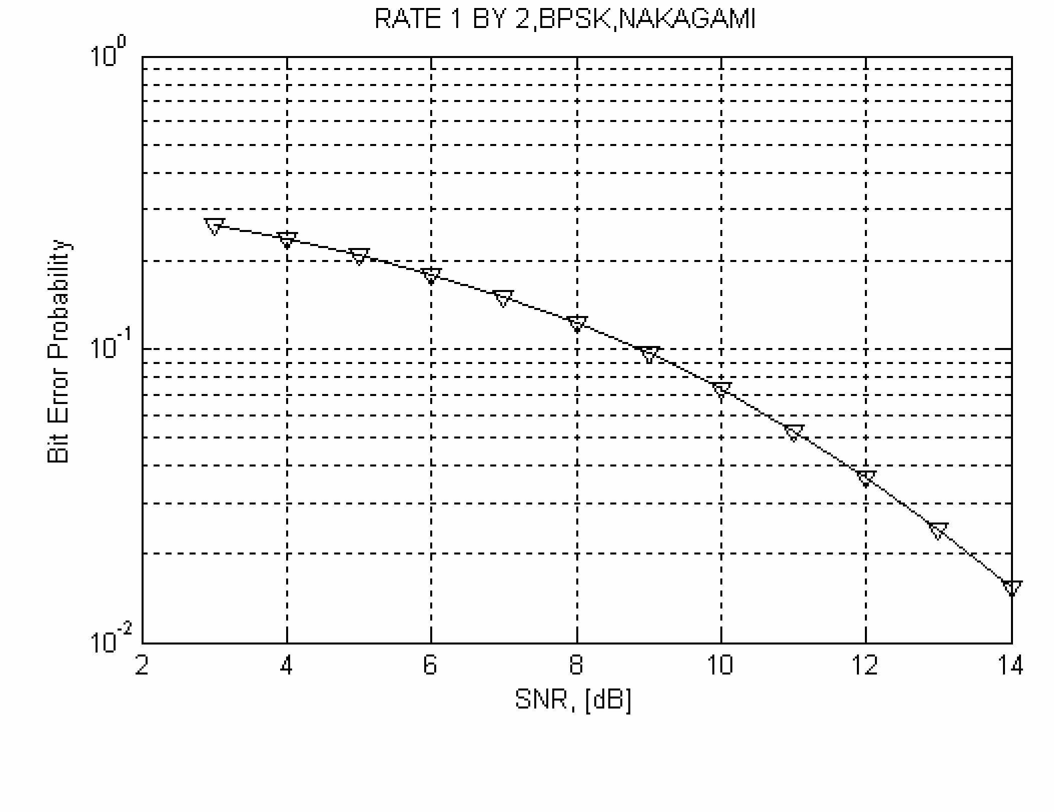
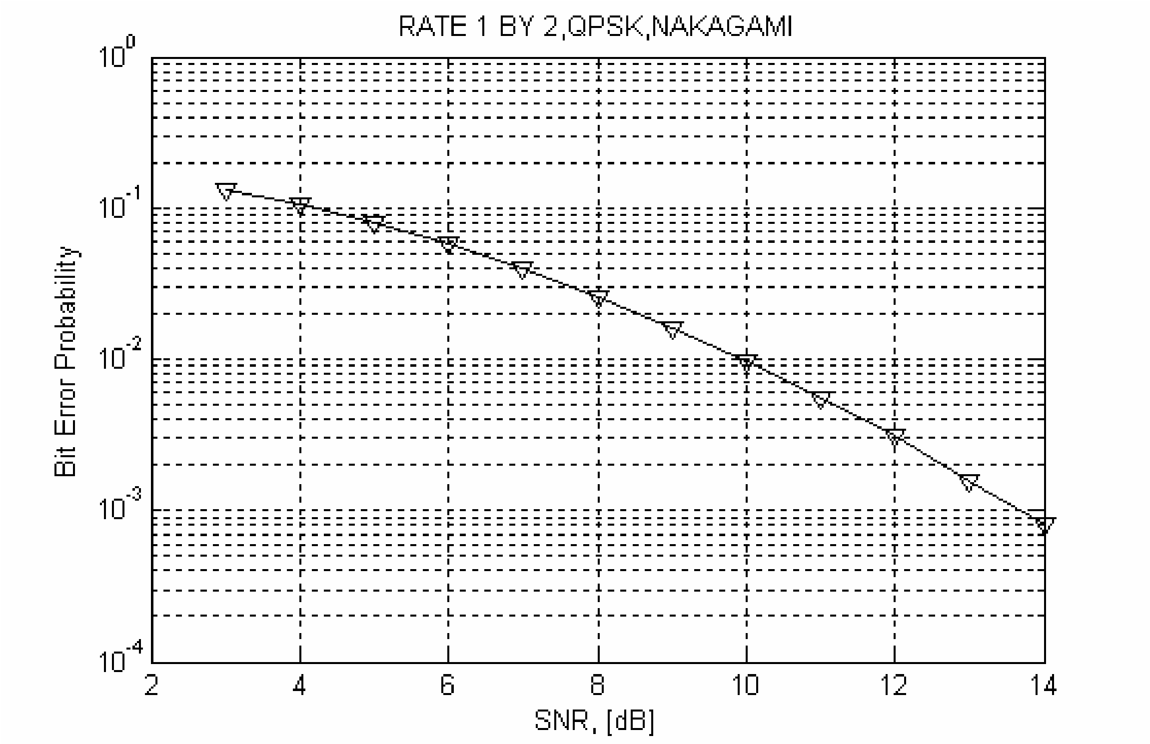


Figure-5.17: BER error performance of BPSK for NAKAGAMI fading for rate 1 by 2 for 3 Transmitting Antennas



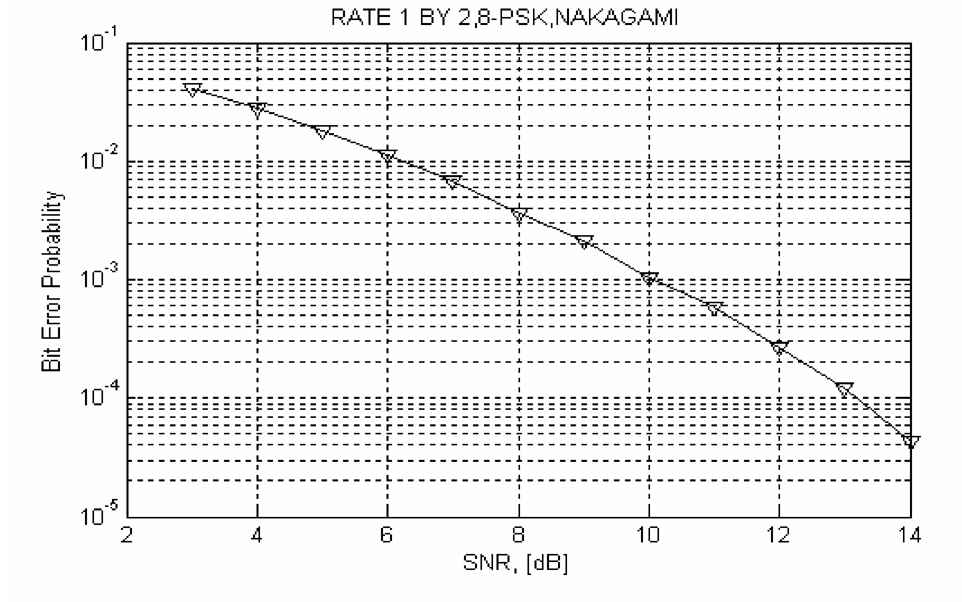


Figure-5.19: BER error performance of 8-PSK for NAKAGAMI fading for rate 1 by 2 for 3 Transmitting Antennas

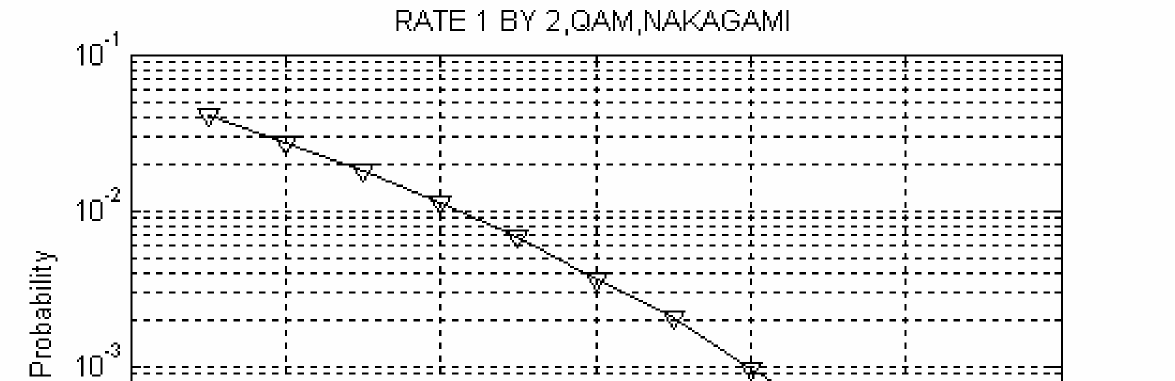


Figure-5.20: BER error performance of 4-QAM for NAKAGAMI fading for rate 1 by 2 for 3 Transmitting Antennas

5.3.1.1 SNR Comparison of Various Modulations under Nakagami Fading

Table-5.5: SNR performance under NAKAGAMI fading at BER 10^{-2}.

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	15dB
QPSK	10 dB
8-PSK	6 dB
4-QAM	6 dB

Table-5.5 shows that at the bit error rate of 10^{-2} 8-PSK modulation technique gives about 9 dB gain over the use of BPSK under NAKAGAMI fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK 4-QAM also gives good performance as compared to other modulation techniques.

