Matlab Simulation of Digital (QPSK) Line-of-Sight Radio Link

by

Syamsul Bahri bin Muhammad

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons.)
(Electrical and Electronics Engineering)

JUNE 2004

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Matlab Simulation of Digital (QPSK) Line-of-Sight Radio Link

by

Syamsul Bahri bin Muhammad

A project dissertation submitted to the
Electrical & Electronics Programme
Universiti Teknologi PETRONAS
in partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(ELECTRICAL & ELECTRONICS ENGINEERING)

Approved by,

(Mr Azman Zakariya)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2004

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

SYAMSUL BAHRI BIN MUHAMMAD
810218-03-5869
Matric ID:1174

ABSTRACT

Telecommunication system is one of the major components in industry. It can be summarized as the transmission, reception, and processing of information between two or more locations, using either digital or analogue transmission. Wireless technologies become essential when guided media connections are difficult to provide economically.

Wireless communication system affected by external (atmosphere) factors. Studies need to be done at certain places before actual communication system been implemented. The wireless transmissions over large water areas are different as compared to transmission over land in term of propagation conditions, radio wave reflection over water and ducting, which make them more difficult to design. However, they are very essential to remote-island or off-shore location to communicate with offices on main land.

The main objective of this project is to develop a MATLAB simulation for QPSK that considered external factors in radio transmission. The analysis carried out was on BER performance for QPSK system, phasor and constellation analysis. This analysis is to determine that the simulation is well defined with the theoretical value. Factors involved in determining system performance such as multipath fading and AWGN also has been considered. The simulation output of the Maximal Ratio Combining (MRC) Space Diversity configuration for multiple receive antennas which shows the improvement in the received signal is also been analyzed.

ACKNOWLEDGEMENT

I would like to gratefully acknowledge the enthusiastic supervision of Encik Azman Zakariya who always providing resources and subjects, and offering direction during the duration of this project. I also would like to thanks all lecturers and staff who help me directly or indirectly in completing this thesis.

I would like to thank all the students of the Universiti Teknologi PETRONAS with whom I interact every day and established a strong friendship. I thank for the theoretical discussions and support while completing this project.

Finally, I am forever indebted to my family for their support and encouragement when it was most required.

A final word of thanks to God for making all this possible.

TABLE OF CONTENTS

CERTIFICATION OF APPROVAL		i
CERTIFICATION OF ORIGINALITY		ii
ABSTRACT		iii
ACKNOWLEDGEMENTS		iv
ABBREVIATIONS AND NOMENCLATURES		ix
CHAPTER 1:	**INTRODUCTION**	1
1.1	Background of Study	1
1.2	Problem Statement	5
1.3	Objectives and Scope of Study	6
	1.3.1 Objectives of the Project	6
	1.3.2 Scope of Study	7
CHAPTER 2:	**THEORY**	8
2.1	Quadrature Phase Shift Keying	8
2.2	Transmitter	9
2.3	Receiver	11
2.4	Bit Error Rate	13
2.5	Additive White Gaussian Noise	14
2.6	Fading	15
	2.6.1 Instantaneous SNR per bit	17
	2.6.2 Probability of Error	17

CHAPTER 3:	**METHODOLOGY/PROJECT WORK**	18
3.1	Dest Study	18
3.2	Project Milestone	18
3.3	Tools and Equipmet Used	19
3.4	Project Work	19
3.5	Sample Preparation & Testing	20
CHAPTER 4:	**RESULTS AND DISCUSSION**	21
4.1	Binary Phase Shift Keying (BPSK)	21
4.2	MSK & QPSK Using Simulink	23
4.3	BER Performance of QPSK	25
4.4	Multipath Model	28
4.5	Maximal Ratio Combining	29
4.6	Effect of Antenna Spacing to the BER Performance	31
CHAPTER 5:	**CONCLUSION AND RECOMMENDATION**	33
5.1	Conclusion	33
5.2	Recommendations	34
REFERENCES		35
APPENDICES		

LIST OF FIGURES

FIGURE 1.1	Line-of-sight transmitter-receiver
FIGURE 2.1	Phasor diagram of QPSK
FIGURE 2.2	Constellation diagram of QPSK
FIGURE 2.3	Output phase-versus-time relationship for QPSK modulator
FIGURE 4.1	MATLAB codes for the BPSK modulation
FIGURE 4.2	Input data of BPSK
FIGURE 4.3	Output data of modulated BPSK
FIGURE 4.4	Comparison of QPSK and MSK modulation technique using Simulink
FIGURE 4.5	Simulation result of QPSK BER performance
FIGURE 4.6	Diagram of the Naftali multipath fading model
FIGURE 4.7	BER simulation result of MRC for 1, 2, 3, and 4 receive antennas
FIGURE 4.8	BER simulation result for 2 receive antennas at different spacing
FIGURE A-1	QPSK Transmitter
FIGURE A-2	QPSK Receiver
FIGURE A-3	The Basic Configuration of Microwave Communication System
FIGURE A-4	Full MATLAB Codes for Frequency Modulation
FIGURE A-5	MATLAB Output of Frequency Modulation
FIGURE A-6	Theoretical BER Performance of QPSK Scheme Under AWGN and One-Path Flat Rayleigh Fading Environment
FIGURE A-7	Simulation Result of BER Performance of QPSK Scheme Under AWGN
FIGURE A-8	Eye Diagram of QPSK Output
FIGURE A-9	Eye Diagram of MSK Output
FIGURE A-10	Constellation Diagram of QPSK Output
FIGURE A-11	Constellation Diagram of MSK Output
FIGURE A-12	Full MATLAB Codes of BER Simulation for QPSK
FIGURE A-13	QPSK Transmission Data (`data1`)
FIGURE A-14	QPSK transmission oversampled data (`ich1`)
FIGURE A-15	QPSK transmission oversampled data (`qch1`)
FIGURE A-16	QPSK received signal before demodulate (`ich3`)
FIGURE A-17	QPSK received signal before demodulate (`qch3`)
FIGURE A-18	QPSK Phasor diagram
FIGURE A-19	Input Image Fed For Simulation

FIGURE A-20 Output Image of Simulation (Eb/No = 1 dB)
FIGURE A-21 Output Image of Simulation (Eb/No = 5 dB)
FIGURE A-22 Output Image of Simulation (Eb/No = 10 dB)
FIGURE A-23 Simulation Output file (*.dat) of QPSK BER Performance
FIGURE A-24 MATLAB program for BER performance of multiple antennas
FIGURE A-25 Simulation output image for 1 receiver antenna (Eb/No=10 dB)
FIGURE A-26 Simulation output image for 2 receiver antennas (Eb/No=10 dB)
FIGURE A-27 Simulation output image for 3 receiver antennas (Eb/No=10 dB)
FIGURE A-28 Simulation output image for 4 receiver antennas (Eb/No=10 dB)
FIGURE A-29 MATLAB program for BER performance of antennas spacing
FIGURE A-30 Simulation output image for antenna spacing at d/lambda=0.0001
FIGURE A-31 Simulation output image for antenna spacing at d/lambda=100
FIGURE B-1 Suggested Gantt Chart (1st Semester)
FIGURE B-2 Suggested Gantt Chart (2nd Semester)

ABBREVIATIONS AND NOMENCLATURES

1.	AM	: Amplitude Modulation.
2.	AWGN	: Additive White Gaussian Noise.
3.	BER	: Bit Error Rate.
4.	BPSK	: Binary Phase Shift Keying.
5.	CNR	: Carrier to Noise Ratio.
6.	CP-FSK	: Continuous- Phase Frequency Shift Keying.
7.	dB	: Decibel.
8.	E_b/N_o	: Energy per Bit-to-Noise Power Density Ratio.
9.	FIR	: Finite Impulse Response.
10.	FM	: Frequency Modulation
11.	FSK	: Frequency Shift Keying.
12.	IF	: Intermediate Frequency.
13.	MCMC	: Malaysian Communications and Multimedia Commission.
14.	MRC	: Maximal Ratio Combining.
15.	MSK	: Minimum Shift Keying.
16.	PSK	: Phase Shift Keying.
17.	OQPSK	: Offset Quaternary Phase Shift Keying.
18.	QAM	: Quadrature Amplitude.
19.	QPSK	: Quaternary Phase Shift Keying.
20.	RF	: Radio Frequency.

CHAPTER 1

INTRODUCTION

This chapter serves an overview of the communication system which emphasis on the communication systems available for radio transmission. All of the available system is analysis and compared. Methods for signal modulation are also discussed where each modulation technique is briefly described. The problem statement for the project is discussed on line-of-sight communication system. All the external factors that should be considered in designing a communication links are briefly explained. The specific objectives and scope of study of this project is discussed on the last section of this chapter.

1.1 BACKGROUND OF STUDY

Radio communication is the most economical system to provide for transmissions over a large water area (sea) when reliability and large bandwidth are the main consideration. It was being implemented mostly for oil and gas exploration and production purposes where data transmission between the remote platform and coast (main land) is essential for the operation. Line-of-sight gives definition of a transmitter and receiver which in visual contact with each other. The line-of-sight distance can be up to 200 km apart.

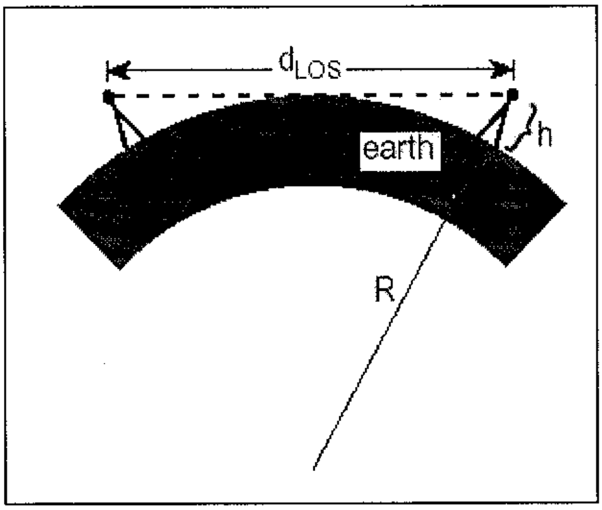


Figure 1.1 Line-of-sight transmitter-receiver

Alternative transmission media for connecting places separated by 70km to 100km are listed below, including the advantages and disadvantages of each:

- **Undersea cable:** The main problem is high risk of cable damage under water where ships operate intensively and problems of bringing up the cables and repeaters from the sea bottom for maintenance. The undersea cable can be up to 300 meters vertical section.
- **Troposcatter link:** Required high transmitter powers and very large antennas, and difficulties to provide large capacity digital connection. This type of communication also has strong interference with other signals. The advantage is that larger distances can be bridged than with line-of-sight links (up to 150 to 250km).
- **Satellite link:** Highly cost especially in the leasing of wide bandwidth with satellite transponders. However, it provides the good quality connection for a long distance transmission.

Advantages of microwave radio communication are as follows:

- Each station requires only a small area of land for outdoor and indoor units.
- Can carry large quantities of information due to high operating frequencies.
- Relatively small antennas (high frequency)
- Fewer repeaters are necessary for amplification.
- Minimum delay time
- Increase reliability and less maintenance

Digital communications covers a broad area of communications techniques, including digital transmission and digital radio. Digital transmission can be defined as the transmittal of digital pulses between two or more points in a communication system. Digital radio is the transmittal of digitally modulated analog carriers between two or more points in a communications system. Digital transmission systems require a physical facility between the transmitter and receiver, such as metallic wire pair, a coaxial cable, or an optical fiber cable. In digital radio systems, the transmission medium could be free space, Earth's atmosphere, or a physical facility such as metallic or optical fiber cable.

There is several method of digital radio modulation, as listed below:

- **Frequency Shift Keying**

  FSK is a simple, low- performance type of digital modulation.

  Binary FSK is a form of constant- amplitude angle modulation similar to conventional frequency modulation (FM) except that the modulating signal is a binary signal that varies between two discrete voltage levels rather than a continuously changing analog waveform. With BFSK, the amplitude can only be one of two values, one for logic 1 condition and one for 0 conditions. Continuous- Phase Frequency Shift Keying (CP- FSK) is binary FSK except the mark and space frequencies are synchronized with the input binary bit rate. Synchronous simply implies that there is a precise time relationship between those two; it does not mean they are equal. The important characteristic is that it has a smooth transition when it changes the mark and space frequencies. It also can be known as Minimum Frequency Shift.

- **Phase Shift Keying**

  PSK is also a form of angle modulated, constant- amplitude modulation. It is similar to phase modulation except that with PSK the input signal is a binary signal and a limited number of output phases.Binary PSK allows two output phases for a single carrier frequency (1 and 0). As the input digital signal changes state, the phase of the output carrier shifts between two angles that are 180 degree out of phase. M-ary encoding is a digital modulation that enables M conditions or combinations possible for a given number of binary variables. It is often advantageous to encode at a level higher than binary. For a four possible output phases, M is replace with 4, (M=4), and for eight possible output phases, M=8 and so on. If M=4, it is also known as Quaternary Phase Shift Keying, uses dibits for four output condition, and for M=8 (eight- phase PSK), uses tribits for 8 output phases.

- **Quadrature Amplitude Modulation**

  QAM is a form of digital modulation where the digital information is contained in both the amplitude and the phase of the transmitted carrier. 8-QAM is an M-ary encoding technique where M=8. The output signal from an 8-QAM modulator is not a constant- amplitude signal.

1.2 PROBLEM STATEMENT

QPSK modulation technique is widely used in digital communication system. This technique is a constant amplitude modulation with four output phases available for a single carrier frequency. The QPSK transmitter circuit modulates the signal and demodulated at the QPSK receiver circuit.

There are several problems that need to be considered for a line-of-sight radio communication. Although it is the most economical transmission alternative compared to other terrestrial communication systems, studies need to be conducted at the respective locations before the actual radio communication system being implemented. Based on the data and results of the studies, the optimum system design and configuration can be proposed by the communication engineers.

The external factors that should be considered in designing a radio communication link are as below:

- **Diffraction:** Ability of the radio wave to be bent slightly downward when it strikes a sharp object. The factors that affect the diffraction of signals are the frequency of the radiated waves and sharpness of the obstacle.
- **Reflection:** The ability of radiated waves being reflected. It might be useful in some applications, such as focusing them into a beam, but can also be a major cause of signal degradation.
- **Refraction:** Refraction is based on the fact that electromagnetic energy travels at different speeds in different media, of different in density.
- **Fresnel Zones:** Radiated path travels more than one path to the receive antenna. Fresnel zones are separated half wavelength ($\frac{1}{2}\lambda$) to each other, which can cause signal cancellation at the receiver.

- **Ducting:** Atmospheric phenomena where a temperature or humidity inversion occurs, creating a layer of special air that will bent away radiated signals from the intended destination.
- **Multipath fading:** Variations in the level of received radio signals, which affected by atmospheric variations in the earth's lower attitude.

These external factors contribute on how the communication can be designed effectively. The configuration of the system will determine the reliability and performance in handling the factors. Each of the factors needs to be included in the simulation to get the accurate output results.

The performance of the system is also affected by the antennas height of the transmitter and receiver. A real application of microwave communication system is usually using transmission path (space diversity) configurations. The performance is depends on the multipath fading and arrangement of antennas at the receiver end.

1.3 OBJECTIVES AND SCOPE OF STUDY

1.3.1 Objectives of the Project

The main objective of this project is to develop a MATLAB simulation of a digital radio link. The digital transmission is using QPSK modulation technique. The external factors affecting the communication system such as noise, fading, and antennas configuration is simulated and analyzed. The study is also taking into consideration the Malaysian Communication and Multimedia Commission (MCMC) technical requirement of the communication system configuration and channel arrangement. The simulation shall be applicable to be used for a radio transmission over maximum of 100km. The simulation is to give output of the analysis such as received signal levels, error performance and availability, bit error ratio (BER), with the system configuration.

1.3.2 Scope of Study

The project is on the research and programming of the basic modulation technique using MATLAB. The filtering and external factors (multipath fading, reflection, Rayleigh fading) are then added to the modulation technique. The other analysis such as the determination of the BER, antenna configuration, system diversity will be carried out after the QPSK is successfully simulated. The simulation result is very important in this project. The result of simulation shall be comparable with the analytical results.

CHAPTER 2

THEORY / LITERATURE REVIEW

This chapter discussed on the theories and literature review of the project. The modulation technique used is QPSK. To achieve a high quality of received signal, the diversity system is used. The diversity system available is discussed where space diversity system is used in this project. The transmitter and receiver application is briefly discussed together with BER measurements and AWGN theoretical definition.

2.1 QUADRATURE PHASE SHIFT KEYING (QPSK)

Quaternary Phase Shift Keying (QPSK) is one form of angle-modulated, constant amplitude digital modulation. QPSK is an *M-ary* encoding technique where $M=4$, meaning that there are four output phases in a single carrier frequency. The binary input data are combined into groups of two bits call dibits. Each dibit will generates one of the four possible output phases, meaning that for each two-bit dibit clocked into the modulator, a single output change occurs. Therefore, the rate of change at the output (baud rate) is one-half of the input bit rate.

Digital microwave communication system use line-of-sight transmission; a direct signal path must exist between transmit and receive antennas. Diversity suggests that there is more than one transmission path or method of transmission available between the transmitter and receiver. The system will select the path or method that produces the highest quality received signal. Generally the quality of signal is determined by evaluating the carrier-to-noise ratio (CNR) at the receiver input. The most common methods used are frequency diversity and space diversity (Appendices Figure A-3).

- **Frequency diversity:** Transmitting two different carrier frequencies with the same intelligence signal, then both are demodulated, and the better quality IF signal is selected.

- **Space diversity:** The intelligence frequency is fed to two or more antennas that are physically separated by an appropriate number of wavelengths. Similarly, the receiver will have two or more antennas to capture the signal

2.2 TRANSMITTER

At the transmitter part (Figure 2.1), QPSK uses dibits that split into two channel, I and Q channels. For logic 1 (+1 V), and for logic 0 (-1 V), two phases output are possible at I balanced modulator ($+\sin\omega_c t$ and $-\sin\omega_c t$), and two phases output at the Q balanced modulator ($+\cos\omega_c t$ and $-\cos\omega_c t$). When the linear summer combines the two quadrature (90 degree out of phase) signals, there are 4 possible resultant phasors given by these expressions:

$$\boxed{+\sin\omega_c t+\cos\omega_c t,\ +\sin\omega_c t-\cos\omega_c t,\ -\sin\omega_c t+\cos\omega_c t,\ -\sin\omega_c t-\cos\omega_c t.}$$

QPSK having four possible output phasors that has exactly same amplitude. The binary information must be encoded entirely in the phase of the output signal. This constant amplitude characteristic is the most important characteristic of PSK that distinguishes from QAM. It also can be seen that the angular separation between any two adjacent phasors in QPSK is 90°. Therefore, it can undergo almost a +45° or -45° shift in phase during transmission and still retain the correct encoded information when demodulated at the receiver.

