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# Study and Analysis of 2x2 MIMO Systems for Different Modulation Techniques using MATLAB

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**Abstract:** The performance of 2x2 Multiple Input multiple Output (MIMO) antenna systems is proposed to analyze by determining the transmit diversity using Alamouti Space Time Coding (STBC) techniques. For the BPSK and QPSK modulation technique transmission characteristics are determine. Adaptive White Gaussian Noise (AWGN) is proposed to presuming flat fading Rayleigh channel. On receiver side, linear equalization techniques such as Zero Forcing (ZF) and Maximum Likelihood Detector (MLD) are proposed to computing BER. The STBC codes for digital transmission shows significant improvement in BER performance with higher levels of digital modulation. MATLAB tool is used for simulation and its performance.

**Keywords**: Multiple Input Multiple Output (MIMO), Space Time Block Code (STBC), Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), Zero Forcing (ZF), Maximum Likelihood Detector (MLD).

## I. INTRODUCTION

A unique characteristic in a wireless channel (mobile radio channel) is a multipath fading environment. The signal at the receiver end contains not only the transmitted radio wave, it also includes a large number of reflected radio waves arrived at different times. Delay in the received signal is the result of reflections from the obstacles such as buildings, mountains, vehicles, hills or trees. These reflected delayed waves interfere with direct waves and cause Inter Symbol Interference (ISI) which causes significant degradation of network performance

MIMO technology has attracted attention in wireless communications, because of better data throughput and link range without additional bandwidth or transmit power MIMO achieves this by higher spectral efficiency and link reliability or diversity MIMO is an important part of modern wireless communication standards such as IEEE 802.11n (Wi-Fi), 4G, Long Term Evolution and WIMAX, The performance of the two transmit two receive antenna case resulting in a 2X2 MIMO channel have been studied. It is assumed that the transmission channel is a flat fading Rayleigh multipath channel and the modulation is BPSK and QPSK includes the Alamouti Space Time Block Coding (STBC) schemes Diversity coding techniques are used when there is no channel knowledge at the transmitter.

Since wireless technologies become a very high demand nowadays, STBC has been chosen to be a subject study for different digital modulation techniques. The present study involves four procedures namely modelling, simulations of the Alamouti STBC transmission system, digital transmission system and computation and comparison of BER. We will study and identify multiple input multiple output (MIMO) technology that gives best bit error rate (BER) performance for different digital modulation Schemes (BPSK, QPSK) using MATLAB simulation.

## II. PROPOSED METHODOLOGY

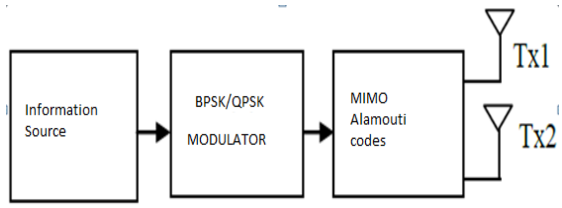


Fig 1: Block Diagram of Alamouti STBC

The figure 1 shows block diagram of proposed methodology Alamouti STBC for BPSK and QPSK modulation techniques, the working procedure as follows
At first, using PN sequence technique generate length of 31 bits random binary data (5 shift register).

- The data is generated from a random source, consists of a series of ones and zeros. The generated data is passed on to the next stage to the symbol mapping.
- The incoming data streams are modulated by using digital modulation techniques. There are two modulation techniques used for it, that are Binary phase shift modulation (BPSK),Quadrature phase shift modulation (QPSK)
- Space-Time Block Coding (STBC) based on Alamouti scheme to provide transmits and receive diversity. In the transmission matrix S1 and S2 represents two consecutive symbols. This signal is passed through Rayleigh multipath fading channels.
- In the STBC decoder received signals were combined and detected by Maximum- Likelihood (ML) detector.
- Demodulator converts the waveforms created at the modulation to the original transformed bits. The demodulator is used for decision rules with the goal of making a decision about which bit “zero” or “one”, is sent.

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## III. IMPLEMENTATION

A. Software Requirement

Our project is simulated using MATLAB R2013a. It can also be done using other versions of MATLAB such as MATLAB 7.9, beta version etc. MATLAB is software which is user friendly and allows even the fresher to understand the software efficiently. It is very flexible. It can be used in various fields such as digital image processing, digital signal processing, medical fields, mathematical operations, simulations, system designing. The main advantages of choosing this software is that it is user friendly, simple codes, easy to design, platform independent, predefined functions, easy to plot.