5.3.2 Simulation results of BER for NAKAGAMI FADING in DIFFERENT MODULATION TECHNIQUES using FOUR TRANSMIT ANTENNAS

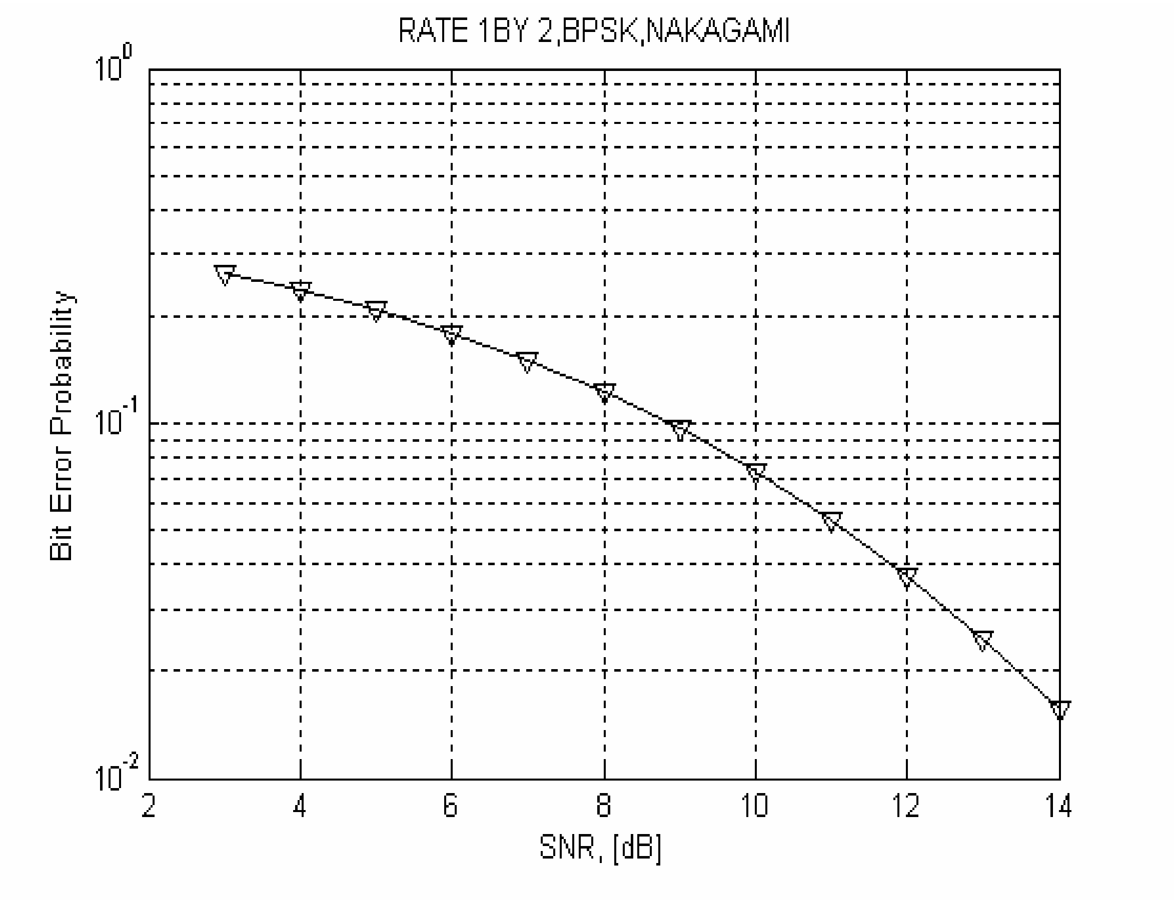


Figure-5.21: BER error performance of BPSK for NAKAGAMI fading for rate 1 by 2 for 4 Transmitting Antennas

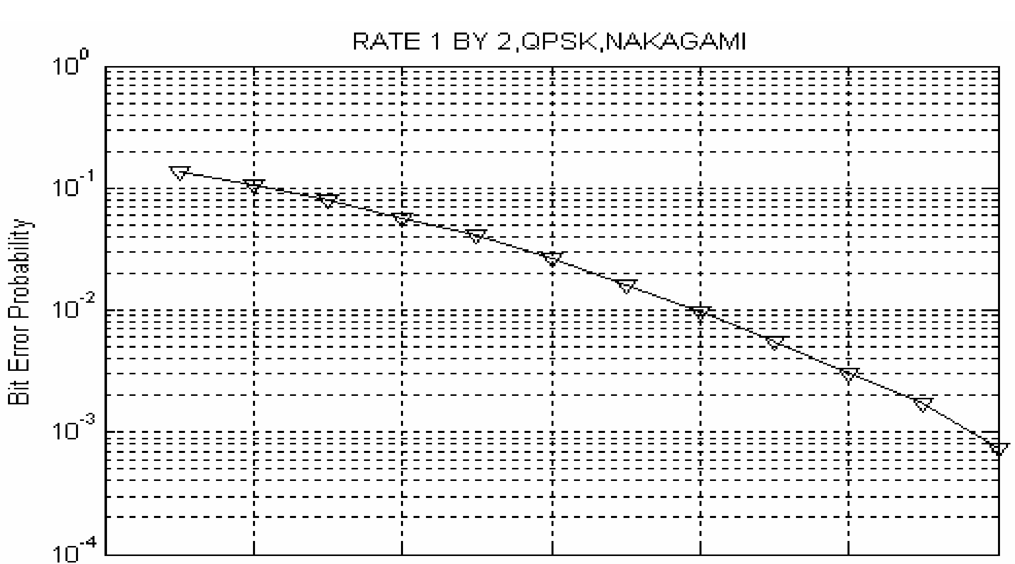


Figure-5.22: BER error performance of QPSK for NAKAGAMI fading for rate 1 by 2 for 4 Transmitting Antennas

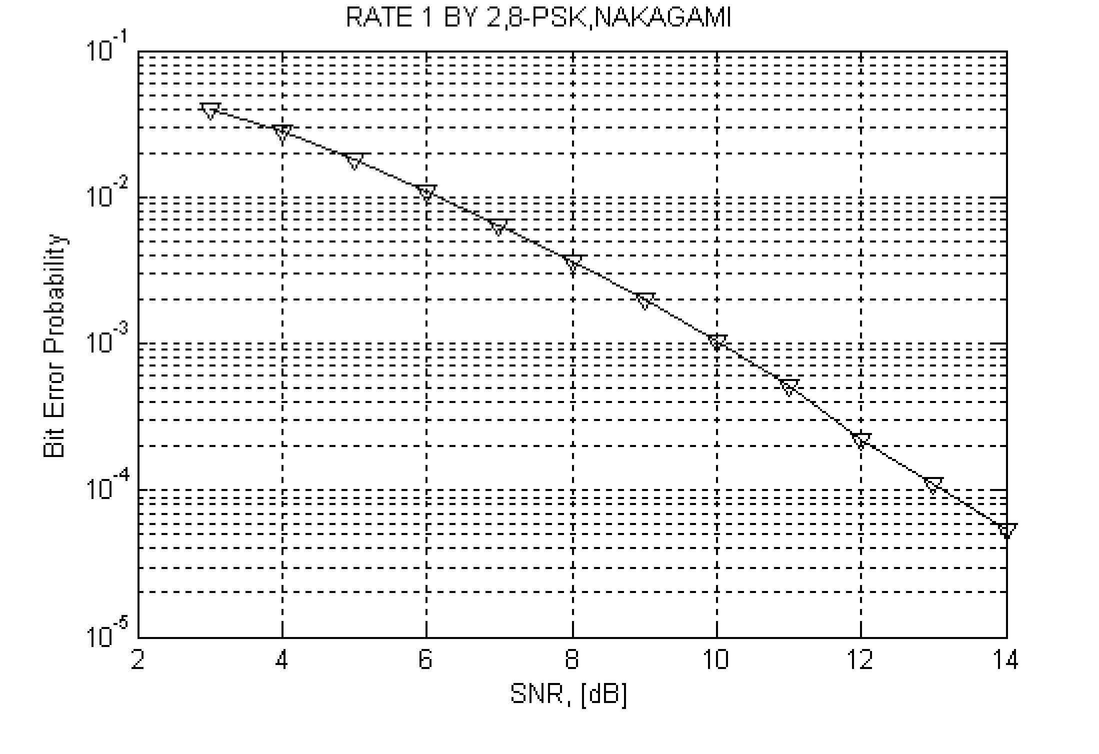


Figure-5.23: BER error performance of 8-PSK for NAKAGAMI fading for rate 1 by 2 for 4 Transmitting Antennas

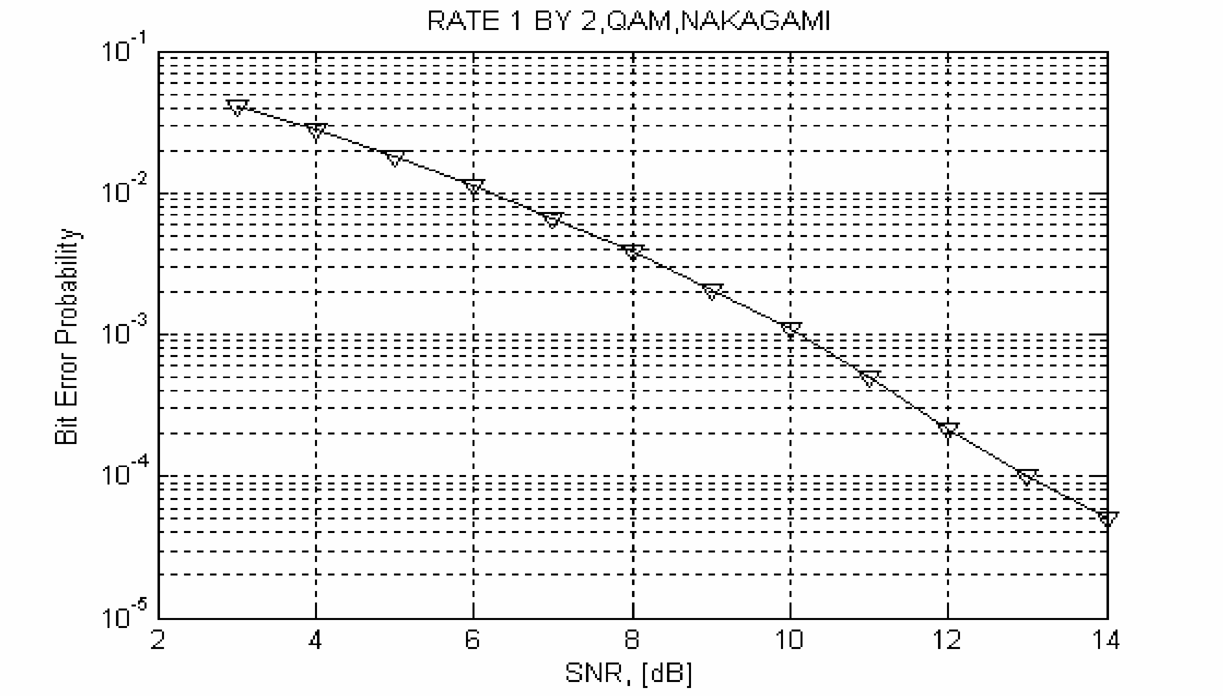


Figure-5.24: BER error performance of 4-QAM for NAKAGAMI fading for rate 1 by 2 for 4 Transmitting Antennas

5.3.2.1 SNR Comparison of Various Modulations under Nakagami Fading.

Table-5.6: SNR performance under NAKAGAMI fading at BER 10^{-2}.