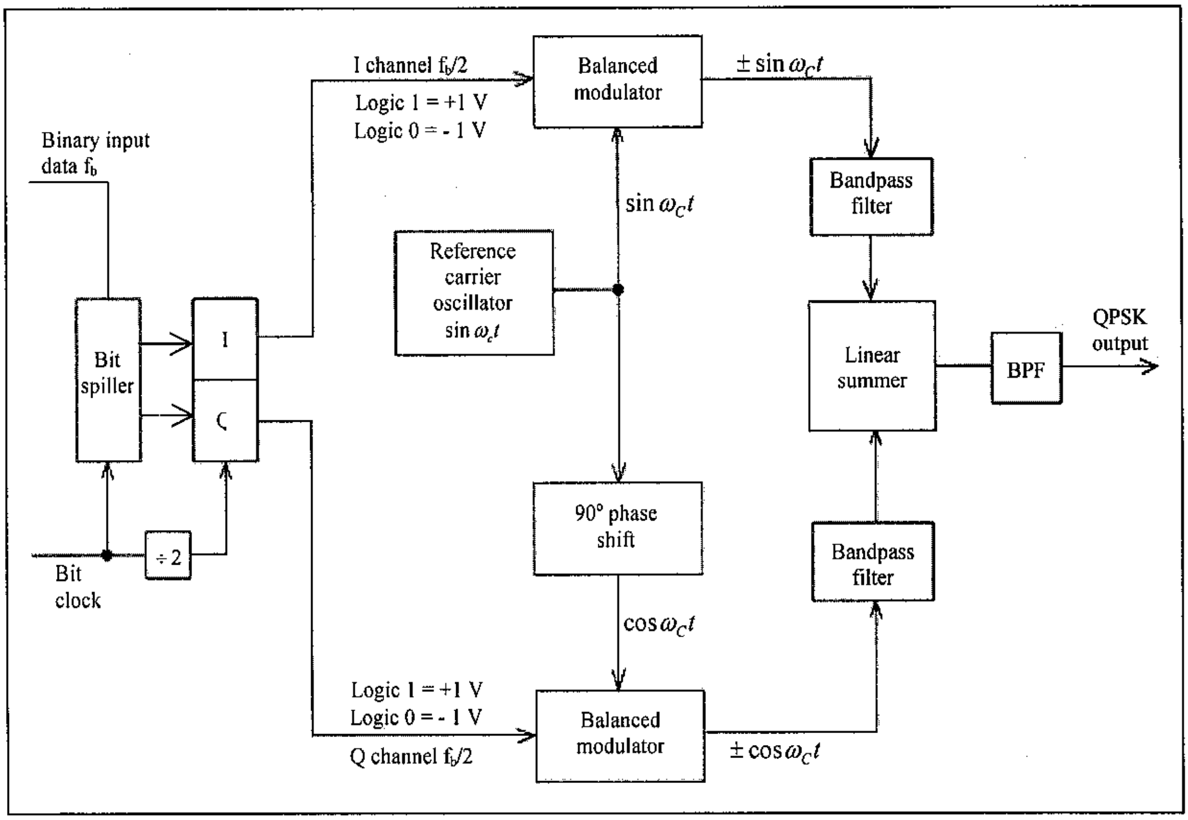


Figure 2.1 QPSK Transmitter

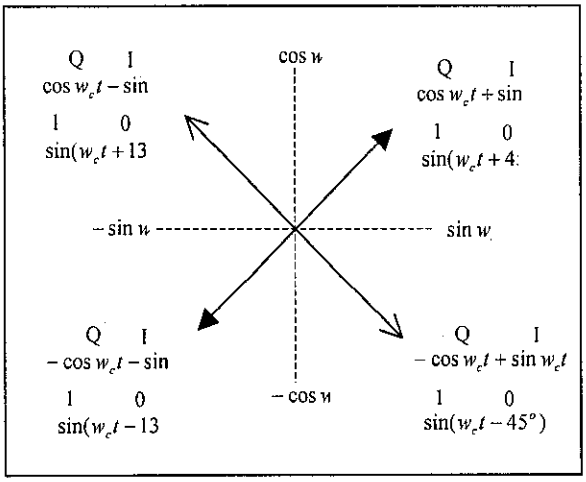


Figure 2.2 Phasor diagram of QPSK

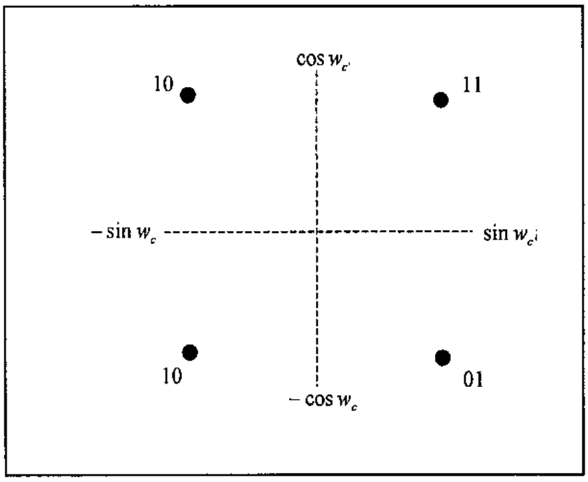


Figure 2.3 Constellation diagram of QPSK

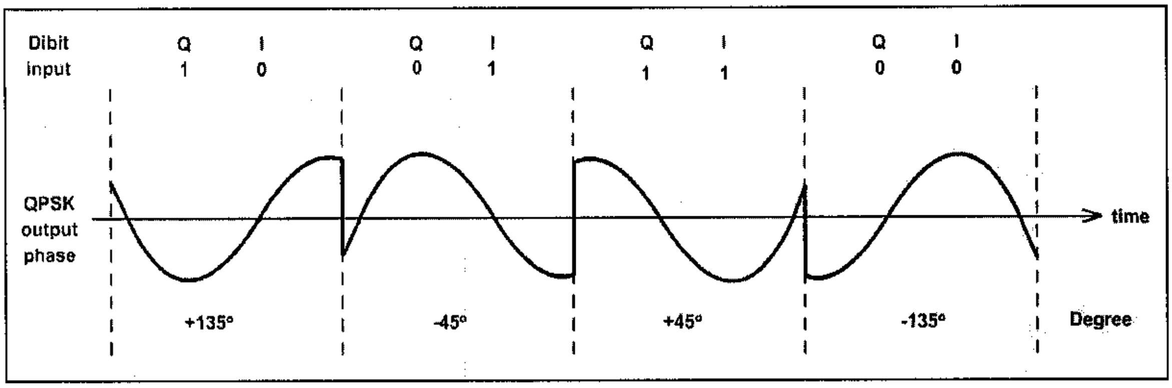


Figure 2.4 Output phase-versus-time relationship for QPSK modulator

2.3 RECEIVER

The block diagram for QPSK receiver is shown in Figure 2.5. The power splitter directs the input QPSK signal to the I and Q products detectors and detectors and the carrier recovery circuit. The carrier recovery circuit reproduces the original transmit carrier oscillator signal. The recovered carrier must be frequency and phase coherent with the transmit reference carrier. The QPSK signal is demodulated in the I and Q product detectors, which generates the original I and Q data bits. The outputs of the product detectors are fed to the bit combining circuit, where they are converted from parallel I and Q data channels to a single binary output data stream.

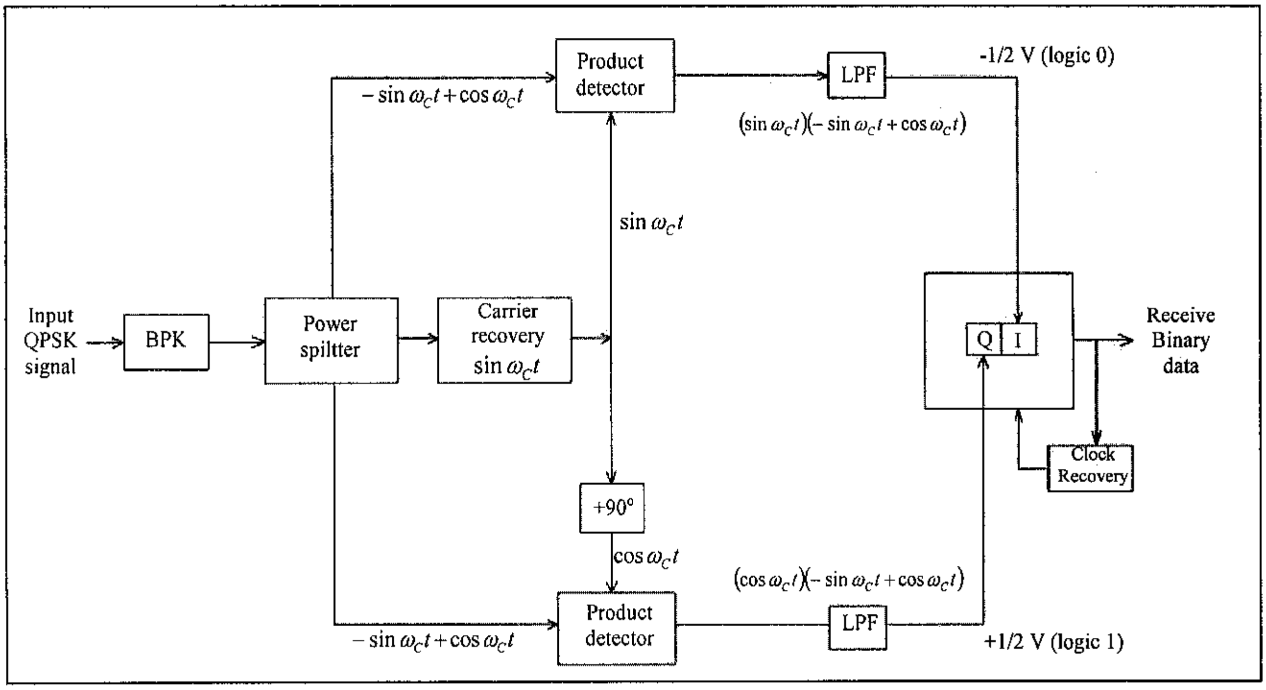


Figure 2.5 QPSK Receiver

The received QPSK signal $(-\sin w_c t + \cos w_c)$ is one of the inputs to the *I* product detector. The other input is the recovered carrier $(-\sin w_c t)$. The output of the *I* product detector is

$$\begin{aligned} I &= (-\sin\omega_c t + \cos\omega_c t)(\sin\omega_c t) \\ &= (-\sin\omega_c t)(\sin\omega_c t) + (\cos\omega_c t)(\sin\omega_c t) \\ &= -\sin^2\omega_c t + (\cos\omega_c t)(\sin\omega_c t) \\ &= -\frac{1}{2}(1-\cos 2\omega_c t) + \frac{1}{2}\sin(\omega_c + \omega_c)t + \frac{1}{2}\sin(\omega_c - \omega_c)t \\ &= -\frac{1}{2} + \frac{1}{2}\cos 2\omega_c t + \frac{1}{2}\sin(\omega_c + \omega_c)t + \frac{1}{2}\sin 0 \\ &= -\frac{1}{2}V(LOGIC\ \ 0) \end{aligned} \tag{2.1}$$

The receive QPSK signal $(-\sin w_c t + \cos w_c)$ is one of the inputs to the *Q* product detector. The other input is the recovered carrier shifted 90 ° in phase $(\cos w_c t)$. The output of the *Q* product detector is

$$\begin{aligned} Q &= (-\sin\omega_c t + \cos\omega_c t)(\cos\omega_c t) \\ &= \cos^2\omega_c t - (\sin\omega_c t)(\cos\omega_c t) \\ &= \frac{1}{2}(1+\cos 2\omega_c t) - \frac{1}{2}\sin(\omega_c + \omega_c)t - \frac{1}{2}\sin(\omega_c - \omega_c)t \\ &= \frac{1}{2} + \frac{1}{2}\cos 2\omega_c t - \frac{1}{2}\sin 2\omega_c t - \frac{1}{2}\sin 0 \\ &= \frac{1}{2}V(LOGIC\ \ 1) \end{aligned} \tag{2.2}$$

2.4 BIT ERROR RATE

BER is frequently being used to determine the performance of a system. It is the measurement of error bits in a given number of data. It is a function of the carrier-to-noise power ratio, or to be specific, the average energy per bit-to-noise power density ratio. Energy per bit-to-noise power density ratio is the ratio of the energy of a single bit to the noise power present in a 1-Hz of bandwidth. E_b/N_o normalizes all multiphase modulation schemes (FSK,PSK, M-ary, QAM) to a common noise bandwidth allowing for a simpler and more accurate comparison of their error performance. The E_b/N_o is given by

$$\frac{E_b}{N_o} = \frac{C/f_b}{N/B} = \frac{CB}{Nf_b} \tag{2.3}$$

where E_b/N_o is the energy per bit-to-noise power density ratio.

Rearranging the above equation yields the following expression:

$$\frac{E_b}{N_o} = \frac{C}{N} \times \frac{B}{f_b} \tag{2.4}$$

where E_b/N_o = energy per bit-to-noise power density ratio.

C/N = carrier-to-noise power ratio.

B/f_b = noise bandwidth-to-bit rate ratio.

Stated in dB,

$$\begin{aligned} \frac{E_b}{N_o}(dB) &= 10\log\frac{C}{N} + 10\log\frac{B}{f_b} \\ &= 10\log E_b - 10\log N_o \end{aligned} \tag{2.5}$$

2.5 ADDITIVE WHITE GAUSSIAN NOISE

Energy per bit E_b and noise power density is defined:

$$E_b = \frac{spow}{br}(W \cdot T / bit) \tag{2.6}$$

$$N_o = \frac{npow}{sr}(W / Hz) \tag{2.7}$$

spow= signal power per symbol

npow= noise power per symbol

from both equation,

$$npow = \frac{spow}{br} \bullet \frac{sr}{E_b / N_o}$$

since E_b/N_o is in dB, it can be written as,

$$npow = \frac{spow}{br} \bullet \frac{sr}{10^{\frac{E_b / N_o}{10}}}$$

Since Gaussian noise is normally distributed equally in in-phase and quadrature-phase channel, the attenuation can be defined as;

$$attn = \sqrt{\frac{1}{2} npow} \tag{2.8}$$

2.6 FADING

Fading is the term used to describe the fluctuations in the amplitude of the received radio signal over time. This phenomenon happens in radio communication channels, due to the interference between two or more versions of the transmitted signal which arrived at the receiver. The resultant received signal can vary widely in amplitude and phase, depending on various factors such as the intensity, relative propagation time of the waves, and bandwidth of the transmitted signal.

The mathematical model of the fading is shown below:

Consider transmitted signal as $s(t) = A\cos 2\pi f_c t$

The received signal can be expressed as

$$y(t) = A\sum_{i=1}^{N} a_i \cos(2\pi f_c t + \theta_i) \tag{2.9}$$

- a_i is the attenuation of the ith multipath component.
- θ_i is the phase-shift of the ith multipath component.

Since a_i and θ_i are random variables, the above expression can be re- written as:

$$y(t) = A\left\{\left(\sum_{i=1}^{N} a_i \cos(\theta_i)\right)\cos(2\pi f_c t) - \left(\sum_{i=1}^{N} a_i \sin(\theta_i)\right)\sin(2\pi f_c t)\right\} \tag{2.10}$$

Replacing random variables with $X_1(t)$ and $X_2(t)$, such the above expression becomes:

$$y(t) = A\{X_1(t)\cos(2\pi f_c t) - X_2(t)\sin(2\pi f_c t)\} \tag{2.11}$$

If the value of N is large (a large number of scattered waves), applying the *Central-Limit Theorem*, we get approximate $X_1(t)$ and $X_2(t)$ to be Gaussian random variables with zero-mean and variance σ^2.

The above expression can be rewritten as:

$$y(t) = AR(t)\cos(2\pi f_c t + \theta(t)) \tag{2.12}$$

where the amplitude of the received waveform *R(t)* is given by

$$R(t) = \sqrt{X_1(t)^2 + X_2(t)^2} \tag{2.13}$$

since the processes $X_1(t)$ and $X_2(t)$ are Gaussian, it can be shown that *R(t)* has a *Rayleigh Distribution* with a probability density function (pdf) given by:

$$f_R(r) = \frac{r}{2\sigma^2} e^{\frac{-r^2}{2\sigma^2}} \quad r \rangle 0 \tag{2.14}$$

The phase of the received waveform $\theta(t)$ is given by:

$$\theta(t) = \tan^{-1}\left(\frac{X_2(t)}{X_1(t)}\right) \tag{2.15}$$

Since the processes $X_1(t)$ and $X_2(t)$ are Gaussian, it can be shown that $\theta(t)$ has a *Uniform Distribution* with a probability density function (pdf) given by :

$$f_\theta(\theta) = \frac{1}{2\pi} \qquad -\pi \le \theta \le \pi \tag{2.16}$$

The distortion in the phase can be easily overcome if differential modulation is employed. It is the amplitude distortion *R(t)* that severely degrades performance of digital communication systems over fading channels. It is usually reasonable to assume that the fading stays essentially constant for at least one signaling interval.

2.6.1 Instantaneous SNR per bit.

Since the fading is assumed constant in the signalling interval, the fading phenomenon can be represented using a random variable R. Since only amplitude distortion is considered, the instantaneous SNR per bit $\gamma_b = R^2 \frac{E_b}{N_o}$

Since R is Rayleigh distributed as given in by $f_R(r) = \frac{r}{2\sigma^2} e^{\frac{-r^2}{2\sigma^2}} \quad r \rangle 0$,

the pdf of γ_b has a chi-squared distribution given by:

$$f_{\gamma_b}(\gamma_b) = \frac{1}{\gamma_b} e^{-\gamma_b/\bar{\gamma}_b} \qquad \gamma_b \geq 0 \tag{2.17}$$

where γ_b is the average SNR per bit given by:

$$\bar{\gamma}_b = \frac{E_b}{N_o} E\{R^2\} \tag{2.18}$$

2.6.2 Probability of Error

The probability of error (P_e) (for binary PSK) is given by:

$$P_e(\gamma_b) = Q(\sqrt{2\gamma_b}) \tag{2.19}$$

The average probability of error given the pdf of the random variable γ_b can be found directly using:

$$P_e = \int_0^\infty P_e(\gamma_b) f_{\gamma_b}(\gamma_b) d\gamma_b \tag{2.20}$$

The result of this integration (specifically for BPSK) is

$$P_e = \frac{1}{2}\left(1 - \sqrt{\frac{\bar{\gamma}_b}{1+\bar{\gamma}_b}}\right) \tag{2.21}$$

For case with high SNR, $\gamma_b \rangle\rangle 1$, the equation can be simplify as:

$$P_e \approx \frac{1}{4\bar{\gamma}_b} \tag{2.22}$$

The last equation shows that the P_e decreases linearly with increasing SNR per bit.

CHAPTER 3

METHODOLOGY / PROJECT WORK

The methodology on how the project was conducted is discussed in this chapter. The preliminary research was conducted to get the overview of the topic and to design the milestone or Gantt chart. This project was planned to be completed in two semester, where the first half of the semester was to concentrate on how basic QPSK communication system can be simulated using MATLAB. The external factors such as diversity configuration and fading factors was next designed in the second half of the semester. The project work was based on MATLAB to simulate the system from theoretical equations and algorithm.

3.1 DESK STUDY

Desk study plays significant impact to strengthen the basic knowledge about anything related to the project. Internet is the main source for the study, as well as to refer in books, journals, articles and reports. MATLAB needs to be self-studied to get familiar with the coding (syntax) and Simulink application.

3.2 PROJECT MILESTONE

The student as well as the supervisor can easily monitor the progress of the project. Since this project is for two semester project, the milestone should be planned in such a way that can fix the time for the two semesters. The overall suggested milestone is in Appendices Figure B-1 and Figure B-2.

3.3 TOOLS AND EQUIPMENT USED

Mathwork's MATLAB is the main software that is used in this simulation.

3.4 PROJECT WORK

The main focus at this stage is to develop a MATLAB coding which show the output of QPSK modulation. Apart from that, the program also would be able to analyse the waveform signal in standard signal analysis practice. The first attempt was to use a simpler coding modulation, Frequency Modulation (FM) (Appendices Figure A-4 and A-5). The detail of Binary Pulse Shift Keying (BPSK) shows the input, modulated and demodulated waveform. The analysis between Minimum Shift Keying (MSK) and QPSK was conducted to compare the performance between those two methods. MATLAB programming for QPSK was started next. The program follows the basic block diagram of the QPSK transmitter and receiver. Subprograms were designed based on the operation of each block. The input for the MATLAB codes was only for digital binary input. The output of the waveform also includes the phasor diagram and constellation diagram.

The BER performance of the QPSK simulation is always compared with the theoretical value of QPSK. The performance of the simulation also been analyzed by replacing the binary input data with picture (monochrome) as the input data. The BER performance affected the quality of the output image can be seen and compared. The space diversity MRC technique is analyzed. The BER performance curve for multiple receiving antennas is plotted.