In this project our purpose is that, performance analysis of Alamouti STBC and also comparing with SISO performance for Different modulation techniques.

B.SISO (Single Input Single Output) SYSTEM

In SISO system, we have just one Transmitter and one Receiver so we have just one channel and that means that there is no diversity. In other words, data is transmitted just one channel and if the channel damage data, received data is different from transmitted data so, communication cannot be provided normally. All in all Bit-Error-Rate can be high which is not acceptable in communication. Figure 2 shows that working principle of SISO system.

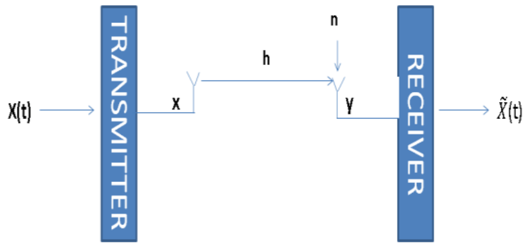


Fig 2:1x1 SISO system

$$y = xh + n \qquad (3.1)$$

x is the transmitted data ,h is the Rayleigh channel, n is the AWGN noise & y is the received data

In order to get transmitted data at the receiver with noise and channel effect we divide **h** both side of ( 3.1) ;

$$\tilde{x} = \frac{y}{h} = x + \frac{n}{h}$$

C.SPACE-TIME BLOCK CODING

Space–time block coding is a technique used in wireless communications to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer. In other words, if we compare with SISO, we have more than one channel between Transmitters and Receivers so, there are diversity. Thanks to this diversity, data and its copies is send on several channels and the Bit-Error-Rate is less than SISO system.

D.ALAMOUTI SPACE-TIME BLOCK CODING

Alamouti STBC is a complex space-time diversity technique that can be used in 2x1 MISO mode or in a 2x2 MIMO mode. It is the only STBC that can achieve its full diversity gain without needing to sacrifice its data rate. this property usually gives Alamouti's code a significant advantage over the higher-order STBCs even though they achieve a better error-rate performance.

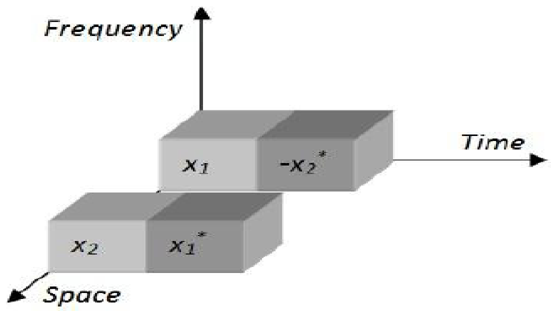


Fig 3: Alamouti Space Time Diversity

Figure 3 shows that two symbols and their conjugate are sent, in two time slots, which brings a diversity gain without having to compromise on the data rate. Over the air, the transmitted symbols will suffer from channel fading and noise at the receiver, their sum will be received. Working principles of 2x1 and 2x2 Alamouti STBC is indicated Figure 4 and Figure 5 respectively.

1) 2x1 Alamouti STBC

The 2x1 Alamouti STBC systems consists of two antenna at transmitter and at receiver side contains one antenna as shown the figure 4

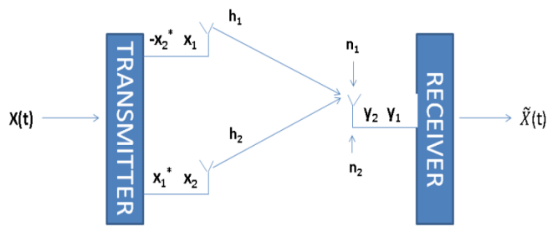


Fig 4: 2x1 Alamouti STBC

| Time | Transmitter 1 | Transmitter 2 |
|---|---|---|
| Time t | $X_1$ | $X_2$ |
| Time t+T | $-X_2^*$ | $X_1^*$ |

Table1:2x1 Alamouti STBC

Table 1 shows that working principle of 2x1 Alamouti STBC. At time t $X_1$ and $X_2$ are transmitted by Transmitter 1 and 2 and after that at time (t+T) their conjugates are transmitted.