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	16dB
QPSK	10 dB
8-PSK	6 dB
4-QAM	6 dB

Table-5.3.2 shows that at the bit error rate of 10^{-2} 8-PSK modulation technique gives about 10 dB gain over the use of BPSK under NAKAGAMI fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK 4-QAM also gives good performance as compared to other modulation techniques.

5.3.3 Simulation results of SER for NAKAGAMI FADING in DIFFERENT MODULATION TECHNIQUES using THREE TRANSMIT ANTENNAS

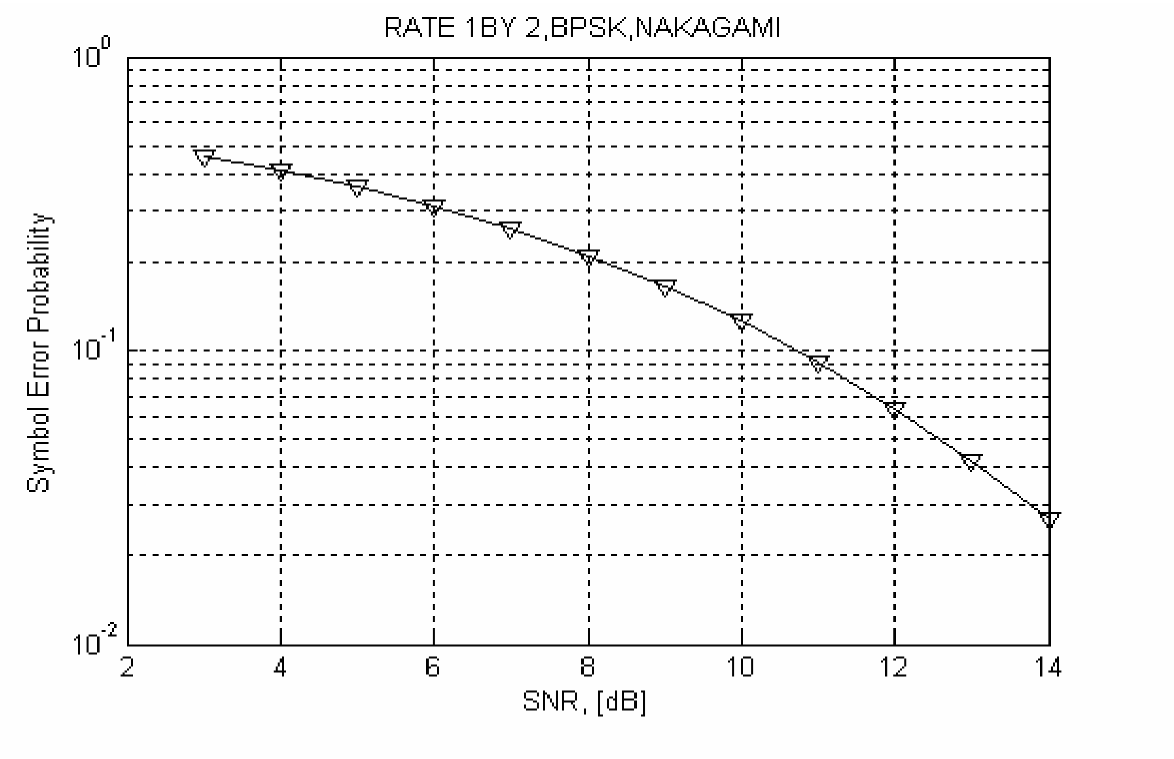


Figure-5.25: SER error performance of BPSK for NAKAGAMI fading for rate 3 by 4 (3 Transmitting Antennas)

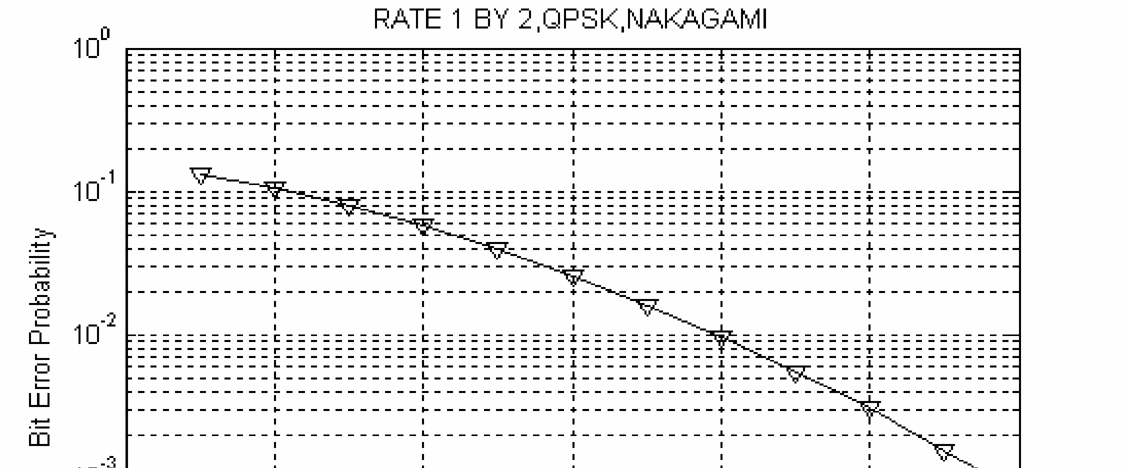


Figure-5.26: SER error performance of QPSK for NAKAGAMI fading for rate 3 by 4 (3 Transmitting Antennas)

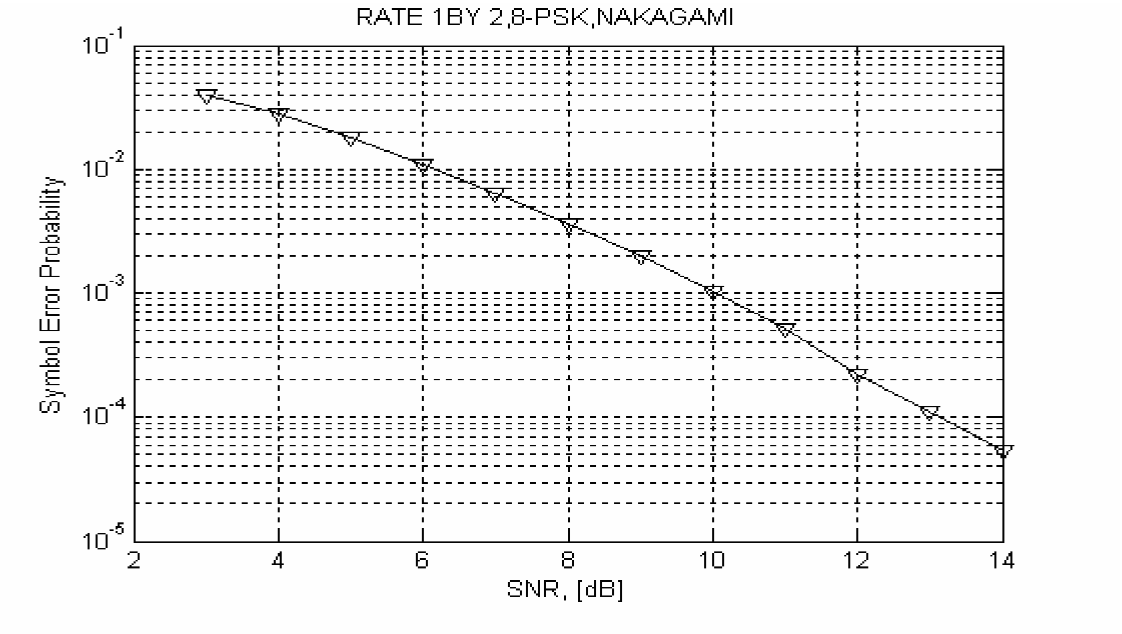


Figure-5.27: SER error performance of 8-PSK for NAKAGAMI fading for rate 3 by 4 (4 Transmitting Antennas)