3.5 SAMPLE PREPARATION AND TESTING

There are three different types of input samples being used in the process of developing the simulation program. Each sample is tested to verify that the program algorithm work and give the expected output. This bottom-up testing is important to make sure that each subprograms work correctly integrates them.

At the first stage, the input samples are defined manually with a limited number of input sequences. At this stage, the purpose of the input samples is to verify the functionality (black-box testing) either the subprograms will give the correct expected outputs. The input of the subsystems also might be from the other subsystem outputs. In this case, the lower level programs are tested first before move to the higher level programs.

After the functionality of the subsystems is verified, the randomly generated (by MATLAB function) input sequence is fed into the program. This input samples will have a larger number of sample sequences. At this stage, the subprograms have been integrated into the main program. The main program is verified by oversee the outputs of BER performance, either comparable with the theoretical QPSK BER performance.

The final input sequence fed into the program is generated from image (monochrome bitmapped) file imported into MATLAB. This input image is simulated to the QPSK modulation and demodulation. At the output end, we can see how the BER performance affected the input image.

CHAPTER 4

RESULTS AND DISCUSSION

This chapter discussed on results of the MATLAB simulations. The simulation results were made in stages. Simpler digital modulation system, BPSK was firstly simulated using MATLAB. This two phase's system then been analyzed before QPSK system using Simulinks was designed. Based on the Simulink algorithm and block diagram of the system, the MATLAB codes was programmed. The MATLAB codes were analyzed to verify that the outputs are the same as the theoretical value. This chapter also discussed further on the BER performance of the system theoretically and compared with the BER simulation output.

4.1 BINARY PHASE SHIFT KEYING (BPSK)

The first attempt in this project is to develop a MATLAB coding of a simpler form of angle- modulated, constant- amplitude digital modulation, Binary Phase Shift Keying (BPSK). With BPSK, two output phases are possible for a single carrier frequency. One output represents a logic 1 and the other a logic 0. The output phase shift 180° as the input digital signal changes state. Figure 4.1 below shows the BPSK program. In the program, it is only to show the waveform of the BPSK output, not on the BPSK algorithm in detail.

```
n=10                                    % no of input data
T=1                                     % bit period
input=rand(1,n)<0.5                     % randomly generated binary input
data
os=100                                  % sampling number in 1 bit
for iii=1:n                             % loop for n number of input sequence
    t=0;
    for jjj=0:100                       % loop for number of sampling

        if input(1,iii)==1              % if input bit is equal to 1
         output(1,:) = sin (2*pi*t);

        else                            % else if input is equal to 0
         output(1,:) = -(sin (2*pi*t));

         end                            % end if-else

         fid=fopen('BPSKoutput2.dat','a');  % save the calculated value in file
                                              BPSKoutput2.dat
         fprintf(fid,'%e\t',output)


    t=t+T/os;
    end                                 %end jjj loop

end                                     %end iii loop
```

Figure 4.1 MATLAB codes for the BPSK modulation

Variable **n** and **T** represent the sequence number of input data and bit period respectively. The input data is randomly generated using **rand(1,0)** function. The equation of BPSK modulation is loop for 100 times to produce smooth sinusoidal curve. The curve is only to show how the 1 and 0 of input bits affect the BPSK modulation. From the graph, we can see that the waveform is 180^{o} out of phase as the input bits change states. BPSK is almost similar to QPSK where the input data is fed into two channels. The code however is designed for transmitter part only. The input and output waveforms are shown in Figure 4.2 and Figure 4.3.

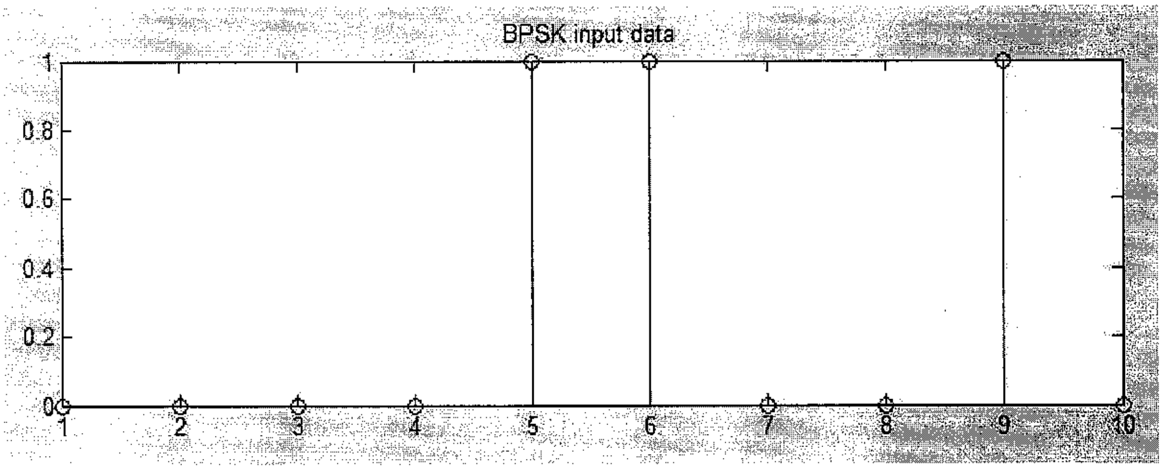


Figure 4.2 Input data of BPSK

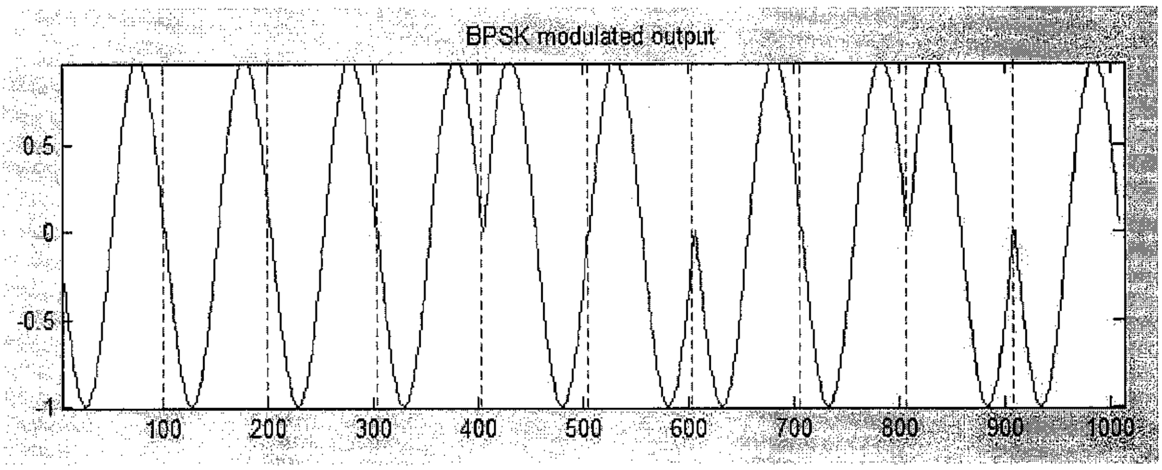


Figure 4.3 Output data of modulated BPSK

4.2 MSK and QPSK USING SIMULINK

The MSK is a type of Continuous-Phase Frequency Shift Keying (CP-FSK) with modulation index h=0.5. The FSK is a type of digital modulation, which varies in frequency. The frequency for logic 1 is higher than frequency for logic 0 (logic 0 use fundamental carrier frequency). The advantage of CP-FSK is there are no phase discontinuities between logic 1 frequency and logic 0 frequencies. This gives CP-FSK has better bit-error performance than conventional binary FSK for a given signal-to-noise ratio. However, it needs a synchronization circuits and is expensive to implement.

The comparison of QPSK and MSK was done using Simulink. The diagram is as shown in Figure 4.4.

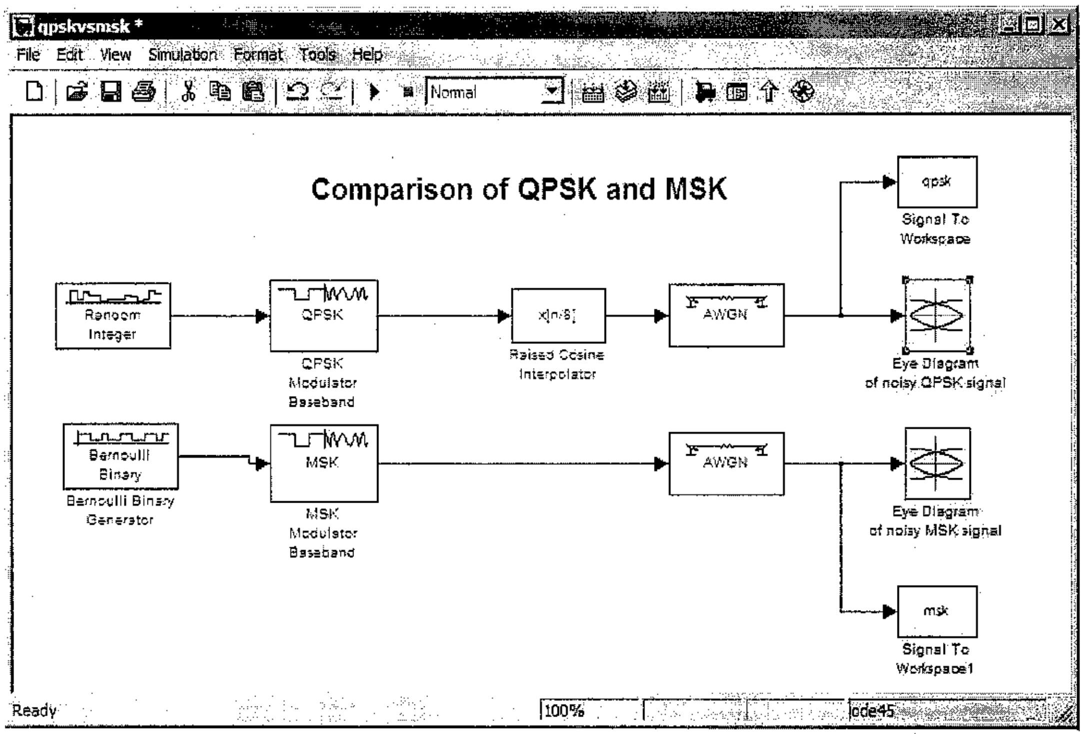


Figure 4.4 Comparison of QPSK and MSK modulation technique using Simulink

- **Random Integer**: Generate random signal in the range of 0 to M-1. Meaning that, for QPSK, it will generate signal from 0 to 3 randomly.
- **Bernoulli Binary Generator**: Generates random binary numbers using Bernoulli distribution.
- **QPSK Modulator Baseband**: Modulates input using QPSK technique.
- **MSK Modulator Baseband**: Modulates input signal using MSK technique.
- **AWGN**: Additive White Gaussian noise to the signal. In the simulation, the signal to noise added is 30dB.
- **Raised Cosine Interpolator**: To upsample then FIR filtered the signal.
- **Eye Scatter Diagram**: Display multiple traces of a modulated signal.
- **Signal to Workspace**: Send the output signal to workspace.

The output of both QPSK and MSK are shown in Appendices Figure A-8 to Figure A-11.

In eye diagram of QPSK, the values of both the inphase and quadrature components of the signal are permitted to change at any symbol interval. For MSK, the symbol interval is half of that for QPSK but the inphase and quadrature components change values in alternate symbol.

For constellation diagram shown for QPSK, there are 4 available signal states. Otherwise for MSK constellation, the round shape show that the phase changes linearly with time and amplitude remains constant.

4.3 BER PERFORMANCE OF QPSK

BER analysis is used for the QPSK modulation technique to measure the performance of the system. Noise is added in this simulation by realizing the equation of AWGN to the program. The theoretical value of BER for QPSK is studied to know the range of the energy per bit- to- noise density ratio. This value is then been simulated using the program. With this we can expect what should be the output of the system. The full MATLAB codes of BER for QPSK are shown in Appendices Figure A-12.

The flow of the program is described below:

- All variable is defined
  - **`sr`**: symbol rate, in Hz
  - **`ml`**: modulation level, used since the data is fed into two channel.
  - **`br`**: bit rate- sr x ml – the total rate for i channel and q channel.
  - **`nd`**: number of data fed into each channel
  - **`IPOINT`**: number of upsampling
  - **`ebn0`**: signal- noise ratio, used in while loop to calculate signal-noise ratio between 0 and 10.

- **data1**: the input data fed into the simulator of vector 1 by 8 [1 1 1 1 0 1 0 1]
- **paradata**: convert the input data to [1 1 1 1 -1 1 -1 1] by equation $(data1).\times 2 - 1$
- **qpskmod**: modulate the data1 by simply devided the data1 into i channel (1st, 3rd, 5th, 7th..)and q channel (2nd, 4th, 6th, 8th). The output is stored in ich and qch.
- **ich** = 1 1 -1 -1

  qch = 1 1 1 1
- **oversample**: oversampled the data by includes 0s in between of the input data. The output is stored in ich1 and qch1 respectively.

```
ich= 1 1 -1 -1
ich1= 1 0 0 0 0 0 0 0 1 0 0 0 0 0 0 0 -1 0 0 0 0 0 0 0 -1 0 0 0 0 0 0 0
```

IPOINT no of zeros inserted

- **attenuation**: The calculation are as the theoretical equations in Chapter 3.
- **awgn**: the value of attenuation is then multiplied with randn newly created vector 1-by-nd, then the result is added to all the vector component of ich1 and qch1. The attenuated value is stored in ich5 and qch5.

```
ich5  = 0.8101    1.1310    -0.7835    -1.2065
qch5 = 1.4401    0.8621    0.8920    1.2261
```

- **demodata**: from the ich5 and qch5, the element from both channel is combined and compared. The positive value is considered 1 and negative value is considered 0.

```
demodata   =  1  1  1  1  0  1  0  1
```

As in the result above, we can see that the demodulated data has no error. This is because we only use 1 loop of simulation and small number of input data. For BER calculation, we need to use a larger input data and with loops.

The output curve of the simulation of the BER performance is shown in Figure 4.5.

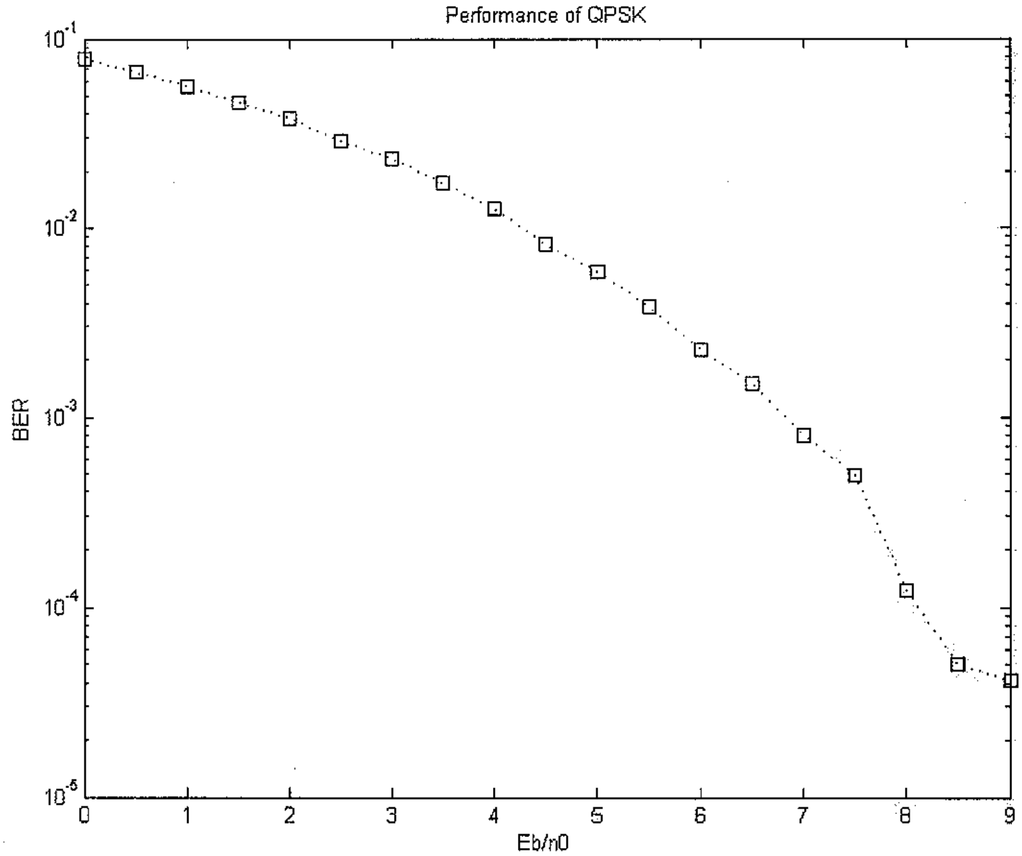


Figure 4.5 Simulation result of QPSK BER performance

From Figure 4.5, the curve shows the value of BER for E_b/N_o in range of 0 dB to 10 dB. Higher value of E_b/N_o will give a smaller value of BER. Since this graph is identical with the theoretical output of QPSK with AWGN, we can conclude that the functionality of the MATLAB codes is correct. From this BER curve, we also can examine the output by introduce an image file as the simulation input. The original image of the geometry is fed to the MATLAB code as an input and the outputs are for E_b/N_o for 1dB, 5dB and 10 dB. The output images can be seen in Appendices Figure A-19 to Figure A-22.

The image for 1 dB E_b/N_o is distorted due to bits errors by AWGN, with BER of 5.573333 X 10^{-2}. Image for 5 dB E_b/N_o is less distorted by 5.925 X 10^{-3}. However, for image with 10 dB E_b/N_o, the error can't clearly be seen (BER of 8.333333 X 10^{-6}).

4.4 MULTIPATH MODEL

Noise is a major consideration for engineers in designing a communication system. Noise corrupts the signal in an additive fashion. The noise is modeled using AWGN channel. The AWGN channel is important in defining the noise added to the transmitted signal, but is inadequate in characterizing signal transmissions over radio channels whose transmissions over radio channels change with time.

Channels whose characteristics change with time are called multipath channels. It occurs when a signal arrives at the receiver in different path which cause signal cancellation or destructive signal due to the various delays. In this simulation, the delay and fading caused by multipath is represented by Naftali model, which is a consistent channel model used in every wireless communication systems. Using this model, we can compose the channel impulse response of complex samples using random uniformly distributed phase and Rayleigh distributed magnitude.