From Table 1 and Figure 4 we can write receiving data;

$y_1 = x_1h_1 + x_2h_2 + n_1$ (First time slot) (3.2)

$y_2 = -x_2^*h_1 + x_1^*h_2 + n_2$ (Second time slot) (3.3)

Where;

$x_1$ and $x_2$ transmitted data,

$y_1$ and $y_2$ received data,

$h_1$ and $h_2$ Rayleigh channel,

$n_1$ and $n_2$ AWGN noise,

In matrix form of these equation (3.2) and (3.3);

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \begin{bmatrix} h_1 \\ h_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \end{bmatrix} \qquad (3.4)$$

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In order to get rid of conjugates of transmitted data at the receiver, we take conjugate of y2;

$$y_1 = x_1 h_1 + x_2 h_2 + n_1 \quad (3.2)$$
$$y_2^* = h_1^*(-x_2) + h_2^* x_1 + n_2^* \quad (3.5)$$

Matrix form of (3.2) and (3.5);

$$\begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \quad (3.6)$$

Let's define channel H

H=$\begin{bmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{bmatrix}$and inverse of H is equal to $H^{-1}$

We multiply both side of equation (3.6) with, $H^{-1}$ then we get ;

$$H^{-1} \begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = H^{-1} \mathrm{H} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + H^{-1} \begin{bmatrix} n_1 \\ n_2^* \end{bmatrix} \quad (3.7)$$

From equation (3.7) we get;

$$H^{-1} \begin{bmatrix} y_1 \\ y_2^* \end{bmatrix} = \begin{bmatrix} \tilde{X_1} \\ \tilde{X_2^*} \end{bmatrix} = \tilde{X} \quad (3.8)$$

From equation (3.8) we write $\tilde{X}$seperately;

$$\tilde{X_1} = X_1 + (h_1^* n_1 + h_2 n_2^*)/(|h_1|^2 + |h_2|^2)$$
$$\tilde{X_2} = X_2 + (n_1 h_2^* - h_2 n_2^*)/(|h_1|^2 + |h_2|^2)$$

Finally we get transmitted data with noise and channel effect. This process is called Equalization.

2) 2x2 Alamouti STBC

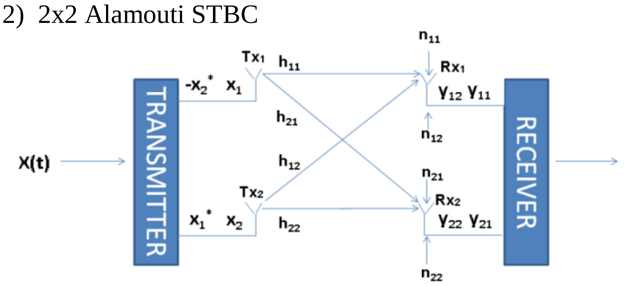


Figure 5:2x2 Alamouti STBC

The 2x2 Alamouti STBC System is shown in figure 5 which is similar to 2x1 Alamouti but we have one more receiver antenna. This system is consists of 2 Transmitter and 2 Receiver. Working principle is also similar to 2x1 Alamouti. In 2x1 Alamouti we send block codes to just one receiver but in this system we send block codes to 2 receiver.

$y_{11}$=$X_1 h_{11}$+$X_2 h_{12}$+$n_{11}$(first timeslot received data in Rx1) (3.9)

$y_{12}$=$-X_2^* h_{11}$+$X_1^* h_{12}$+$n_{12}$(second time slot received data in Rx1) (3.10)

$y_{21}$=$X_1 h_{21}$+$X_2 h_{22}$+$n_{21}$(first time slot received data in Rx2) (3.11)

$y_{22}$=$-X_2^* h_{21}$+$X_1^* h_{22}$+$n_{22}$(second time slot received data in Rx2) (3.12)

Where;

$X_1$ and $X_2$transmitted data

$y_{11}$ and $y_{21}$ are received data (for first time slot)

$y_{12}$ and $y_{22}$ are received data in (for second time slot)

$h_{11}$, $h_{12}$ , $h_{21}$, $h_{22}$ are Rayleigh channel

$n_{11}$ , $n_{12}$ , $n_{21}$, $n_{22} n_{22}$ are AWGN noise

Now we take conjugates of $y_{12}$ , $y_{22}$ to get rid of conjugates of transmitted data at the receiver;

$$y_{12}^* = -x_2 h_{11}^* + x_1 h_{12}^* + n_{12}^* \quad (3.13)$$
$$y_{22}^* = -x_2 h_{21}^* + x_1 h_{22}^* + n_{22}^* \quad (3.14)$$