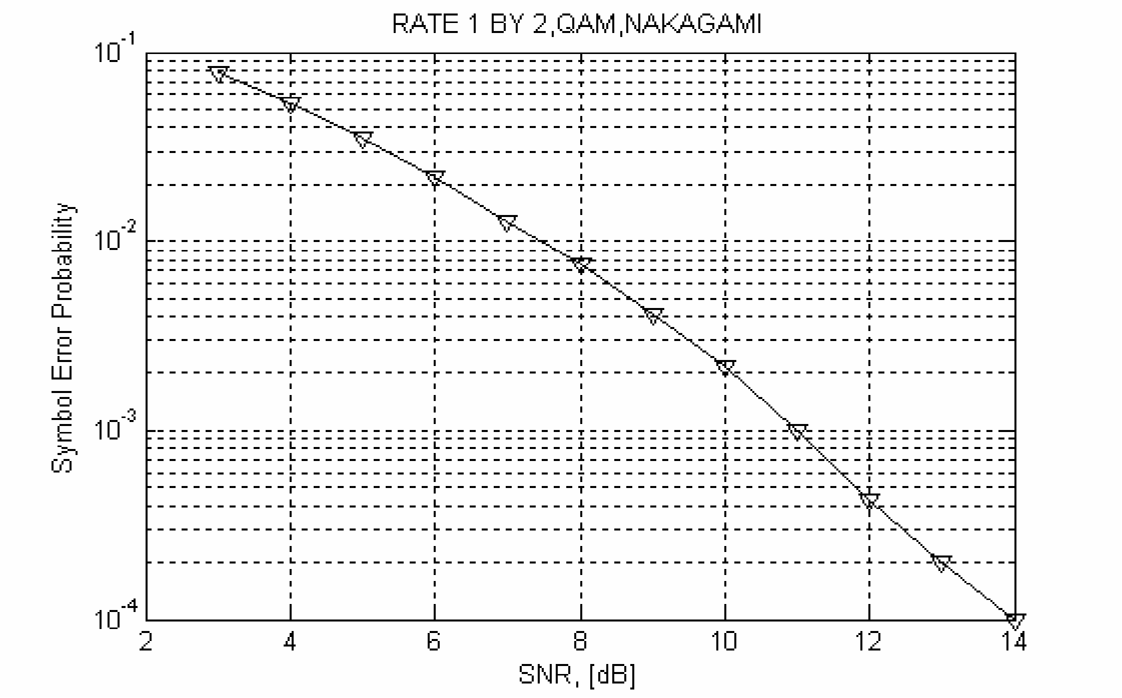


Figure-5.28: SER error performance of 4-QAM for NAKAGAMI fading for rate 3 by 4 (4 Transmitting Antennas)

5.3.3.1 SNR Comparison of Various Modulations under Nakagami Fading

Table-5.7: SNR performance under NAKAGAMI fading at BER 10^{-2}

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	16dB
QPSK	10.5 dB
8-PSK	6 dB
4-QAM	7.5 dB

Table-5.7 shows that at the bit error rate of 10^{-2} 8-PSK modulation technique gives about 10 dB gain over the use of BPSK under NAKAGAMI fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK 4-QAM also gives good performance as compared to other modulation techniques.

5.3.4 Simulation results of SER for NAKAGAMI FADING in DIFFERENT MODULATION TECHNIQUES using FOUR TRANSMIT ANTENNAS

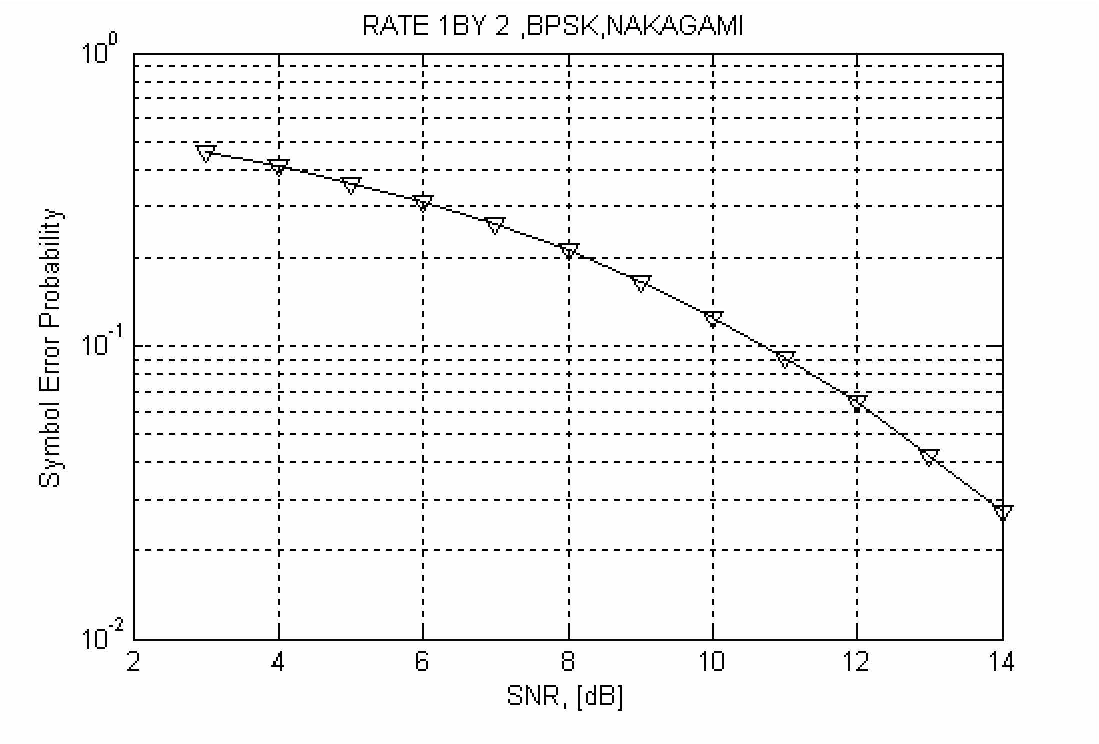


Figure-5.29: SER error performance of BPSK for NAKAGAMI fading for rate 3 by 4 (4 Transmitting Antennas)

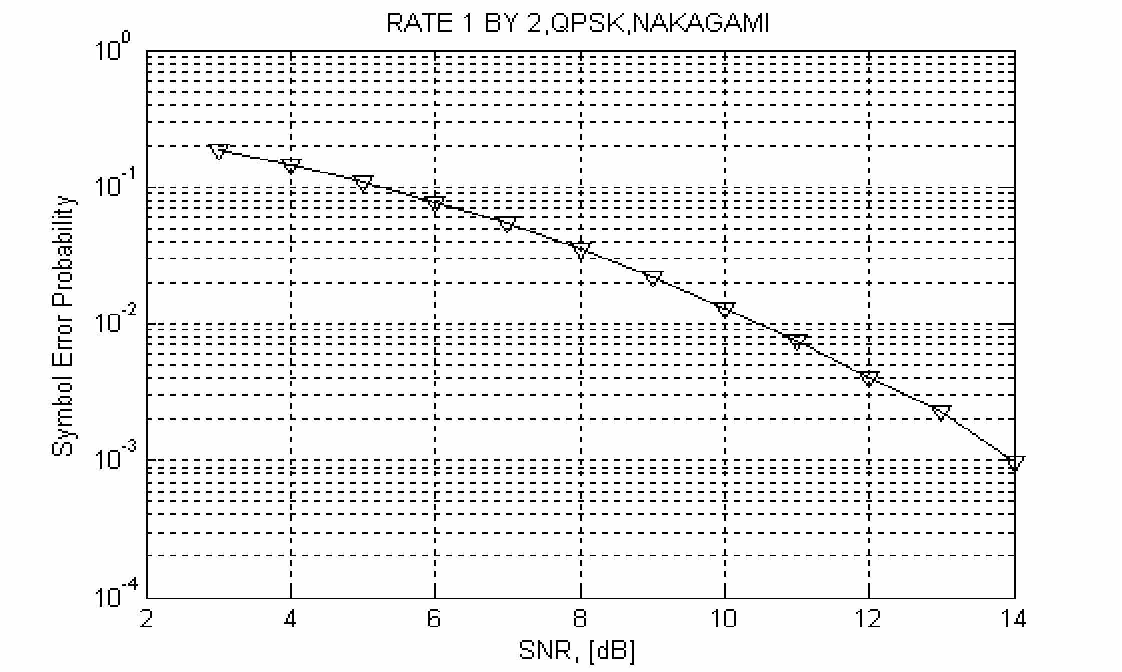


Figure-5.30: SER error performance of QPSK for NAKAGAMI fading for rate 3 by 4 (4 Transmitting Antennas)

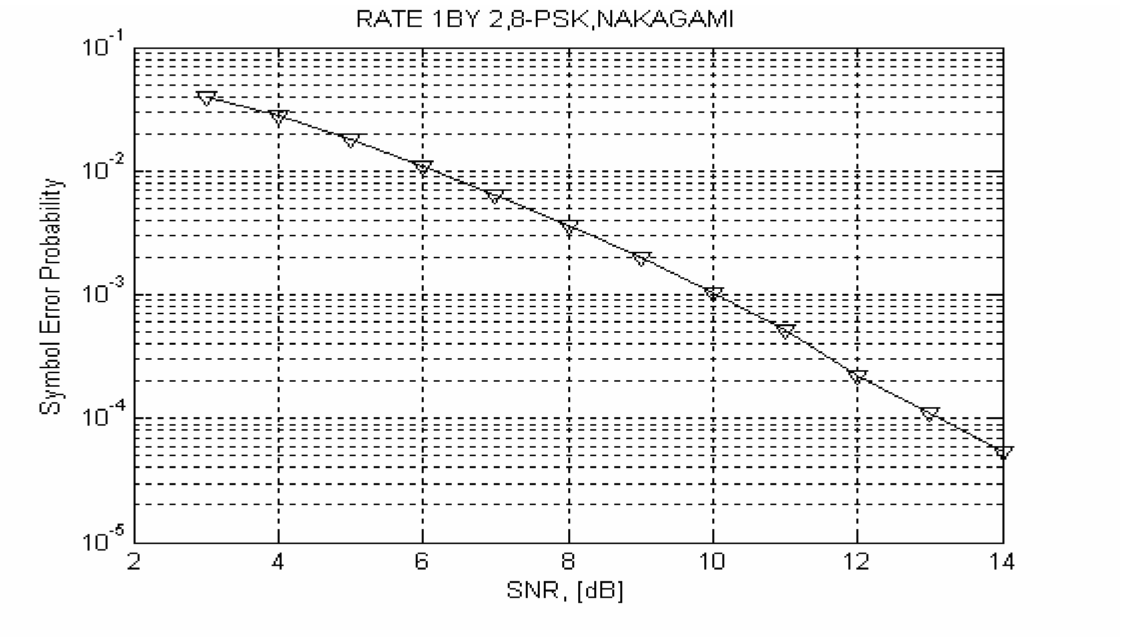


Figure-5.31: SER error performance of 8-PSK for NAKAGAMI fading for rate 3 by 4 (4 Transmitting Antennas)