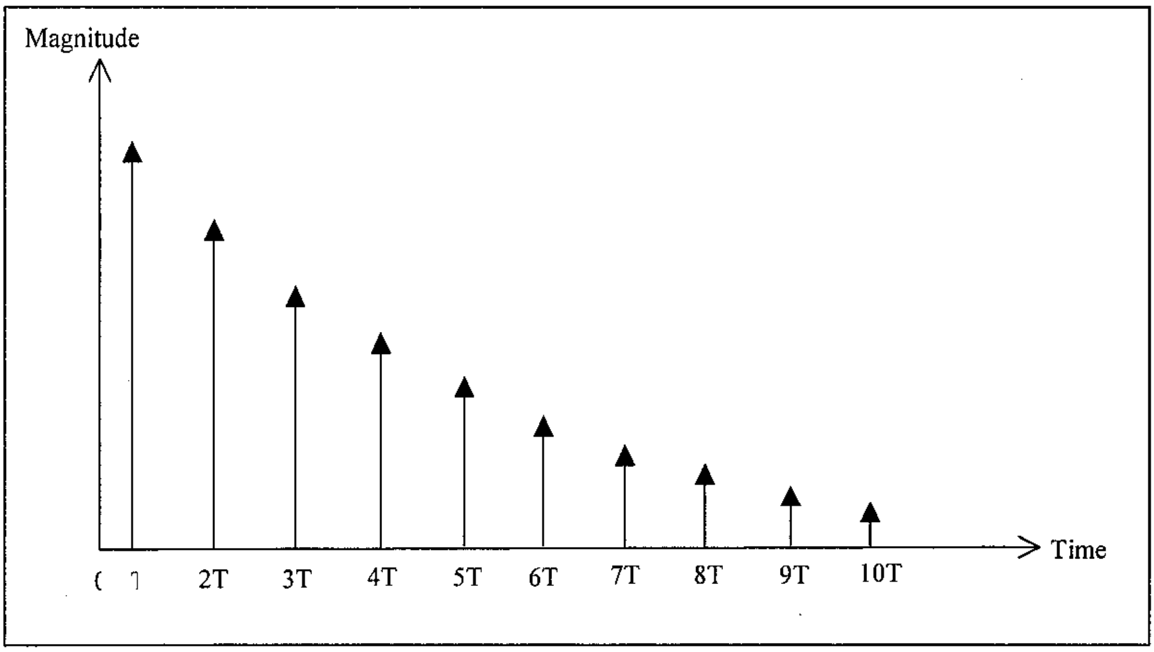


Figure 4.6 Diagram of the Naftali multipath fading model

The mathematical Naftali model for the channel is given below:

$$h_k = N\left(0, \frac{1}{2}\sigma_k^2\right) + jN\left(0, \frac{1}{2}\sigma_k^2\right) \tag{4.1}$$

$$\sigma_k^2 = \sigma_0^2\, e^{-kT_0/T} \tag{4.2}$$

$$\sigma_k^2 = 1 - e^{-kT_0/T} \tag{4.3}$$

where $N\left(0, \frac{1}{2}\sigma_k^2\right)$ is a zero mean Gaussian random variable with variance $\frac{1}{2}\sigma_k^2$ produced by generating an N(0,1) and multiplying it by $\sigma_k / \sqrt{2}$, where $\sigma_k^2 = 1 - e^{-kT_0/T}$ is chosen so that the condition $\sigma_k^2 = 1$ is satisfied to ensure the same average received signal power.

4.5 MAXIMAL RATIO COMBINING (MRC)

A popular method to mitigate the effect of multipath fading is diversity, a process of obtaining multiple independent signal branches through many dimensions including space, polarization, frequency and time. The collection of independently fading signal branches can then be combined in a variety of ways to improve the received signal-to-noise ratio (SNR).

The three most prevalent space diversity combining techniques are selection combining (SC), equal gain combining (EGC), and MRC. MRC is the most complex combining technique compared to the other, but also yields the highest SNR.

In this project, it is assumed that the antennas are spaced far apart enough such that the received signal branch at each antenna will experience independent channel fading. In the simulation, the QPSK transmitted signal for both I Channel and Q channel (symbol of 1 and -1) is added to the multipath fading, then added to AWGN which forming the received signal.

The matrix equation for the received signal branches is shown below:

$$y = Hx + N \tag{4.4}$$

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} x + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \tag{4.5}$$

where $y = \begin{bmatrix} y_1 \\ y_2 \end{bmatrix}$ is the received signal vector, $H = \begin{bmatrix} h_1 \\ h_2 \end{bmatrix}$ is the channel matrix, and $N = \begin{bmatrix} n_1 \\ n_2 \end{bmatrix}$ is the noise matrix for two receive antennas. The MRC receiver then co-phases and weights the received signal by multiplying it by the conjugate transpose of the matrix (assuming the receiver knows the channel perfectly) and normalizing the result:

$$H^* y = \left(|h_1|^2 + |h_2|^2\right)x + H^* N \tag{4.6}$$

$$\hat{x} = \frac{H^* y}{|h_1|^2 + |h_2|^2} = x + \frac{H^* N}{|h_1|^2 + |h_2|^2} \tag{4.7}$$

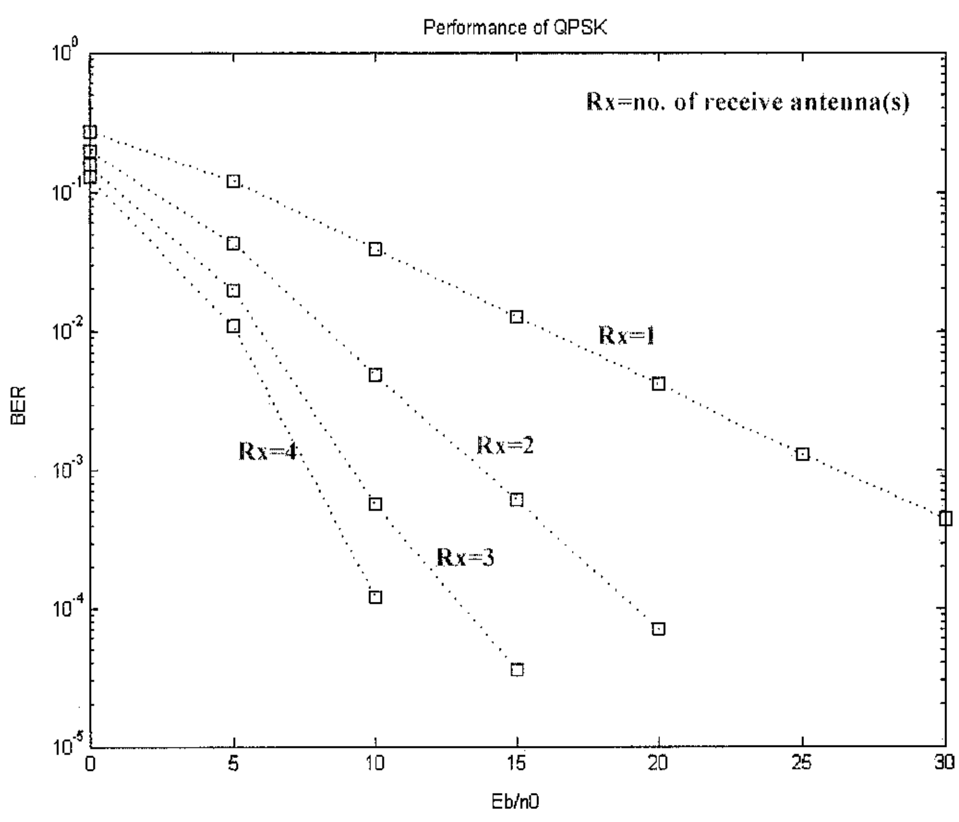


Figure 4.7 BER simulation result of MRC for 1, 2, 3, and 4 receive antennas

The graph in Figure 4.7 shows that as the number of receive antenna increases, the BER performance increased. The plotted graph shows the same behavior as the analysis. The simulation is fed with only 1000 input data due to long simulation time. It is assumed in this simulation that the antennas are equally spaced to the independent fading channels. The effect of the BER on the multiple antennas can also be seen by comparing the output images as shown in Appendices Figure A-25 to Figure A-28.

4.6 EFFECT OF ANTENNAS SPACING TO THE BER PERFORMANCE

In the simulation, we address only the case with two receive antennas. The correlation coefficient between the two fading channels is dependant on the separation distance between the two antennas. In the simulation, the Stuber's simple Bessel function model is used for the correlation coefficient between received signals:

$$\rho = J_0^2(2\pi d / \lambda_c) \tag{4.8}$$

where $J_0(x)$ = zeroth- order Bessel function of the first kind,

d = is the separation distance between the two antennas,

λ_c = the carrier wavelength.

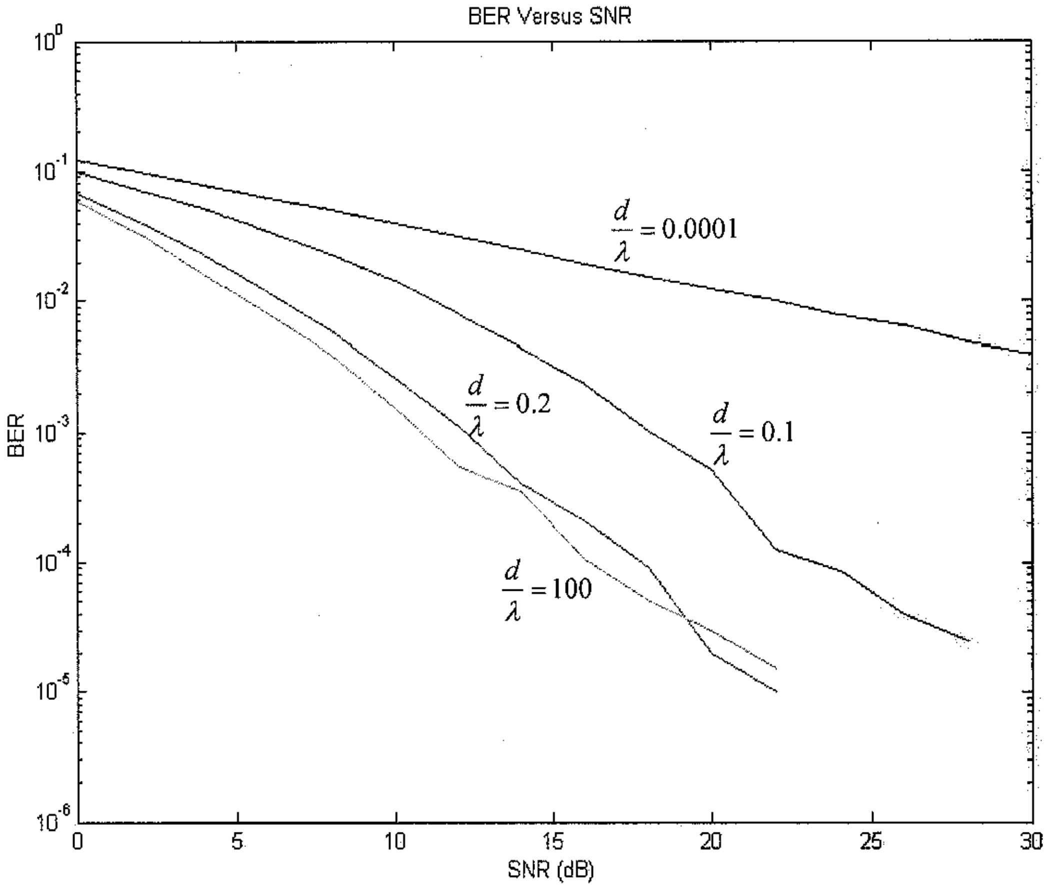


Figure 4.8 BER simulation result for 2 receive antennas at different spacing

It is shown that the performance of the communication system increase when the antenna spacing is greater. This is due to the multipath channel of the communication system. The effect of the antenna spacing also can be seen by comparing the simulation output of the images, as shown in the Appendices Figure A-30 to Figure A-31.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

The output of the simulation for BER performance of QPSK system is comparable with the theoretical value. All of the algorithms used; AWGN, multipath, and space diversity are from the mathematical model. The equation is realized to the MATLAB program and is considered correct by observing the simulation outputs.

From the simulation output, we can see that higher Signal to Noise Ration (SNR) will give the better received signal. The bitmapped image has been fed as the input and been simulated to see the difference and effect of BER to the input data. Discreet input data is fed to the system to minimize the complexity of the coding.

The MRC technique improved the received signal. It is clearly seen when the simulation for 1, 2, 3 and 4 antennas is carried out. It is limit to 1000 input data only to reduce the simulation time. The curve will be smoothly converge for a higher data input fed into the system. Higher number of receive antennas will give the better BER performance for the QPSK system.

This basic simulation for QPSK system where only major factors contribute to the performance of the system are been considered. The simulation can still be improved to give the true simulation output and requirements of the real communication systems installed. The completion of this project shall help communication engineers to design and configure radio communication systems with less time constraint.

5.2 RECOMMENDATIONS

There are several improvements that are recommended for this simulation. The input data can be replaced with analogue audio sound. Minor changes need to be done to the program to read the input from audio files. Analogue to Digital Converter (ADC) filter needs to be designed into the simulation.

This simulation is a code- based simulator program. MATLAB has a special feature where the programs can be graphically controlled by user. This interactive feature enable non- technical user to access and run the simulation.

The simulation outputs are supposedly to be comparable with the theoretical and real performance outputs. It is recommended that industry (telecommunication companies) can provide details of the real performance of the installed system. Some of the external factors are unique to one place, and differed throughout the years. The simulation program can be designed to simulate the performance of communication system exclusive to that place based on the provided information.

All communication systems in Malaysia are required to follows the specifications provided by Malaysian Communication and Multimedia Commission (MCMC). It is also recommended that this simulation follows the requirements for the microwave communication system designed.

REFERENCES

[1] Wayne Tomasi, Electronic Communication Systems; Fundamentals Through Advanced, 4th Edition, Prentice Hall International, 2001

[2] Hiroshi Harada, *Simulation and Software Radio for Mobile Communications*, Artech House, 1st. Ed. 2002.

[3] Floyd M. Gardner, *Simulation Techniques*, John Wiley and Sons, 1997.

[4] Stephen G. Wilson, Digital Modulation and Coding, Prentice Hall International, 1996.

[5] http://www.mathworks.com/matlabcentral/ fileexchange. 2003 The Mathworks Inc.

[6] http://iwce-mrt.com/ar/radio_microwave_ path_design_2

[7] Ian Sommerville, *Software Engineering*, 6th Edition, Addison Wesley, 2001. (page 443-445).

[8] William Starlings, *Data & Computer Communications*, 6th Edition, Prentice Hall, 2003. (page 75-96).

[9] Andrew Kondo, *Maximal Ratio Combining with Correlated Rayleigh Fading Channel*, 2002.

[10] Vijaya Chandran Ramasami, *BER Performance Over Fading Channels and Diversity Combining*, 2001.

[11] Fernando Torrelio, *Simplifying the Path Alignment of Microwave Communication Systems*, Aurora Genesis Communication Inc., 1999.

[12] *Technical Requirements For Line-Of-Sight Radio Relay Systems*, Malaysian Communications and Multimedia Commission(MCMC), 2002.

[13] Carmela Cozzo, *Space Diversity in Presence of Discrete Multipath Fading Channel*, IEEE, 2003.

[14] Jukka Henriksson, Jouko Tormanen, Nokia Research Report, 1988.

[15] J. E. Flood P Lochrame, *Transmission Systems*, Peter Deregnus Limited, 1995.

[16] J. Dunlop, D. G. Smith, *Telecommunications Engineering*, 3rd Edition, Stanley Thornos (Publishers) Limited, 1994.

[17] Stephen Jones, Ron Kovac, *Introduction to Communications Technologies – A Guide for Non- Engineers*, Averbach Publications, 2003.

[18] Alister Burr, *Modulation and Coding for Wireless Communications*, Pearson Education Limited, Prentice Hall, 2001.

[19] John C. Hancock, *The Principles of Communication Theory*, McGraw-Hill Publishing Company Limited, 1998.

[20] Micheal C. Jeruchim, Philip Balahan, K. Sam Shanmugan, *Simulation of Communication Systems – Modelling, Methodology, and Techniques*, 2nd Edition, Kluwer Academic / Plenum Publishers, 2000.

[21] John G. Nellist, *Understanding Telecommunications & Lightwave Systems- An Entry Level Guide*, 3rd Edition, Wiley Interscience, 2002.