We write (3.9) ,(3.11), (3.13), (3.14) together to getting matrix form;

$$y_{11} = x_1 h_{11} + x_2 h_{12} + n_{11} \quad (3.9)$$
$$y_{12}^* = -x_2 h_{11}^* + x_1 h_{12}^* + n_{12}^* \quad (3.13)$$
$$y_{21} = x_1 h_{21} + x_2 h_{22} + n_{21} \quad (3.11)$$
$$y_{22}^* = -x_2 h_{21}^* + x_1 h_{22}^* + n_{22}^* \quad (3.14)$$

In matrix form of equations;

$$\begin{bmatrix} Y_{11} \\ Y_{12}^* \\ Y_{21} \\ Y_{22}^* \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} \\ h_{12}^* & -h_{11}^* \\ h_{21} & h_{22} \\ h_{22}^* & -h_{12}^* \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} n_{11} \\ n_{12}^* \\ n_{21} \\ n_{22}^* \end{bmatrix} \quad (3.15)$$

As can be seen from the (3.29) we get rid of conjugates of transmitted data.

We define X,Y,H,N matrices ;

$$X = \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \quad ,Y = \begin{bmatrix} Y_{11} \\ Y_{12}^* \\ Y_{21} \\ Y_{22}^* \end{bmatrix} \quad ,H = \begin{bmatrix} h_{11} & h_{12} \\ h_{12}^* & -h_{11}^* \\ h_{21} & h_{22} \\ h_{22}^* & -h_{12}^* \end{bmatrix}$$

$$,N = \begin{bmatrix} n_{11} \\ n_{12}^* \\ n_{21} \\ n_{22}^* \end{bmatrix}$$

We get;

$$Y=XH+N \quad (3.16)$$

In order to get transmitted data at the receiver, we eliminate "**H** " matrix as 2x1 Alamouti STBC, however this is not easy as before. Since, 2x1 Alamouti STBCs "**H**" matrix is the square matrix and we eliminate multiply with its inverse easily. In 2x2 Alamouti STBCs H matrix is not square matrix so its inverse is not exists. Because of this reason we use Hermitian transposition, indicated with the symbol H. It is equivalent to transpose and do a complex conjugation of the matrix.

$$\mathrm{H^H} = \begin{bmatrix} \mathrm{h_{11}^*} & \mathrm{h_{12}} & \mathrm{h_{21}^*} & \mathrm{h_{22}} \\ \mathrm{h_{12}^*} & -\mathrm{h_{11}} & \mathrm{h_{22}^*} & -\mathrm{h_{21}} \end{bmatrix}$$
$$= \begin{bmatrix} |\mathrm{h_{11}}|^2 + |\mathrm{h_{12}}|^2 + |\mathrm{h_{21}}|^2 + |\mathrm{h_{22}}|^2 & 0 \\ 0 & |\mathrm{h_{11}}|^2 + |\mathrm{h_{12}}|^2 + |\mathrm{h_{21}}|^2 + |\mathrm{h_{22}}|^2 \end{bmatrix}$$

We define d:

$$\mathrm{d} = |\mathrm{h_{11}}|^2 + |\mathrm{h_{12}}|^2 + |\mathrm{h_{21}}|^2 + |\mathrm{h_{22}}|^2$$

Then

$$\mathrm{H^H H} = \begin{bmatrix} \mathrm{d} & 0 \\ 0 & \mathrm{d} \end{bmatrix}$$

In order to get identity matrix;

$$\frac{1}{\mathrm{d}} = \begin{bmatrix} \mathrm{d} & 0 \\ 0 & \mathrm{d} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} = \mathrm{I}$$

We multiply both side of equation 3.16 with$\frac{1}{\mathrm{d}}\mathrm{H^H}$;

$$\frac{1}{\mathrm{d}} \mathrm{H^H Y} = \frac{1}{\mathrm{d}} \mathrm{H^H H Y} + \frac{1}{\mathrm{d}} \mathrm{H^H N}$$
$$= \mathrm{X} + \frac{1}{\mathrm{d}} \mathrm{H^H N} = \tilde{\mathrm{X}}$$

As a result we get transmitted data at the receiver with noise and channel effect;

$$\tilde{\mathrm{X}}_1 = \frac{1}{\mathrm{d}} (\mathrm{h_{11}^* y_{11}} + \mathrm{h_{12} y_{12}} + \mathrm{h_{12}^* y_{21}} + \mathrm{h_{22} y_{22}})$$
$$\tilde{\mathrm{X}}_2 = \frac{1}{\mathrm{d}} (\mathrm{h_{12}^* y_{11}} - \mathrm{h_{12} y_{12}} + \mathrm{h_{22}^* y_{21}} + \mathrm{h_{22} y_{22}})$$