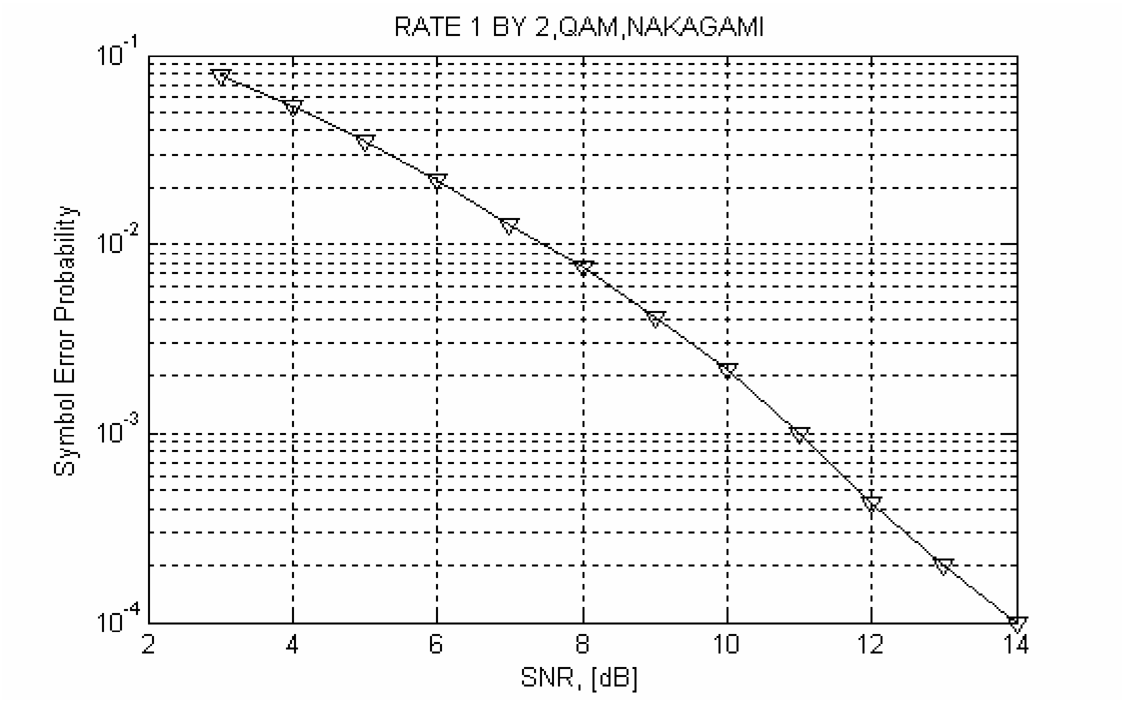


Figure-5.32: SER error performance of 8-PSK for NAKAGAMI fading for rate 3 by 4 (4 Transmitting Antennas)

5.3.4.1 SNR Comparison of Various Modulations under NAKAGAMI Fading

Table-5.8: SNR performance under NAKAGAMI fading at BER 10^{-2}

Modulation Technique	Signal to Noise ratio(SNR)
BPSK	16dB
QPSK	10.5 dB
8-PSK	6 dB
4-QAM	7.5 dB

Table-5.8 shows that at the bit error rate of 10^{-2} 8-PSK modulation technique gives about 10 dB gain over the use of BPSK under NAKAGAMI fading environment. So, the performance of 8-PSK modulation technique is better in comparison to BPSK and QPSK 4-QAM also gives good performance as compared to other modulation techniques.

CHAPTER 6

COMBINED PLOTS OF DIFFERENT NUMBER OF ANTENNAS AT DIFFERENT RATES

In this combined plot of uncoded transmission is compared with two, three and four antennas under different modulation schemes. The performance of different rate codes was simulated in different fading environments but with same AWGN in all cases. The performance is shown below.

6.1 COMBINED PLOTS FOR TWO, THREE AND FOUR ANTENNAS AT 3 BITS/SEC/HZ USING RAYLEIGH FADING

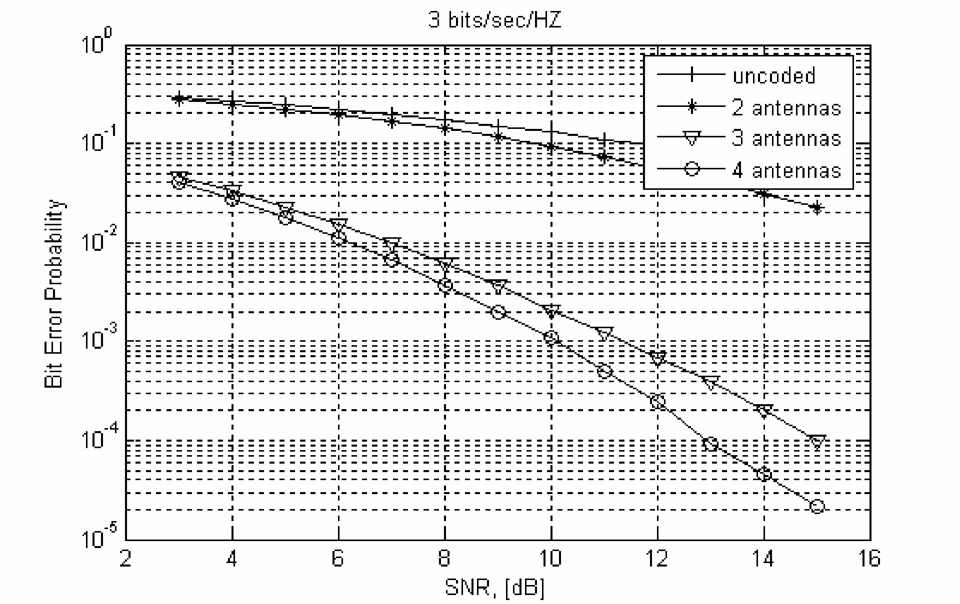


Figure-6.1: BER versus SNR for space time block codes at 3bits/sec/Hz;one receive antenna

Table-6.1: SNR performance of different no. of transmit antennas at BER $10^{-1.5}$

No. of antennas used	**Signal to Noise ratio (SNR)**
Uncoded	16dB
2 Tx	14 dB
3 Tx	5 dB
4 Tx	4 dB

Figure 6.1-show bit error rate for transmission of 3 bits/sec/Hz. The results are reported for an uncoded 8-PSK and space-time block codes using two, three and four antennas. Simulation results are given for one receive antenna. The transmissions using two transmit antennas employs the 8-PSK constellation and the code G_2 .For three and four transmit antennas, the 16-Qam constellation and the codes H_3 and H_4, respectively, are used. Since H_3 and H_4 are rate ¾ codes, the total transmission rate in each case is 3 bits/sec/Hz. It is seen that at the bit error rate of $10^{-1.5}$ the rate ¾ 16-QAM codes H_4 gives about 10 dB gain over the use of an 8-PSK G_2 code.

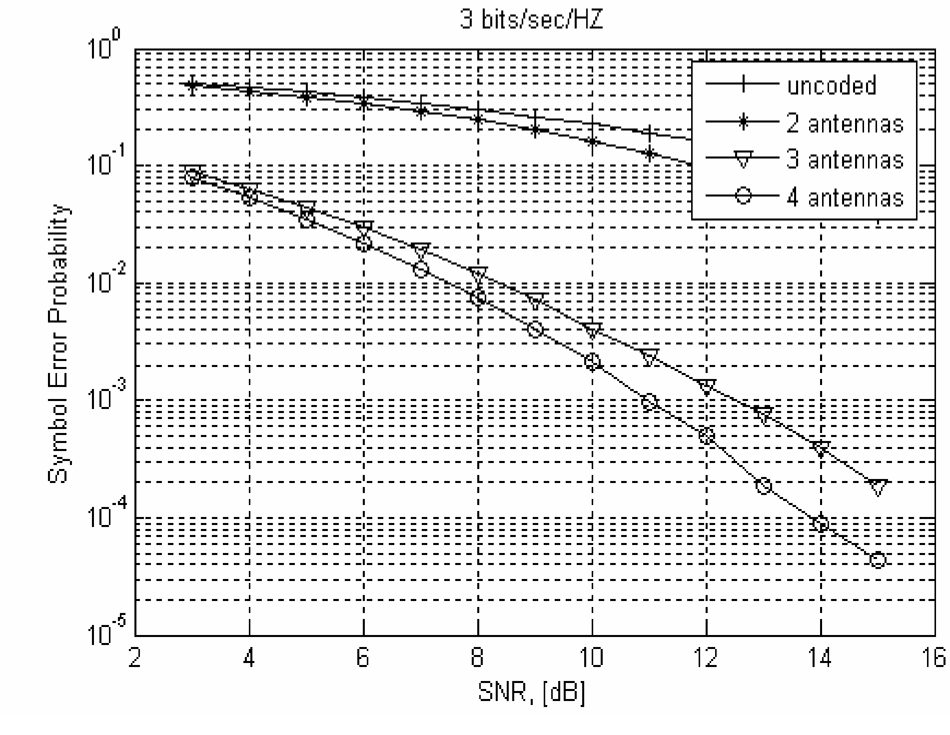


Figure-6.2: SER versus SNR for space time block codes at 3bits/sec/Hz;one receive antenna

Table-6.2: SNR performance of different no. of transmit antennas at BER 10^{-1}.

No. of antennas used	**Signal to Noise ratio (SNR)**
Uncoded	14dB
2 Tx	12 dB
3 Tx	3.5 dB
4 Tx	3 dB

Figure 6.2-show bit error rate for transmission of 3 bits/sec/Hz. It is seen that at the bit error rate of $10^{-1.5}$ the rate ¾ 16-QAM codes H_4 gives about 9 dB gain over the use of an 8-PSK G_2 code.