APPENDICES

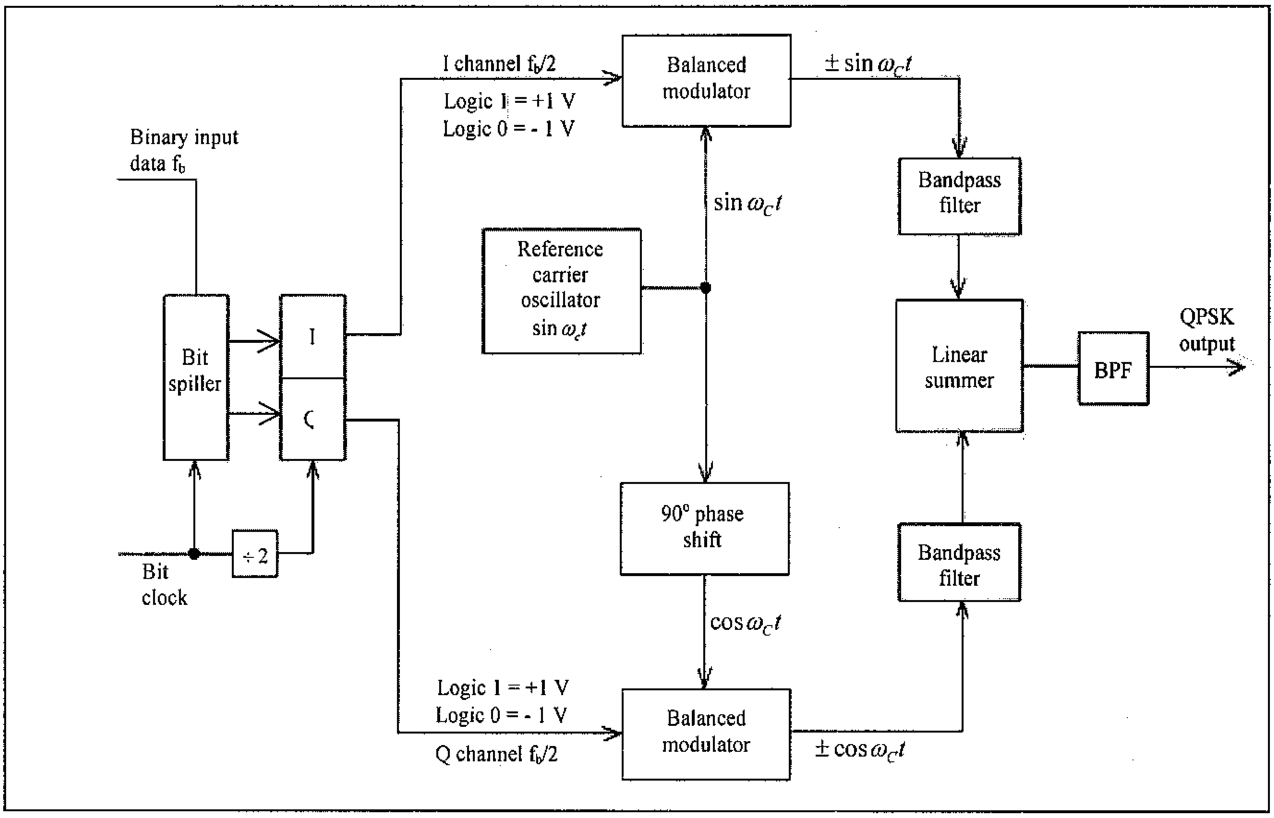


Figure A-1 QPSK Transmitter

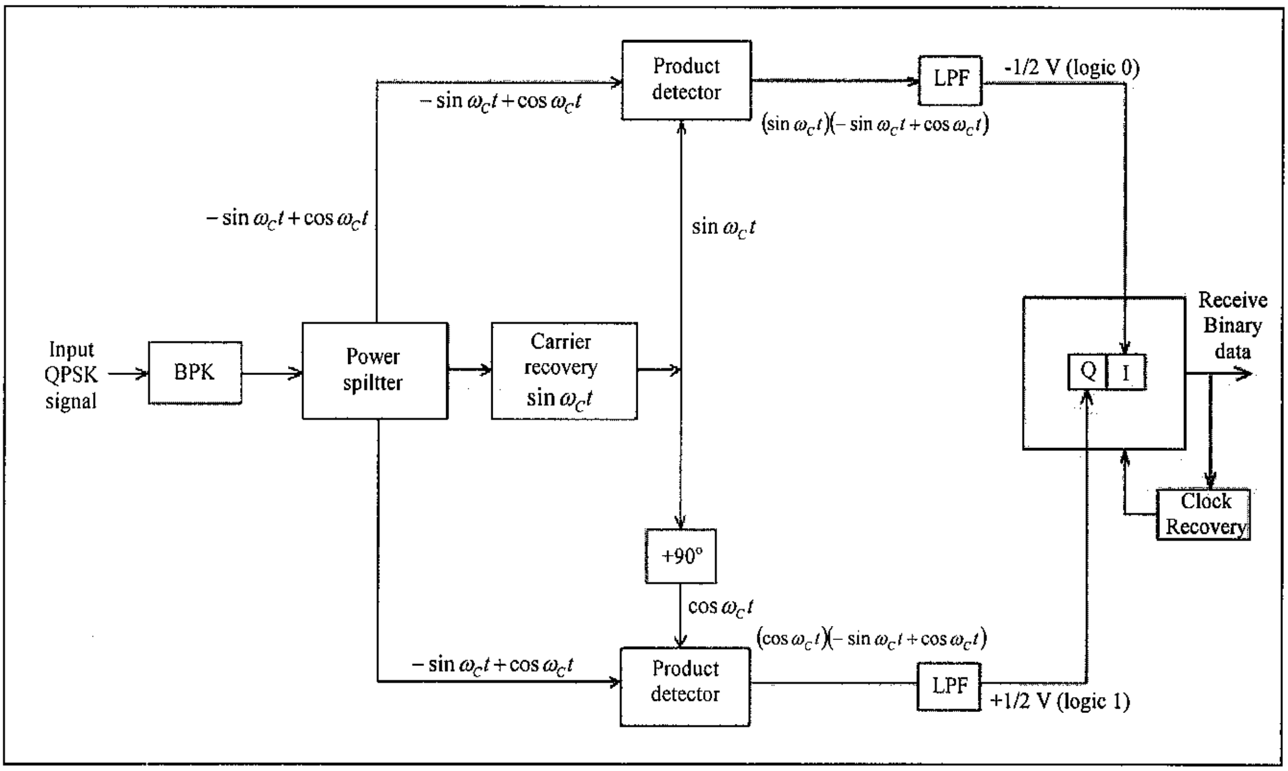


Figure A-2 QPSK Receiver

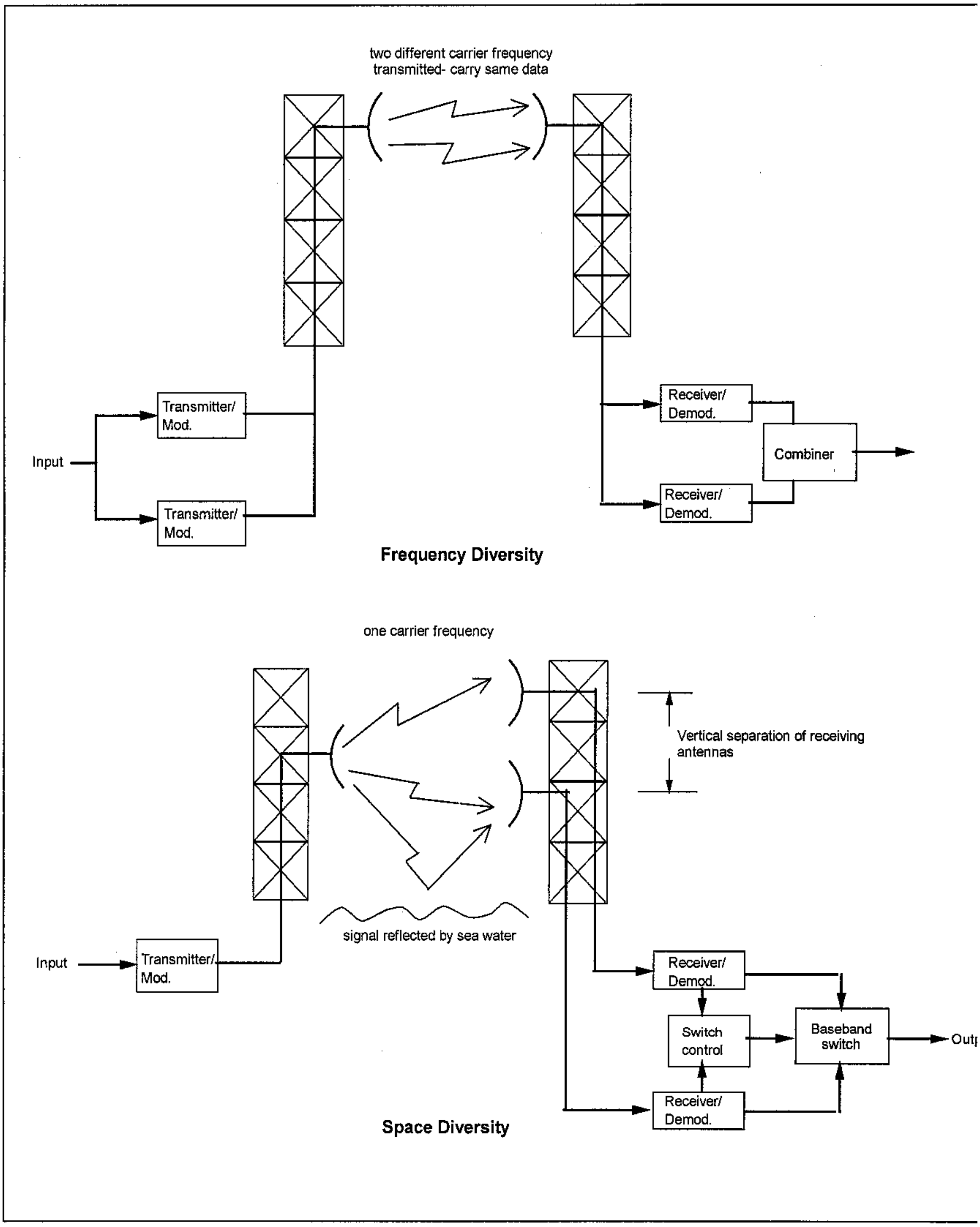


Figure A-3 The Basic Configuration of Microwave Communication System

```
Vc=1;                        % carrier voltage
fc=10;                       % carrier frequency
Wc=2*pi*fc;                  % omega of carrier
Vi=1;                        % signal voltage
fi=1;                        % intelligence frequency
Wi=2*pi*fi;                  % omega of intelligence signal
t=0:0.01:5;                  % time range
K=40;                        % deviation sensitivity
carrier=Vc*cos (Wc*t);       % carrier signal
int=Vi*cos (Wi*t);           % intelligence signal

mod=Vc*cos(Wc*t + (K*Vi/Wi)*sin (Wi*t));          % modulation equation
subplot (3,1,1);
plot (t,carrier);
xlabel('carrier waveform')
subplot (3,1,2);
plot (t,int);
xlabel('input waveform')
subplot (3,1,3);
plot (t,mod);
xlabel('frequency modulated waveform')
```

Figure A-4 MATLAB Codes for Frequency Modulation

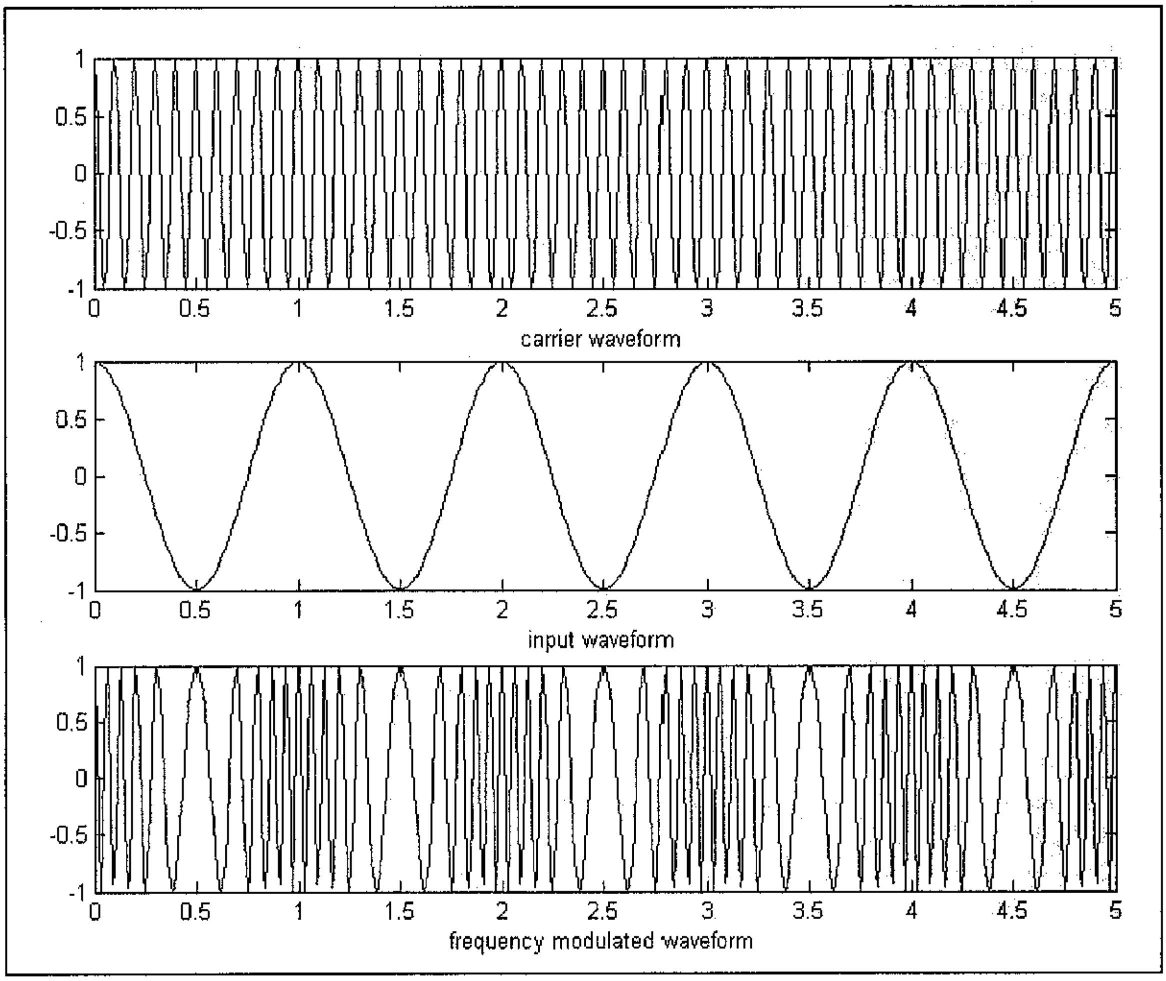


Figure A-5 MATLAB Output of Frequency Modulation

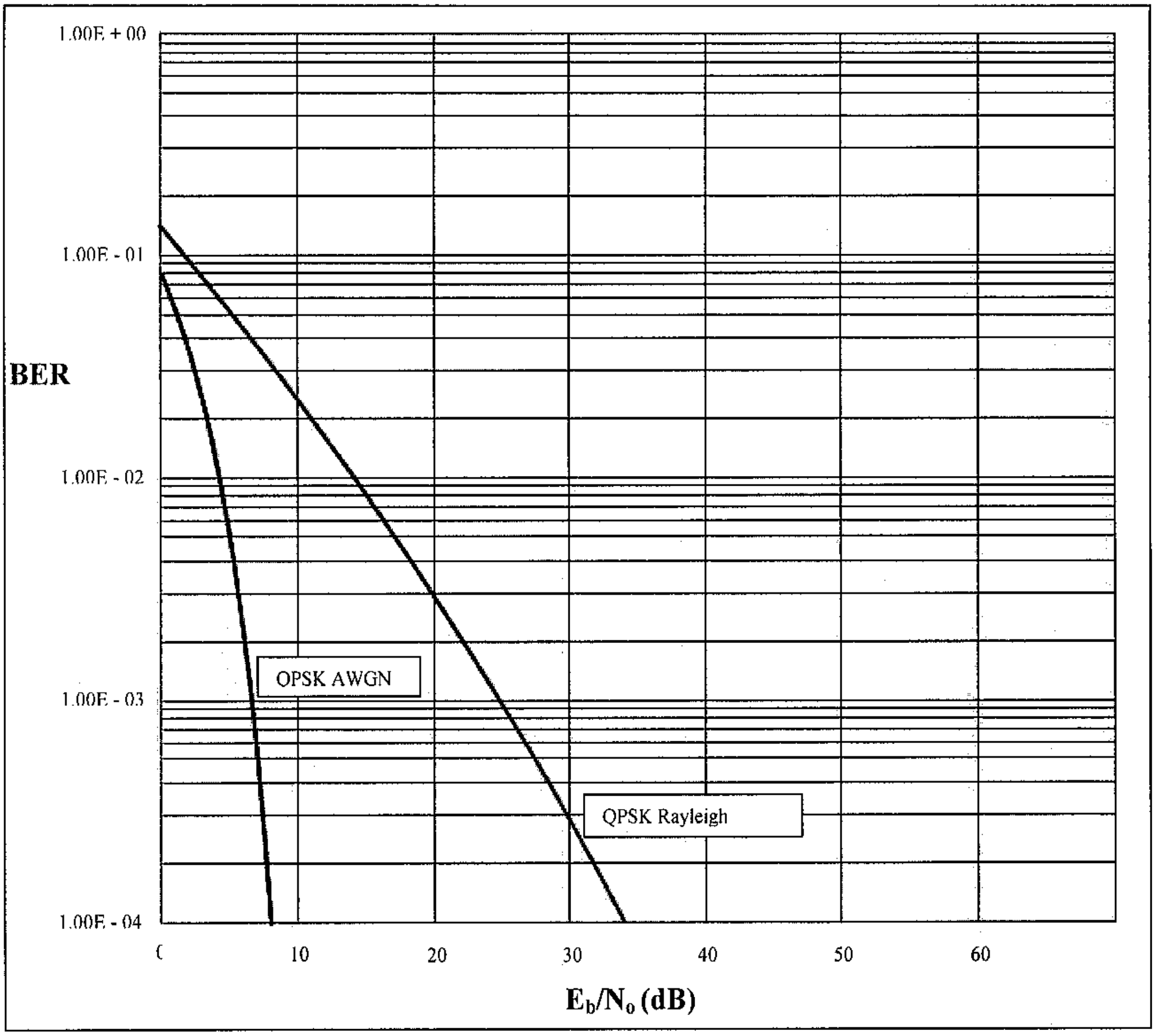


Figure A-6 Theoretical BER Performance of QPSK Scheme Under AWGN and One-Path Flat Rayleigh Fading Environment