6.2 COMBINED PLOTS FOR TWO, THREE AND FOUR ANTENNAS AT 2 BITS/SEC/HZ USING RAYLEIGH FADING

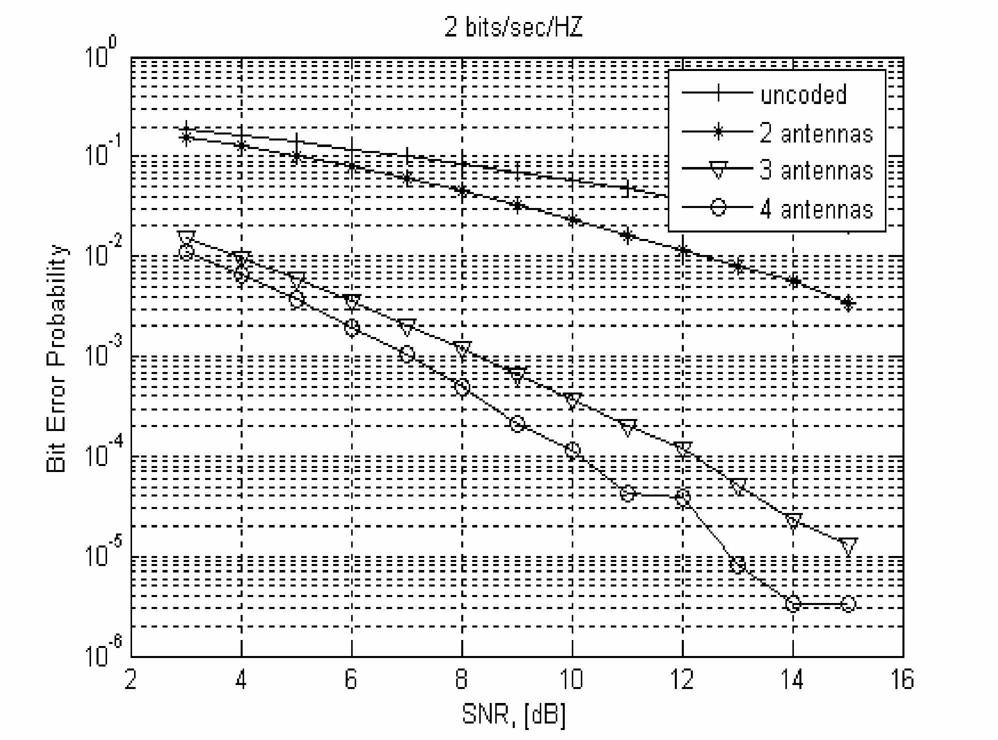


Figure-6.3: BER versus SNR for space time block codes at 2bits/sec/Hz;one receive antenna

Table-6.3: SNR performance of different no. of transmit antennas at BER 10^{-2}

No. of antennas used	**Signal to Noise ratio (SNR)**
Uncoded	14dB
2 Tx	12 dB
3 Tx	4 dB
4 Tx	3 dB

Figure 6.3-show symbol error rate for transmission of 2 bits/sec/Hz. The results are reported for an uncoded 4-PSK and space-time block codes using two, three and four antennas. Simulation results are given for one receive antenna. The transmissions using two transmit antennas employs the 4-PSK constellation and the code G_2 .For three and four transmit antennas, the 16-Qam constellation and the codes G_3 and G_4, respectively, are used. Since G_3 and G_4 are rate1/2 codes, the total transmission rate in each case is 2 bits/sec/Hz. It is seen that at the bit error rate of 10^{-2} the rate ¾ 16-QAM code G_4 gives about 9 dB gain over the use of an 4-PSK G_2 code.

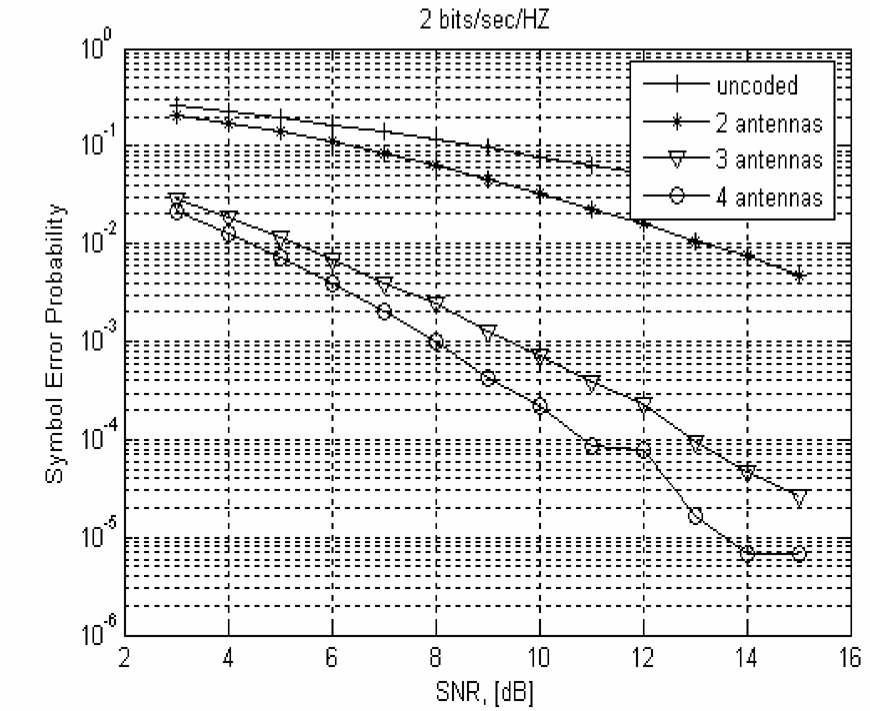


Figure-6.4: SER versus SNR for space time block codes at 2bits/sec/Hz;one receive antenna

Table-6.4: SNR performance of different no. of transmit antennas at BER 10^{-2}.

No. of antennas used	**Signal to Noise ratio (SNR)**
Uncoded	14dB
2 Tx	12 dB
3 Tx	3.5 dB
4 Tx	3 dB

Figure 6.4-show symbol error rate for transmission of 2 bits/sec/Hz. It is seen that at the bit error rate of 10^{-2} the rate ¾ 16-QAM codes G_4 gives about 8.5 dB gain over the use of an 4-PSK G_2 code.

6.3 COMBINED PLOTS FOR TWO, THREE AND FOUR ANTENNAS AT 1 BITS/SEC/HZ, ONE RECEIVE ANTENNA USING RAYLEIGH FADING

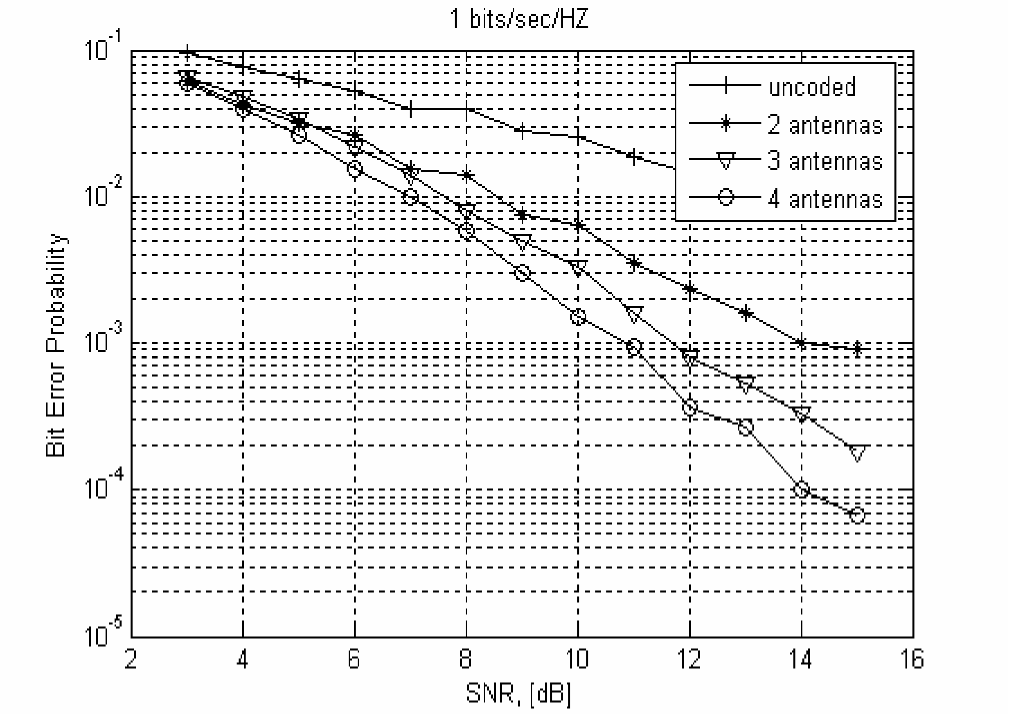


Figure-6.5: BER versus SNR for space time block codes at 1bits/sec/Hz;one receive antenna

Table-6.5: SNR performance of different no. of transmit antennas at BER 10^{-3}

No. of antennas used	**Signal to Noise ratio (SNR)**
Uncoded	16dB

2 Tx	14 dB
3 Tx	12 dB
4 Tx	11 dB

Figure 6.5-show symbol error rate for transmission of 1 bits/sec/Hz. The results are reported for an uncoded 2-PSK and space-time block codes using two, three and four antennas. Simulation results are given for one receive antenna. The transmissions using two transmit antennas employs the 2-PSK constellation and the code G_2 .For three and four transmit antennas, the 4-PSK constellation and the codes G_3 and G_4, respectively, are used. Since G_3 and G_4 are rate1/2 codes, the total transmission rate in each case is 1bits/sec/Hz. It is seen that at the bit error rate of 10^{-3} the rate 1/2 4-PSK code G_4 gives about 3 dB gain over the use of an 2-PSK G_2 code.

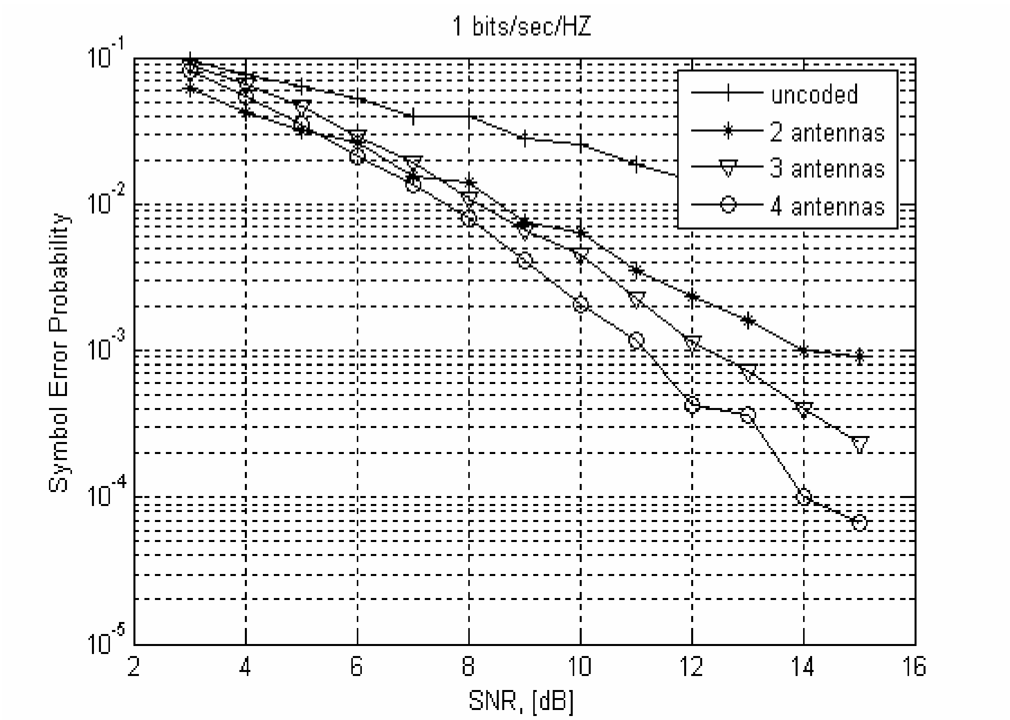


Figure-6.6: SER versus SNR for space time block codes at 1bits/sec/Hz;one receive antenna

Table-6.6: SNR performance of different no. of transmit antennas at BER 10^{-3}.

No. of antennas used	**Signal to Noise ratio (SNR)**
Uncoded	16dB
2 Tx	14 dB

3 Tx	12 dB
4 Tx	11 dB

Figure 6.6-show symbol error rate for transmission of 1 bits/sec/Hz. It is seen that at the bit error rate of 10^{-3} the rate 1/2 4-PSK codes G_4 gives about 3 dB gain over the use of an 2-PSK G_2 code.

6.4 COMBINED PLOTS FOR TWO, THREE AND FOUR ANTENNAS AT 1 BITS/SEC/HZ, TWO RECEIVE ANTENNA USING RAYLEIGH FADING

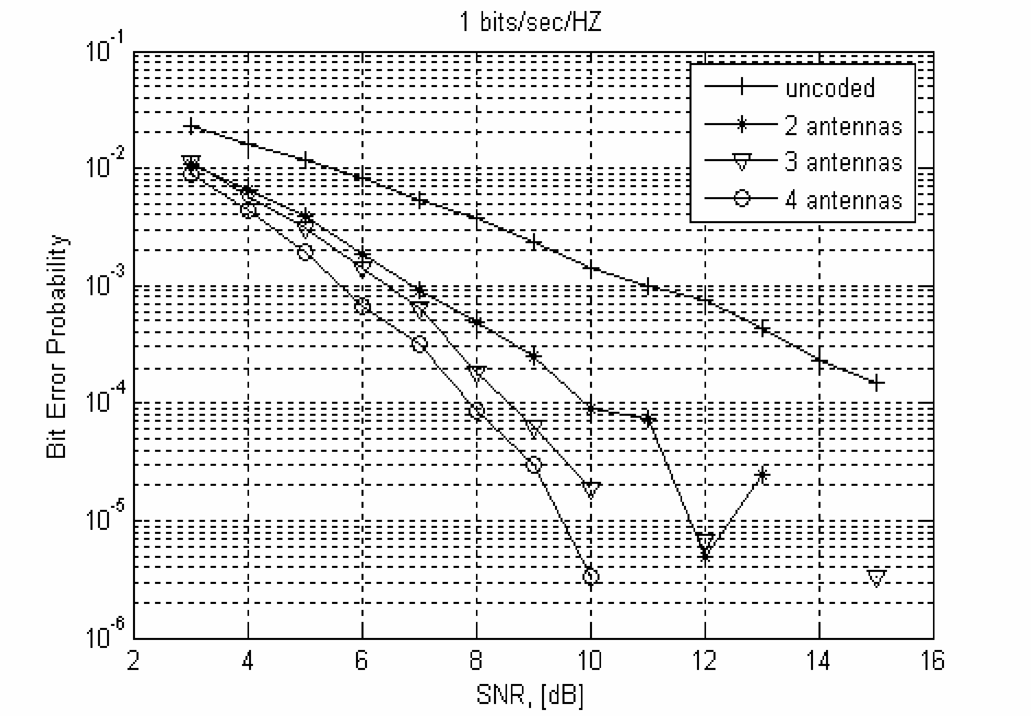


Figure-6.7: BER versus SNR for space-time block codes at 1bits/sec/Hz; two receive antenna

Table-6.7: SNR performance of different no. of transmit antennas at BER 10^{-3}

No. of antennas used	**Signal to Noise ratio (SNR)**
Uncoded	11dB
2 Tx	7 dB
3 Tx	6.5 dB
4 Tx	5.8 dB

Figure 6.7-show symbol error rate for transmission of 1 bits/sec/Hz. The results are reported for an uncoded 2-PSK and space-time block codes using two, three and four antennas. Simulation results are given for one receive antenna. The transmissions using two transmit antennas employs the 2-PSK constellation and the code G_2 .For three and four transmit antennas, the 4-PSK constellation and the codes G_3 and G_4, respectively, are used. Since G_3 and G_4 are rate1/2 codes, the total transmission rate in each case is 1bits/sec/Hz. It is seen that at the bit error rate of 10^{-3} the rate 1/2 4-PSK code G_4 gives about 1.2 dB gain over the use of an 2-PSK G_2 code.

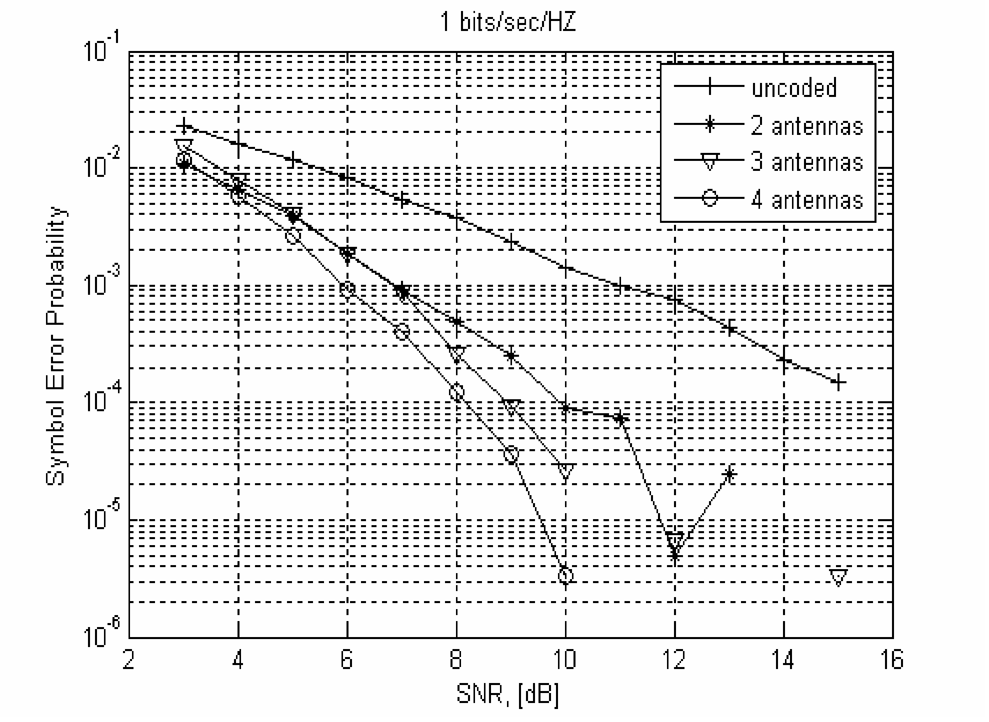


Figure-6.8: SER versus SNR for space-time block codes at 1bits/sec/Hz; two receive antenna

Table-6.8: SNR performance of different no. of transmit antennas at BER 10^{-3}.

No. of antennas used	**Signal to Noise ratio (SNR)**
Uncoded	11dB
2 Tx	7 dB
3 Tx	6.5 dB
4 Tx	6 dB

Figure 6.8-show symbol error rate for transmission of 1 bits/sec/Hz. It is seen that at the bit error rate of 10^{-3} the rate 1/2 4-PSK codes G_4 gives about 1 dB gain over the use of an 2-PSK G_2 code. If the number of receive antennas is increased, the gain reduces. The reason is that much of the diversity is already achieved by two transmit and two receive antennas.

CHAPTER 7

CONCLUSIONS AND FUTURE SCOPES

In this thesis a comparative study of different rate scheme is done. Performance of rate 3 by 4 and rate 1 by 2 schemes is studied under different fading environments using different modulation techniques.

In chapter 3 the simulation results for rate 3 by 4, for three and four transmit antennas in case of RAYLEIGH fading channel using different modulation techniques is presented. For BER of less than 10^{-2} 8-PSK gives about 9 dB gain over the use BPSK. The performance of 4-QAM and 8-PSK is approximately same. Similar performances are observed for SER. The simulation results for rate 1 by 2, for three and four transmit antennas in case of RAYLEIGH fading channel using different modulation techniques is presented. For BER of less than 10^{-2} 8-PSK gives about 9 dB gain over the use BPSK.4-QAM and QPSK differ in performance by approximately 2.5 dB. Similarly results for SER is also presented.