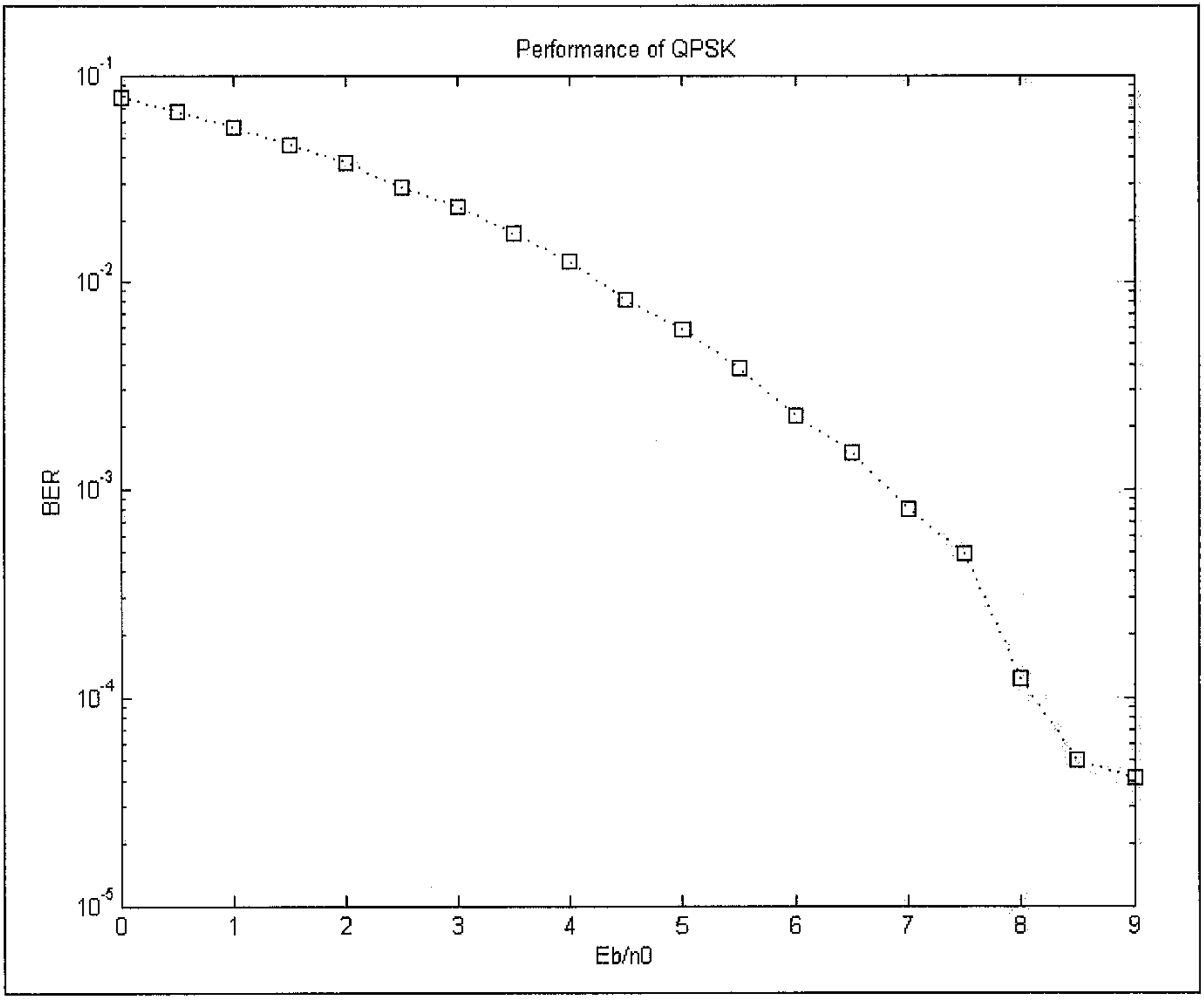


Figure A-7 Simulation Result of BER Performance of QPSK Scheme Under AWGN

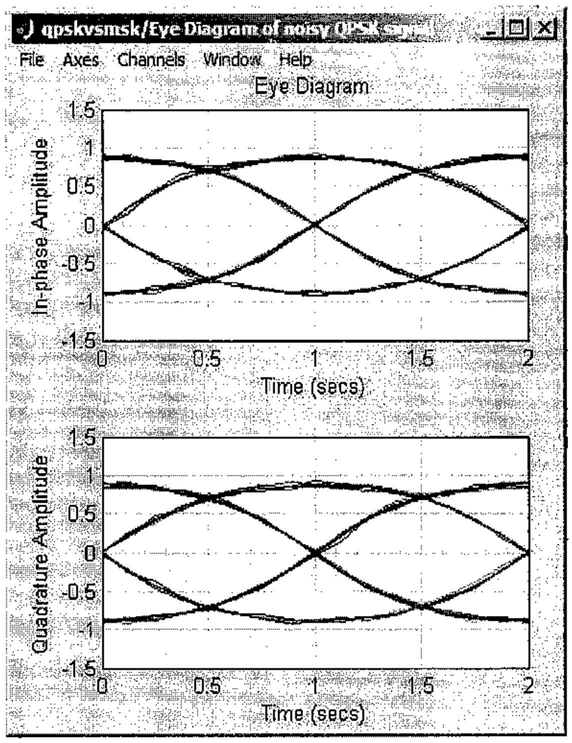


Figure A-8 Eye Diagram of QPSK Output

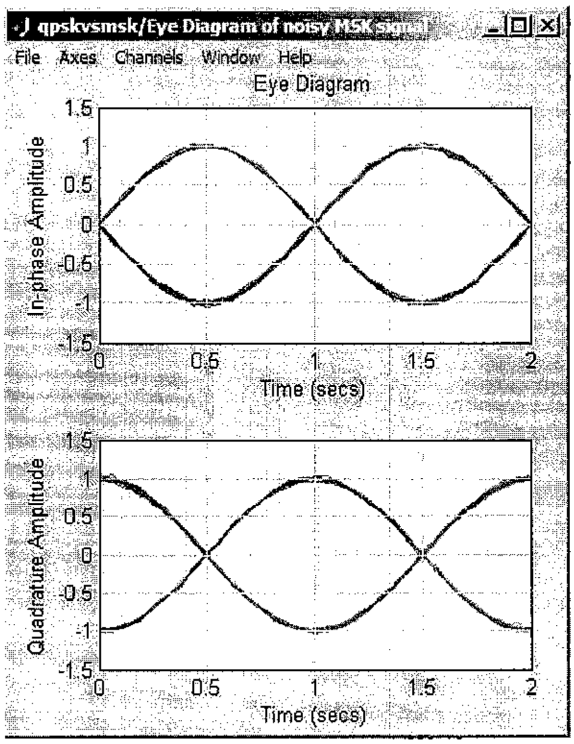


Figure A-9 Eye Diagram of MSK Output

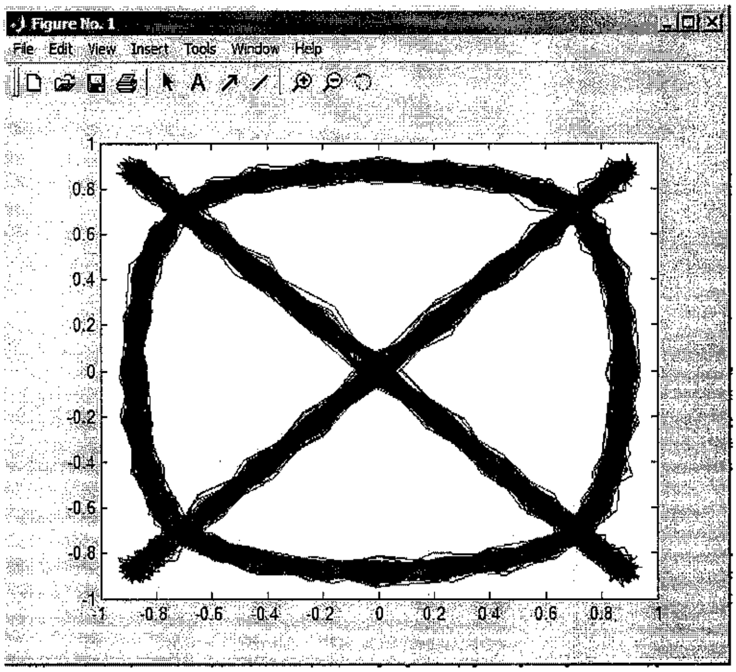


Figure A-10 Constellation Diagram of QPSK Output

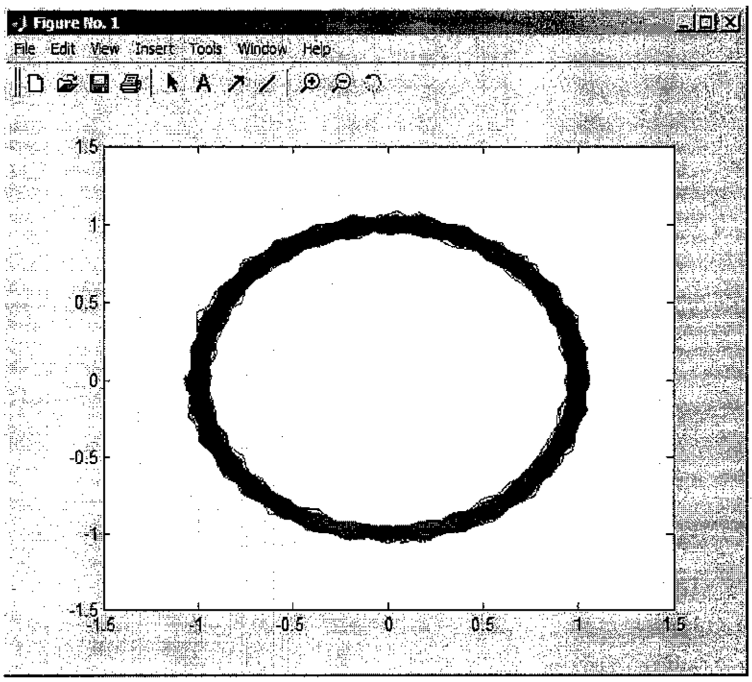


Figure A-11 Constellation Diagram of MSK Output

```
sr=256000.0;                      % frequency of symbol in 1 channel(Hz)
ml=2;                             % modulation level (BPSK=1, QPSK=2 )
br=sr.*ml;                        % freauency of the iniput data (bit/s)
nd=400/2;                         % no of data fed into the simulator
IPOINT=8;                         % no of oversamples

ebn0=10.0;                        % Ebergy per bit-to-noise power density ratio (Eb/No)

while ebn0>=0.0

ebn0_no=ebn0                      % display Eb/No number in workspace

im_mat=zeros(300,400);            % create zeros in matrix 300X400
input=imread('kotak.bmp');        % read image file (kotak.bmp) as the input binary data
columnNo=1;
for qqq=1:300

    column=input(qqq,:);         % read binary input data column by column, 1 to 300.
    data1=column;


nloop=300;                 % simulation loop (to increase the number of input data)
noe=0;
nod=0;

for iii=1:nloop


%%%%%%%%%%%%%%%% QPSK MODULATION %%%%%%%%%%%%

paradata=data1;
paradata2=paradata.*2-1;                    % to convert 1->0 and 0->-1

ii=1;
for jj=1:nd
    isi=paradata2(1,ii);                    % odd sequance data fed into i-channel
    isq=paradata2(1,ii+1);                  % even sequence data fed into 1-channel

    iout(1,jj)=isi;
    qout(1,jj)=isq;
    ii=ii+2;
end                                          % jj loops ends
ich=iout(1:nd);                              % binary data in i-channel
qch=qout(1:nd);                              % binary data in q-channel

%%%%%%%%%%%%%%%% OVERSAMPLE %%%%%%%%%%%%%%%%
idata=ich;
qdata=qch;
nsymb=length(ich);
sample=IPOINT;

iout=zeros(1,nsymb*sample);        % create zeros of length nsymb*sample in i-channel
qout=zeros(1,nsymb*sample);        % create zeros of length nsymb*sample in q-channel
iout(1:sample:1+sample*(nsymb-1))=idata;   % insert IPOINT no. of zeros in between of
                                                         % data in i-channel
qout(1:sample:1+sample*(nsymb-1))=qdata;   % insert IPOINT no. of zeros in between of
                                                         % data in q-channel
ich1=iout;
qch1=qout;

%%%%%%%%%%%%%%%% ATTENUATION %%%%%%%%%%%%%%
spow=sum(ich1 .* ich1 + qch1 .* qch1) / nd;      % realise attenuation equation
attn=0.5*spow*sr/br*10.^(-ebn0/10);
attn=sqrt(attn);
```

```
%%%%%%%%%%%%%%%% AWGN %%%%%%%%%%%%%%%%%%%%%%%%%%
idata=ich1;                  % attenuation fed into the input data of both channels
qdata=qch1;

iout=randn(1,length(idata)).*attn;    % randomly generated noise input for i- channel
qout=randn(1,length(qdata)).*attn;    % randomly generated noise input for q- channel

iout=iout+idata(1:length(idata));     % noise is add to the input data for i- channel
qout=qout+qdata(1:length(qdata));     % noise is add to the input data for q- channel

ich3=iout;
qch3=qout;

ich5=ich3(1:IPOINT:length(ich3));
qch5=qch3(1:IPOINT:length(qch3));

%%%%%%%%%%%%%%%% DEMODULATION %%%%%%%%%%%%%%%%%%
idata=ich5;
qdata=qch5;

demodata=zeros(1,ml*nd);                       % create zeros of 1-by-ml*nd vector
demodata(1,(1:ml:ml*nd-1))=idata(1,(1:nd))>=0;  % to combine the input + noise data
                                                          % of both channels
demodata(1,(2:ml:ml*nd))=qdata(1,(1:nd))>=0;

%%%%%%%%%%%%%%%% BER %%%%%%%%%%%%%%%%%%%%%%%%%%

noe2=sum(abs(data1-demodata));        % compare output data with input data to locate
                                                                 % errors.
nod2=length(data1);                   % length of data
noe=noe+noe2;                         % total number of errors
nod=nod+nod2;                         % total number of data
end                                   % iii loop ends

output=demodata;                      % realize th output od demodulated data
for www=1:400                         % www loop starts for image column sequence
im_mat(qqq,www)=output(1,www);

end                                   % www loop ends
end                                   % qqq loop ends
ber=noe/nod;                          % BER calculated saved to file
fid=fopen('BERqpsk_awgn.dat','a');
fprintf(fid,'%e\t%e\t\n',ebn0,noe/nod);

ebn0=ebn0-0.5;
end                                   % while loop ends
fclose(fid);
```

Figure A-12 Full MATLAB Codes of BER Simulation for QPSK

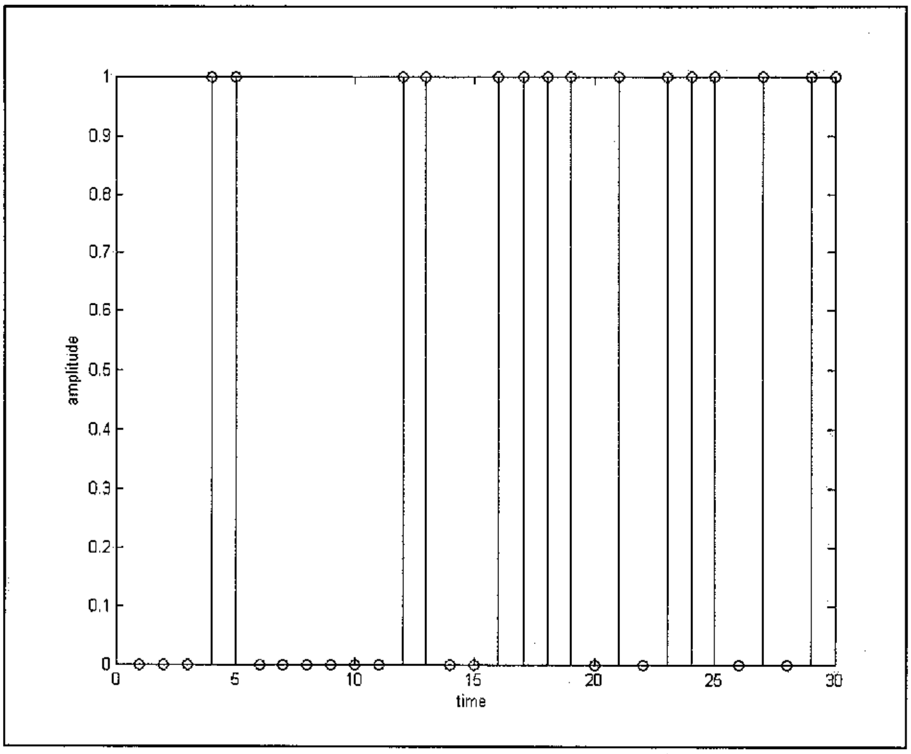


Figure A-13 QPSK Transmission Data (`data1`)

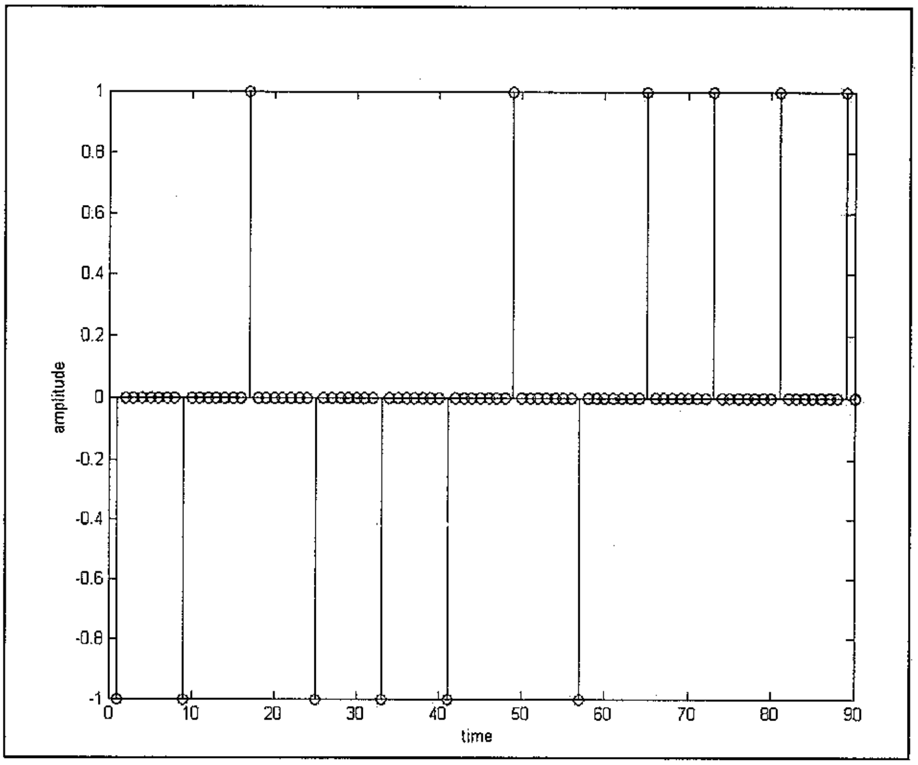


Figure A-14 QPSK transmission oversampled data (`ich1`)

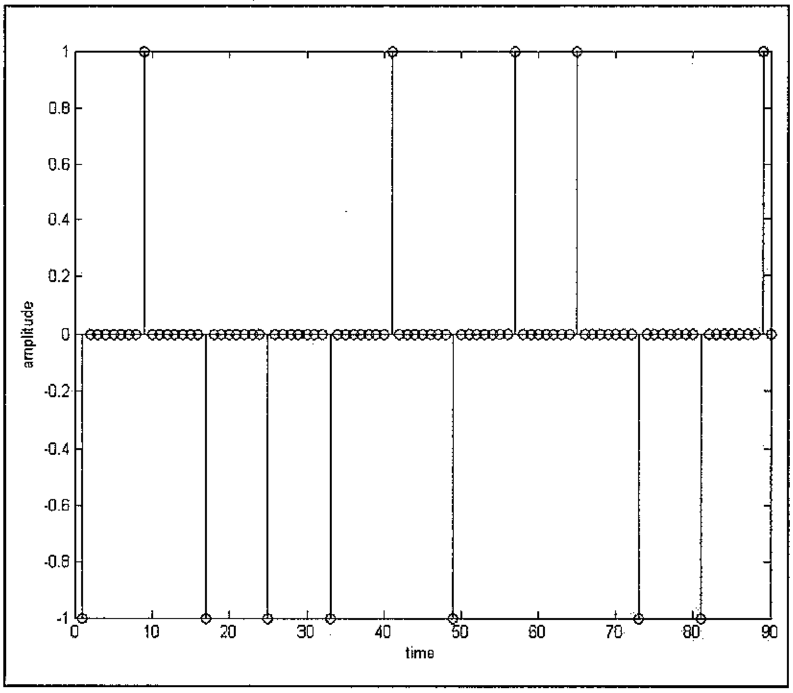


Figure A-15 QPSK transmission oversampled data (`qch1`)

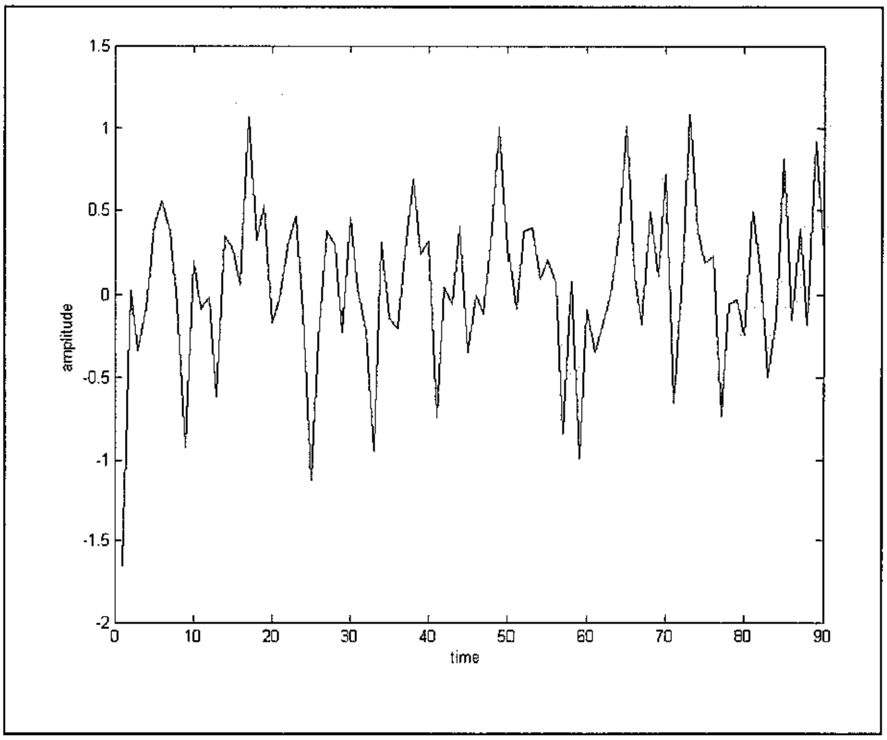


Figure A-16 QPSK received signal before demodulate (`ich3`)

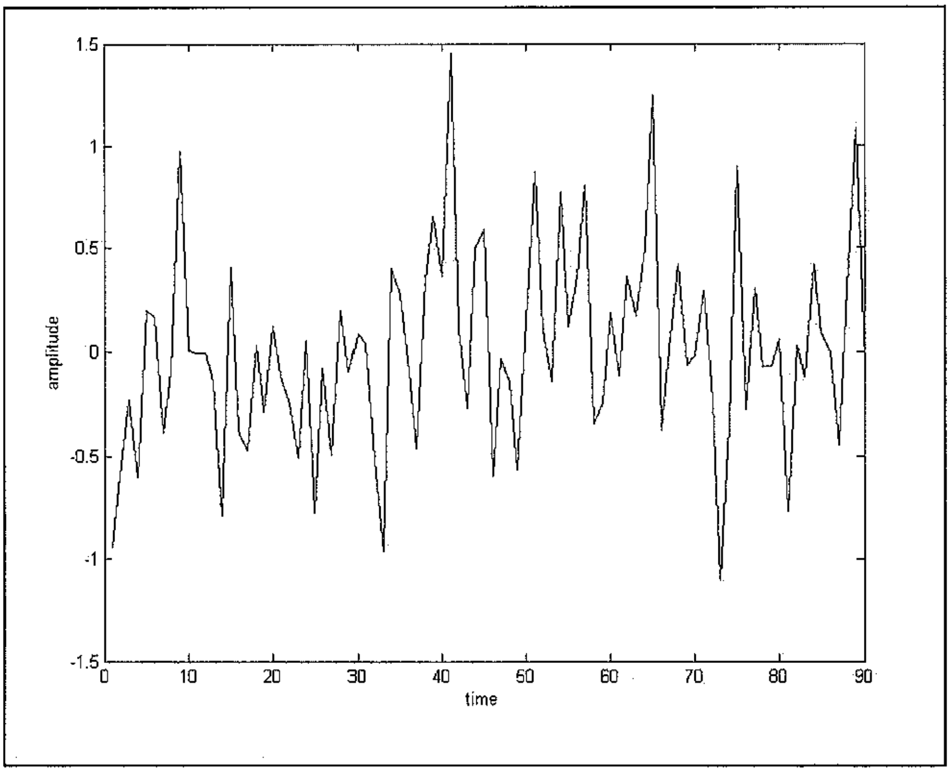


Figure A-17 QPSK received signal before demodulate (`qch3`)

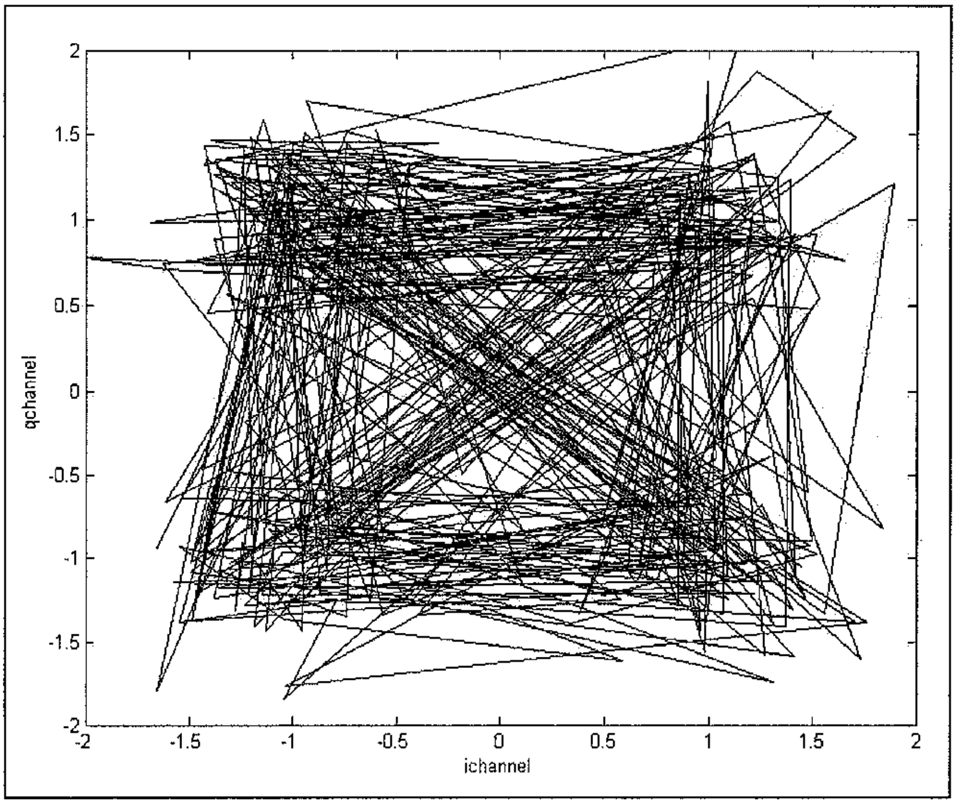


Figure A-18 QPSK Phasor diagram

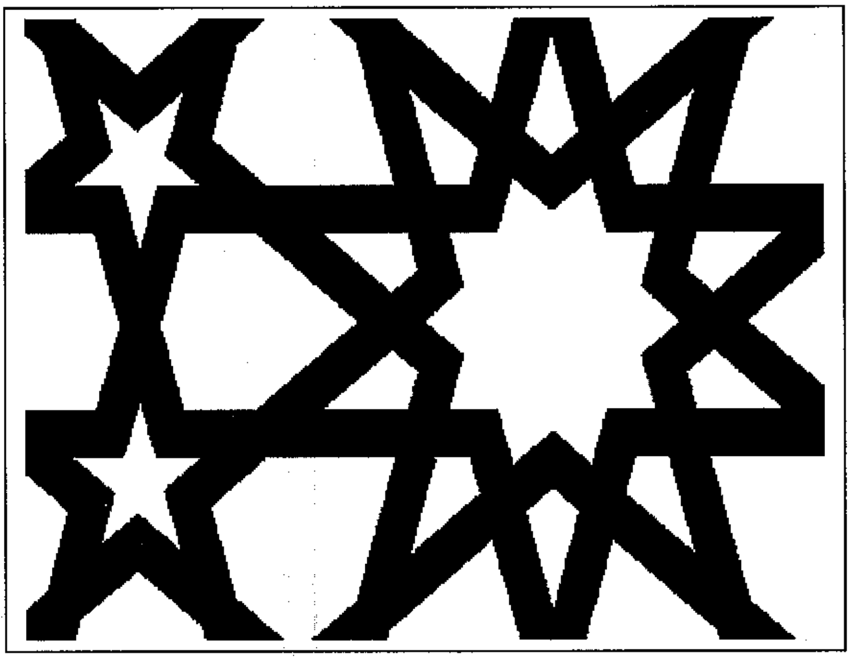


Figure A-19 Input Image Fed For Simulation

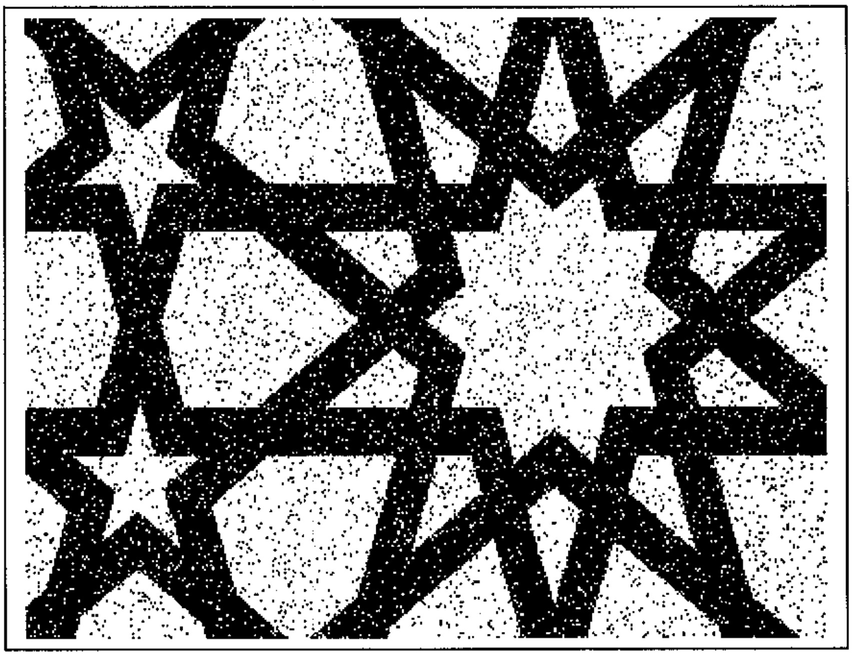


Figure A-20 Output Image of Simulation (Eb/No = 1 dB)

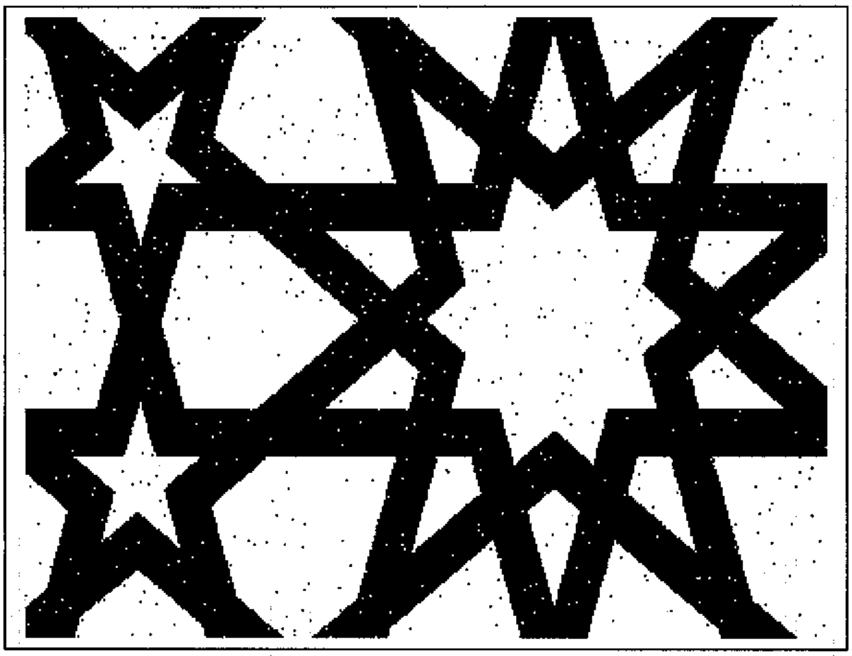


Figure A-21 Output Image of Simulation (Eb/No = 5 dB)

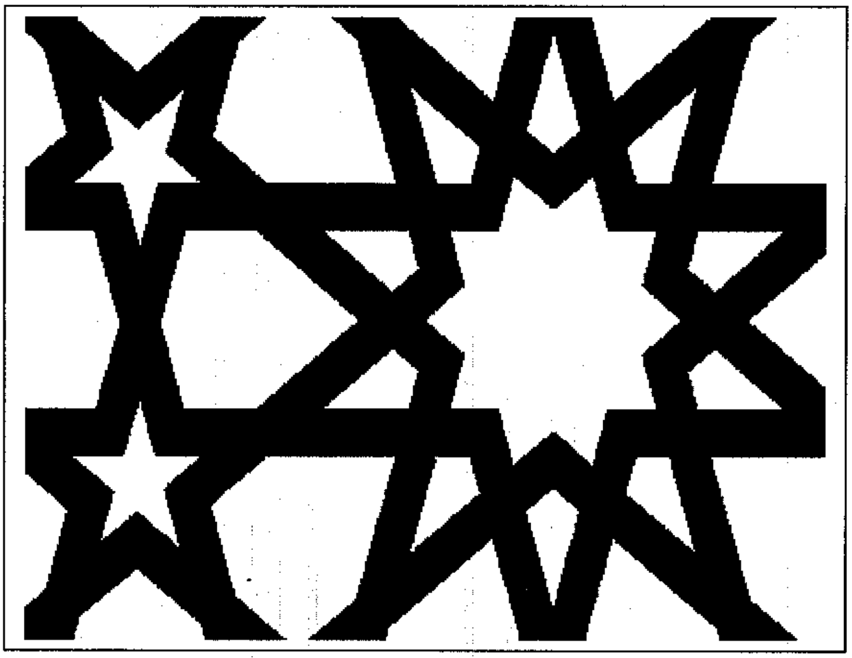


Figure A-22 Output Image of Simulation (Eb/No = 10 dB)

```
1.000000e+001  0.000000e+000
9.500000e+000  0.000000e+000
9.000000e+000  4.166667e-005
8.500000e+000  5.000000e-005
8.000000e+000  1.250000e-004
7.500000e+000  4.916667e-004
7.000000e+000  8.000000e-004
6.500000e+000  1.483333e-003
6.000000e+000  2.275000e-003
5.500000e+000  3.858333e-003
5.000000e+000  5.925000e-003
4.500000e+000  8.275000e-003
4.000000e+000  1.253333e-002
3.500000e+000  1.738333e-002
3.000000e+000  2.316667e-002
2.500000e+000  2.872500e-002
2.000000e+000  3.755833e-002
1.500000e+000  4.602500e-002
1.000000e+000  5.658333e-002
5.000000e-001  6.674167e-002
0.000000e+000  7.780833e-002
```

Figure A-23 Simulation Output file (*.dat) of QPSK BER Performance

```
sr=7000000000.0;                                   % frequency of symbol in 1
channel(Hz)
ml=2;                                             % modulation level (BPSK=1, QPSK=2 )
br=sr.*ml;                                        % freauency of the input data (bit/s)
nd=1000;                                         % no of data fed into the simulator
IPOINT=8;                                         % no of oversamples

%%%%%%%%%%%%%%%FADING INIT%%%%%%%%%%%%%%%%%%%%%
Ray_chan=[1 2 3 4];


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for k=1:1:4

ebn0=30.0;                                         % Ebergy per bit-to-noise power
density ratio (Eb/No)

while ebn0>=0.0

ebn0_no=ebn0                                      % display Eb/No number in workspace


input=1000;                                       % read image file (artgeo.bmp) as the
input binary data

data1=rand(1,nd*ml)>0.5;

nloop=2;                                        % simulation loop (to increase the
number of input data)
noe=0;
nod=0;

for iii=1:nloop


%%%%%%%%%%%%%%% QPSK MODULATION %%%%%%%%%%%

paradata=data1;
paradata2=paradata.*2-1;                          % to convert 1 -> 1 and 0 -> -1

ii=1;
for jj=1:nd
    isi=paradata2(1,ii);                          % odd sequance data fed into i-channel
    isq=paradata2(1,ii+1);                        % even sequence data fed into 1-
channel

    iout(1,jj)=isi;
    qout(1,jj)=isq;
    ii=ii+2;
end                                                % jj loops ends
ich=iout(1:nd);                                    % binary data in i-channel
qch=qout(1:nd);                                    % binary data in q-channel

%%%%%%%%%%%%%%% OVERSAMPLE %%%%%%%%%%%%%%%%
idata=ich;
qdata=qch;
nsymb=length(ich);
sample=IPOINT;

iout=zeros(1,nsymb*sample);                        % create zeros of length nsymb*sample
in i-channel
qout=zeros(1,nsymb*sample);                        % create zeros of length nsymb*sample
in q-channel
iout(1:sample:1+sample*(nsymb-1))=idata;           % insert IPOINT no. of zeros in
between of data in i-channel
qout(1:sample:1+sample*(nsymb-1))=qdata;           % insert IPOINT no. of zeros in
between of data in q-channel
ich1=iout;
qch1=qout;
```

```
%%%%%%%%%%%%%%%% ATTENUATION %%%%%%%%%%%%%%
spow=sum(ich1 .* ich1 + qch1 .* qch1) / nd;       % realise attenuation equation
attn=0.5*spow*sr/br*10.^(-ebn0/10);
attn=sqrt(attn);

%%%%%%%%%%%%%%%FADING CHANNEL%%%%%%%%%%%%%%%%%%

iSignal_Tx=ich1;
qSignal_Tx=qch1;

iRay_fad=sqrt(0.5)*(rand(Ray_chan(k),length(iSignal_Tx)) +
i*rand(Ray_chan(k),length(iSignal_Tx)));           %generate Rayleigh fading
channels
qRay_fad=sqrt(0.5)*(rand(Ray_chan(k),length(qSignal_Tx)) +
i*rand(Ray_chan(k),length(qSignal_Tx)));

noise_power = 1 / (10^(ebn0/10));
i_n=sqrt(noise_power/2)*(randn(Ray_chan(k),length(iSignal_Tx)) +
i*randn(Ray_chan(k),length(iSignal_Tx)));
q_n=sqrt(noise_power/2)*(randn(Ray_chan(k),length(qSignal_Tx)) +
i*randn(Ray_chan(k),length(qSignal_Tx)));

for kron_count=1:1:Ray_chan(k)
    kron_matrix(kron_count,1)=1;
end

iY = iRay_fad .* (kron(iSignal_Tx,kron_matrix))+i_n;  %MRC combining
qY = qRay_fad .* (kron(qSignal_Tx,kron_matrix))+q_n;
iX_MRC=[];
qX_MRC=[];

for ij=1:length(iSignal_Tx)
    iZ_hat=iRay_fad(:,ij)'*iY(:,ij);
    iX_MRC_NEXT=iZ_hat/norm(iRay_fad(:,ij))^2;
    iX_MRC=[iX_MRC iX_MRC_NEXT];
end

for qj=1:length(qSignal_Tx)
    qZ_hat=qRay_fad(:,qj)'*qY(:,qj);
    qX_MRC_NEXT=qZ_hat/norm(qRay_fad(:,qj))^2;
    qX_MRC=[qX_MRC qX_MRC_NEXT];
end

iX_hat(find(real(iX_MRC>0)))=1;
iX_hat(find(real(iX_MRC<0)))=-1;

qX_hat(find(real(qX_MRC>0)))=1;
qX_hat(find(real(qX_MRC<0)))=-1;


%%%%%%%%%%%%%%%% AWGN %%%%%%%%%%%%%%%%%%%%%%%%%%%
idata=iX_hat;



iout=randn(1,length(idata)).*attn;
qout=randn(1,length(qdata)).*attn;
iout=iout+idata(1:length(idata));
qout=qout+qdata(1:length(qdata));

ich3=iout;
qch3=qout;

ich5=ich3(1:IPOINT:length(ich3));
qch5=qch3(1:IPOINT:length(qch3));
```

```
%%%%%%%%%%%%%%%% DEMODULATION %%%%%%%%%%%%%%%%%%
idata=ich5;
qdata=qch5;

demodata=zeros(1,ml*nd);                          % create zeros of 1-by-ml*nd vector
demodata(1,(1:ml:ml*nd-1))=idata(1,(1:nd))>=0;    % to combine the ipnut + noise data of
both channels
demodata(1,(2:ml:ml*nd))=qdata(1,(1:nd))>=0;

%%%%%%%%%%%%%%%% BER %%%%%%%%%%%%%%%%%%%%%%%%%%%

noe2=sum(abs(data1-demodata));                    % compare output data with input data
to locate errors.
nod2=length(data1);                               % length of data
noe=noe+noe2;                                     % total number of errors
nod=nod+nod2;                                     % total number of data
end                                               % iii loop ends

output=demodata;                                  % realize th output of demodulated data


ber=noe/nod;                                      % BER calculated saved to file

fid=fopen('BERqpsk_awgn.dat','a');
fprintf(fid,'%e\t%e\t\n',ebn0,noe/nod);
fclose(fid);
ebn0=ebn0-5;


if (Ray_chan==1)
    fid1=fopen('Ray_1.dat','a');
    fprintf(fid1,'%e\t%e\t\n',ebno,noe/nod);
    fclose(fid1);
end
if (Ray_chan==2)
    fid2=fopen('Ray_2.dat','a');
    fprintf(fid2,'%e\t%e\t\n',ebno,noe/nod);
    fclose(fid2);
end
if (Ray_chan==3)
    fid3=fopen('Ray_3.dat','a');
    fprintf(fid3,'%e\t%e\t\n',ebno,noe/nod);
    fclose(fid3);
end
if (Ray_chan==4)
    fid4=fopen('Ray_4.dat','a');
    fprintf(fid4,'%e\t%e\t\n',ebno,noe/nod);
    fclose(fid4);

end
end                           % while loop ends
end                           % end k loop
```

Figure A-24 MATLAB program for BER performance of multiple antennas

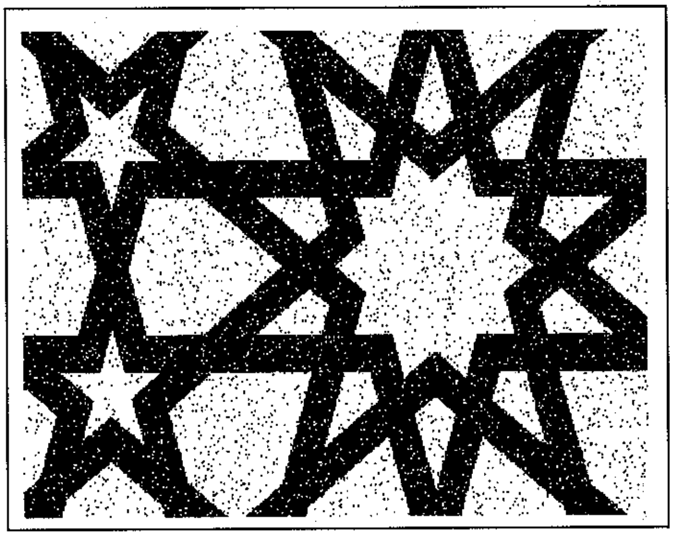


Figure A-25 Simulation output image for 1 receiver antenna (Eb/No=10 dB)

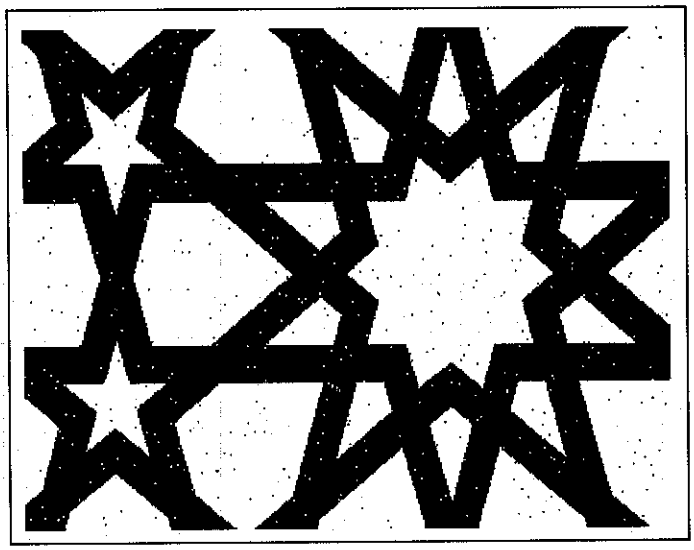


Figure A-26 Simulation output image for 2 receiver antennas (Eb/No=10 dB)