In chapter 4 the simulation results for rate 3 by 4 and rate 1by 2 schemes, for three and four transmit antennas in case of RICIAN fading channel using different modulation techniques is presented. For rate 3 by 4 performance gain improvement in case of 8-PSK is 8 dB more as compared to BPSK. In case of. rate 1 by2 performance gain improvement is approximately 13 dB .Thus, the performance of the 4-QAM and 8-PSK is best when RICIAN fading in present .

In chapter 5 the simulation results for rate 3 by 4 and rate 1by 2 schemes,for three and four transmit antennas in case of NAKAGAMI fading channel using different modulation techniques is presented. For rate 3 by 4 performance gain improvement in case of 8-PSK is 7 dB more as compared to BPSK. In case of. rate 1 by 2 performance gain improvement is 9 dB .Thus, the performance of the 4-QAM and 8-PSK is best when NAKAGAMI fading in present.

In chapter 6 the simulation results for uncoded, two, three and four antennas under different modulation schemes is presented. The results are concluded here.

Table-7.1: SNR performance of different fading at BER 10^{-2}.

N bits/sec/Hz	UNCODED	2 TX (2^N PSK)	3TX(16QAM)	4TX (16-QAM)
3	16dB	14dB	5dB	4dB
2	14dB	12dB	4dB	3dB
1	16dB	14dB	12dB	11dB

The above simulations demonstrate that significant gains can be achieved by increasing the number of transmit antennas with very little decoding complexity.

Performance results for different fading environments using QPSK modulation are described next.

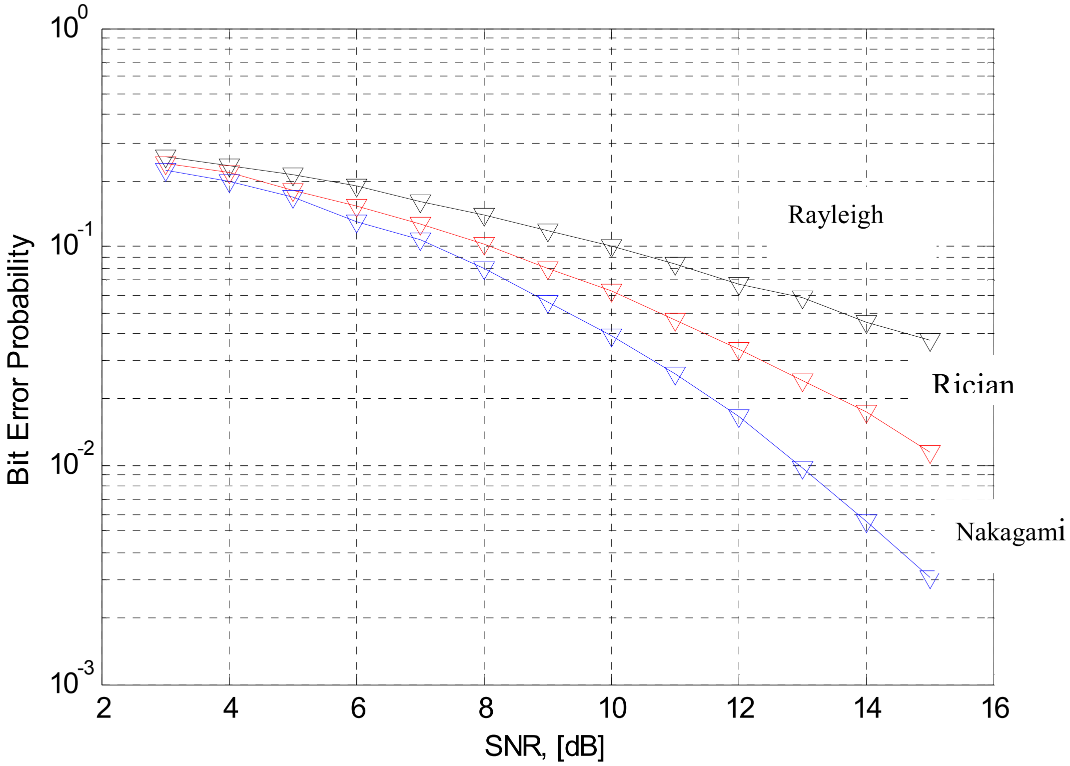


Figure-7.1: BER performance of QPSK under different fading environments

Table-7.2: SNR performance of different fading at BER 10^{-1}.

Fading environments	**Signal to Noise ratio (SNR)**
Rayleigh	10db
Rician	8 db
Nakagami	7.5 db

Figures 7.1 show bit error rate, for rate 3 by 4 scheme using qpsk modulation technique .The results are reported for Rayleigh, Rician, Nakagami fading channels .It is seen that at the bit error of 10^{-1}, the rate ¾ nakagami fading gives about 2.5 dB gain over the use of Rayleigh fading and gives about 2 dB gain over the use of Rician fading. Hence, the performance of system is better in case of nakagami fading as compared to Rician and Rayleigh fading environments.

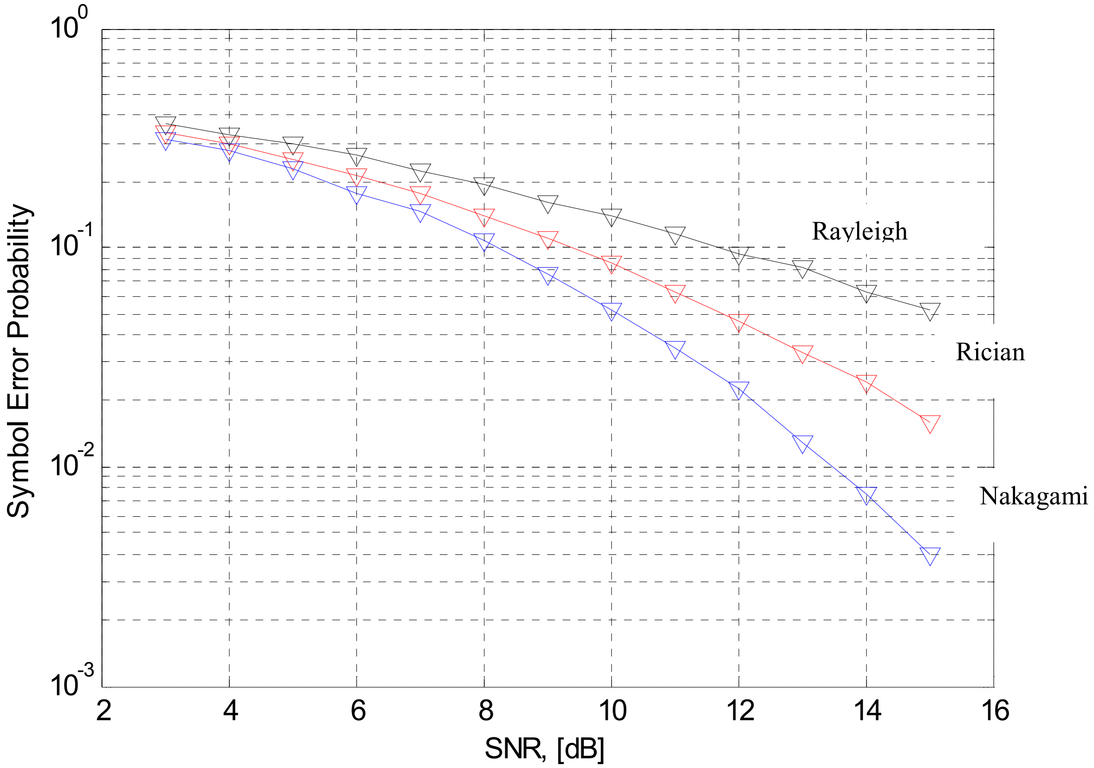


Figure-7.2: SER performance of QPSK under different fading environments

Table-7.3: SNR performance of different fading at SER 10^{-1}.

Fading environments	**Signal to Noise ratio (SNR)**
Rayleigh	12dB
Rician	9.5dB
Nakagami	8.2dB

Figures 7.2 show symbol error rate, respectively, for rate 3 by 4 scheme using qpsk modulation technique .the results are reported for Rayleigh, Rician, Nakagami fading channels .It is seen that at the bit error of 10^{-1}, the rate ¾ nakagami fading gives about 3.8 dB gain over the use of Rayleigh fading and gives about 2.5 dB gain over the use of Rician fading. Hence, the performance of system is better in case of nakagami fading as compared to Rician and Rayleigh fading environments.

Applications of fractional rate schemes include improving performance in case of microwave links and aeronautical telemetry. This can be further extended to various other applications in wireless communications.

FUTURE SCOPE OF WORK

This thesis examined the performance of RATE 3 by 4 and RATE 1 by 2 schemes using different modulation techniques under different fading environments. Some of the possible areas for future scope of work are:

- In this system co-channel interference and inter-symbol interference (ISI) are not considered and so it is called as an open loop system. Transmit diversity with feedback can be used to improve the system performance.
- Diversity and spatial multiplexing can be combined to study trade off between diversity and multiplexing for different rate schemes.
- Further studies are going on orthogonal space-time block codes for transmission rate>1 using multiple antennas at the transmitter and receiver.
- This system can be further extended to delay diversity for frequency selective and frequency flat channels.
- Space-time block coding can be concatenated with space-time trellis coding to further improve the performance.

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LIST OF PUBLICATIONS

- Submitted a paper on "**PERFORMANCE OF FARCTIONAL RATE STBC CODES IN WIRELESS COMMUNICATIONS"** in conference on **NATIONAL CONFERENCE ON WIRELESS NETWORKS AND EMBEDDED SYSTEMS AT** CHITKARA INSTITUTE OF ENGG & TECH, CHANDIGARH in June 2006.

- Presented a paper on **"WIRELESS SENSOR NETWORKS- A REVIEW"** in **NATIONAL CONFERENCE ON SENSORS** at THAPAR INSTITUTE OF ENGG. & TECH., PATIALA in Nov2005.

- Presented a paper on **"A REVIEW OFPROBLEMS IN WIRLESS SENSOR NETWORKS"** in **NATIONAL CONFERENCE ON SENSORS** at THAPAR INSTITUTE OF ENGG. & TECH., PATIALA in Nov2005.

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