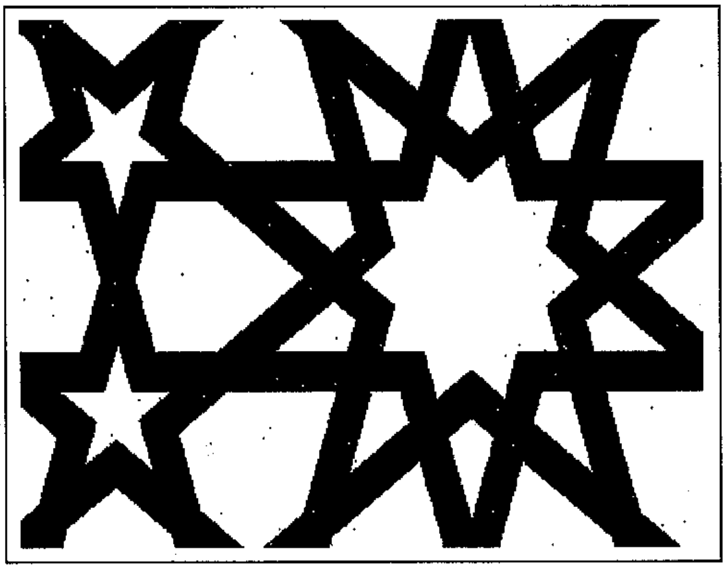


Figure A-27 Simulation output image for 3 receiver antennas (Eb/No=10 dB)

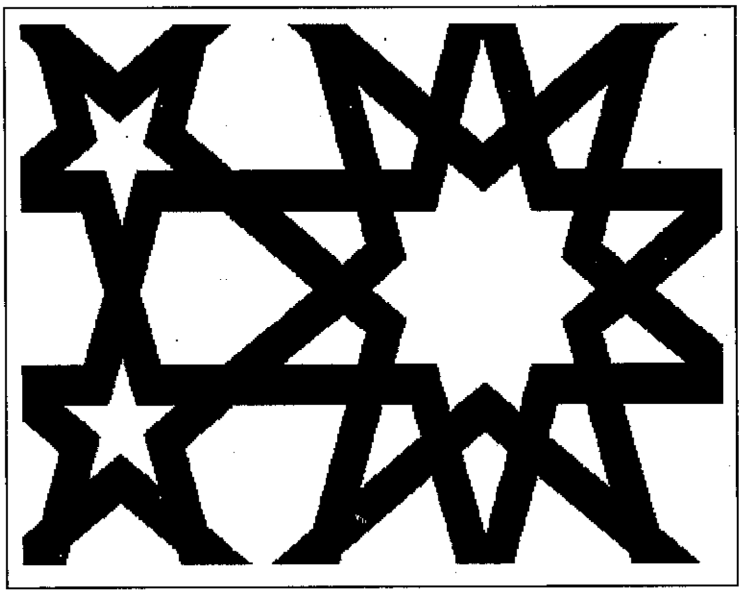


Figure A-28 Simulation output image for 4 receiver antennas (Eb/No=10 dB)

```
sr=7000000000.0;                           % frequency of symbol in 1 channel(Hz)
ml=2;                                      % modulation level (BPSK=1, QPSK=2 )
br=sr.*ml;                                 % freauency of the input data (bit/s)
nd=1000;                                   % no of data fed into the simulator
IPOINT=8;                                  % no of oversamples

ebn0_loop=0:2:30;

%%%%%%%%%%%%%%%%ANTENNA DISTANCE INIT%%%%%%%%%%%%%%%%%%%%
distance(1)=0.0001;
distance(2)=0.1;
distance(3)=0.2;
distance(4)=100;


%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for one_over_lambda_c=distance
    BER=[];



for ebn0=ebn0_loop

    ebn0_no=ebn0;

%bessel function init

    p=(besselj(0,2*pi*one_over_lambda_c))^2;
    chanvariance=1;
    XY12variance=chanvariance/2;
    XY3variance=XY12variance*(1+p);
    XY4variance=XY12variance*(1-p);
    BER_next=0;



input=1000;                  % read image file (artgeo.bmp) as the input binary data

data1=rand(1,nd*ml)>0.5;

nloop=200;                   % simulation loop (to increase the number of input data)
noe=0;
nod=0;

for iii=1:nloop


%%%%%%%%%%%%%%%% QPSK MODULATION %%%%%%%%%%%%

paradata=data1;
paradata2=paradata.*2-1;                   % to convert 1 -> 1 and 0 -> -1

ii=1;
for jj=1:nd
    isi=paradata2(1,ii);                   % odd sequance data fed into i-channel
    isq=paradata2(1,ii+1);                 % even sequence data fed into 1-channel

    iout(1,jj)=isi;
    qout(1,jj)=isq;
    ii=ii+2;
end                                        % jj loops ends
ich1=iout(1:nd);                           % binary data in i-channel
qch1=qout(1:nd);                           % binary data in q-channel
```

```
%%%%%%%%%%%%%%%%FADING CHANNEL%%%%%%%%%%%%%%%%%%%


iH3=sqrt(XY3variance)*(randn(1,length(ichl))+i*randn(1,length(ichl)));
qH3=sqrt(XY3variance)*(randn(1,length(qchl))+i*randn(1,length(qchl)));

iH4=sqrt(XY4variance)*(randn(1,length(ichl))+i*randn(1,length(ichl)));
qH4=sqrt(XY4variance)*(randn(1,length(qchl))+i*randn(1,length(qchl)));

iH=cat(1,iH3,iH4);
qH=cat(1,qH3,qH4);

avgSNR3=(1+p)*(10^(ebn0/10));
noise_power3=1/avgSNR3;

iN3=sqrt(noise_power3/2)*(randn(1,length(ichl))+i*randn(1,length(ichl)));
qN3=sqrt(noise_power3/2)*(randn(1,length(qchl))+i*randn(1,length(qchl)));

avgSNR4=(1-p)*(10^(ebn0/10));
noise_power4=1/avgSNR4;

iN4=sqrt(noise_power4/2)*(randn(1,length(ichl))+i*randn(1,length(ichl)));
qN4=sqrt(noise_power4/2)*(randn(1,length(qchl))+i*randn(1,length(qchl)));

iN=cat(1, iN3, iN4);
qN=cat(1, qN3, qN4);

iY=[];
qY=[];

for ij=1:length(ichl)
    iY_next=iH(:,ij)*ichl(ij)+iN(:,ij);
    iY=[iY iY_next];
end

for qj=1:length(qchl)
    qY_next=qH(:,ij)*ichl(ij)+qN(:,ij);
    qY=[qY qY_next];
end

%%%%%
X_MRC=[];

for ij=1:length(qchl)
    Z_hat=iH(:,ij)'*iY(:,ij);
    X_MRC=[X_MRC X_MRC_next];
end

X_hat(find(real(X_MRC>0)))=1;
X_hat(find(real(X_MRC<0)))=-1;

BER_next = BER_next + length(find((ichl - X_hat) ~= 0)) / length(ichl);
           end
           BER = [BER BER_next/nloop];
   end
```

Figure A-29 MATLAB program for BER performance of antennas spacing

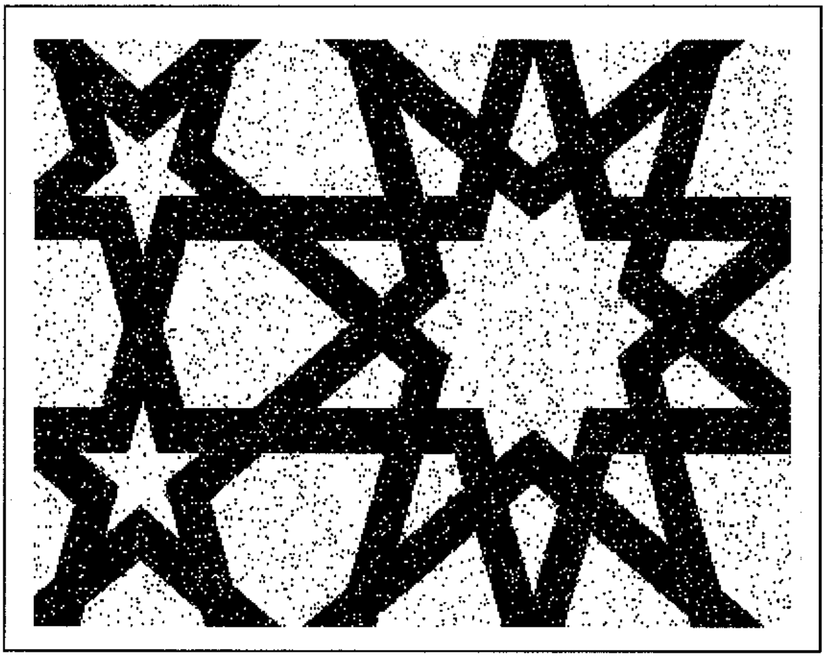


Figure A-30 Simulation output image for antenna spacing at d/lambda=0.0001

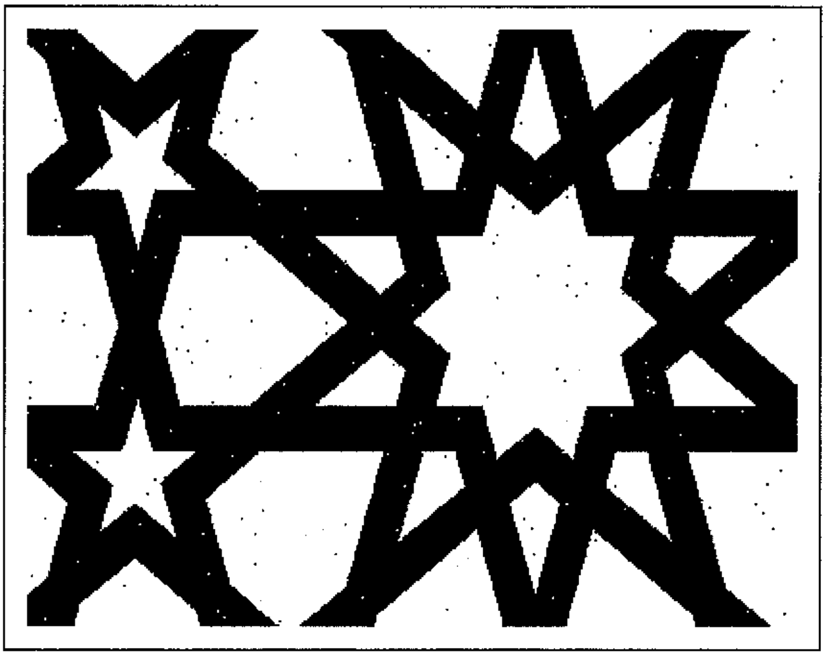
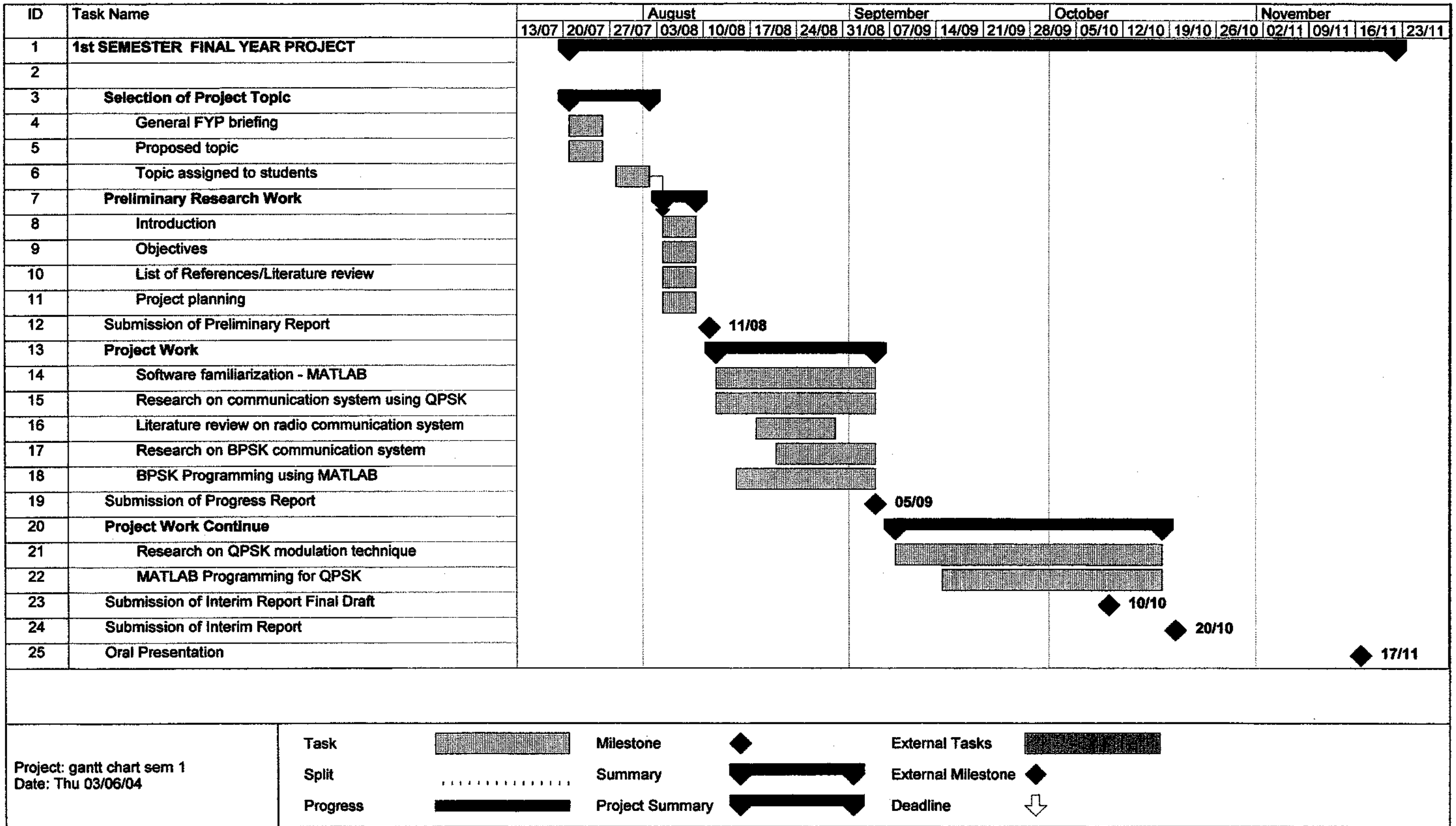
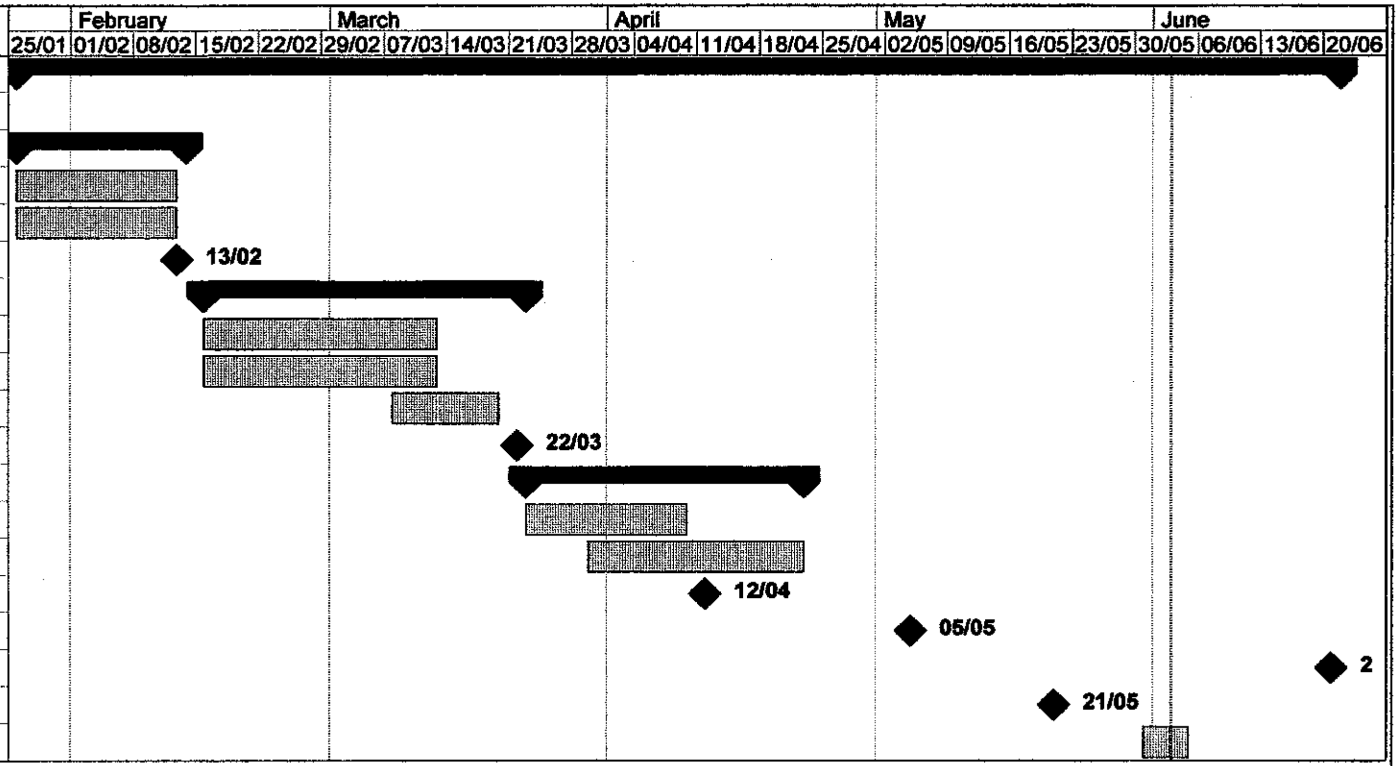


Figure A-31 Simulation output image for antenna spacing at d/lambda=100

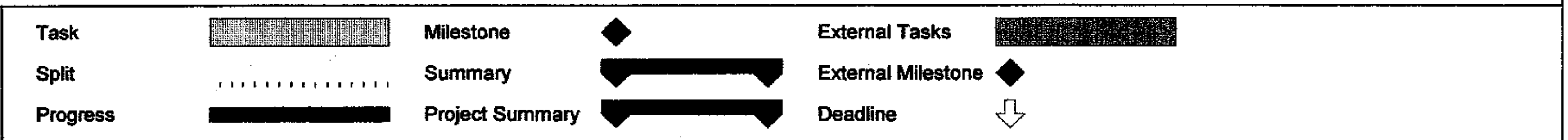


APPENDIX B-1 : GANTT CHART FOR THE FIRST SEMESTER FINAL YEAR PROJECT

ID	Task Name
1	**2nd SEMESTER FINAL YEAR PROJECT**
2	
3	**Project Work Continue**
4	Research on fading mathematical model
5	Research on diversity configuration
6	Submission of 1st Progress Report
7	**Project Work Continue**
8	Research on Rayleigh fading channel
9	Research on Maximal Ratio Combining
10	MATLAB Implementation
11	Submission of 2st Progress Report
12	**Project Work Continue**
13	Emphasizing MATLAB Programming
14	Dissertation report preparation
15	Submission of Dissertation (Draft)
16	Submission of Dissertation (Soft Cover)
17	Submission of Dissertation (Hard Cover)
18	Extended Abstract
19	Oral Presentation



Project: gantt chart sem 1
Date: Thu 03/06/04



APPENDIX B-2 : GANTT CHART FOR THE SECOND SEMESTER FINAL YEAR PROJECT