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E. Bit-Error-Rate Analysis on MATLAB

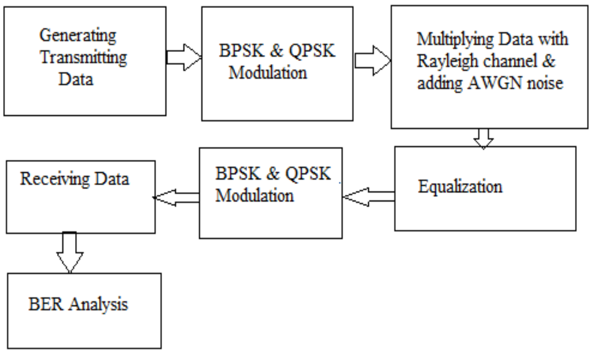


Fig 6: Flow chart for BER Analysis

In our project we used BPSK&QPSK modulation. Figure 6 shows how we do performance analysis of SISO, (2x1) and (2x2) Alamouti Space Time Coding with BPSK&QPSK modulation with block diagrams step by step.

## IV.RESULTS

A.2X2 MIMO System for BPSK Modulation Techniques

The Matlab/Octave script performs the following
(a) Generate random binary sequence of +1′s and -1′s.
(b) Group them into pair of two symbols and send two symbols in one time slot
(c) Multiply the symbols with the channel and then add white Gaussian noise.
(d) Equalize the received symbols
(e) Perform hard decision decoding and count the bit errors
(f) Repeat for multiple values of $\frac{E_b}{N_o}$ and plot the simulation and theoretical result as shown the below figure 7

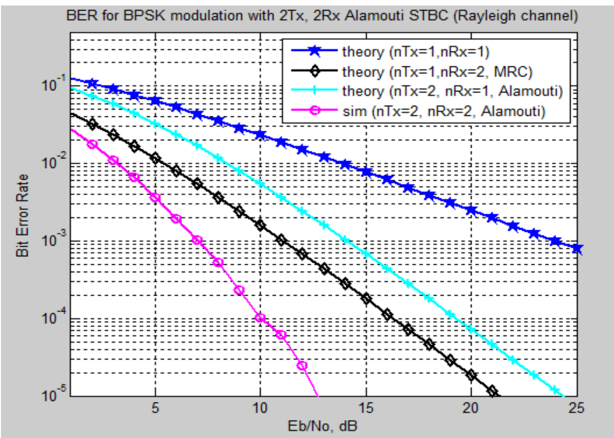


Fig7: BER for BPSK modulation for 2x2 Alamouti STBC

The below Table 2shows the comparison of different schemes by using BPSK modulation at constant SNR of 13db. Single input single output (SISO) with 1x1 antenna gives the BER of 0.01208, maximum ratio combining (MRC) with 1x2 antenna gives the BER of 0.001606, and Almouti scheme (transmit diversity) with 2x2 antennas gives the BER of 1.1e-005.

Thus the Almouti scheme with 2x2 antennas shows the better performance when compared to MRC case.
This is because the effective channel information from 2 receive antenna over 2 symbols results in diversity order of 4. In general Nr receive antennas, the diversity order of 2 transmit antenna Almouti STBC is 2Nr.
In Almouti STBC scheme we also see that $(H^H H)$ diagonal matrix ensures that there is no crosstalk between$s_0, s_1$ s after the equalizer and the noise term is still white.

| Types of scheme | Types of modulation | No of Tx Antenna | No of Rx Antenna | BER | SNR |
|---|---|---|---|---|---|
| SISO 1x1 | BPSK | 1 | 1 | 0.01208 | 13db |
| MRC 1x2 | BPSK | 1 | 2 | 0.001606 | 13db |
| MISO 2x1 | BPSK | 2 | 1 | 0.0004341 | 13db |
| MIMO 2x2 | BPSK | 2 | 2 | 1.1e^-5 | 13db |

Table 2: BER values for some of SNR_dB values of different schemes by using BPSK modulation

B.2X2 MIMO System for QPSK Modulation Techniques

The Matlab/Octave script performs the following
(a) Generate random binary sequence of +1′s and -1′s.
(b) Group them into pair of two symbols and send two symbols in one time slot
(c) Multiply the symbols with the channel and then add white Gaussian noise.
(d) Equalize the received symbols
(e) Perform hard decision decoding and count the bit errors
(f) Repeat for multiple values of $\frac{E_b}{N_o}$ and plot the simulation and theoretical result as shown the below figure 8

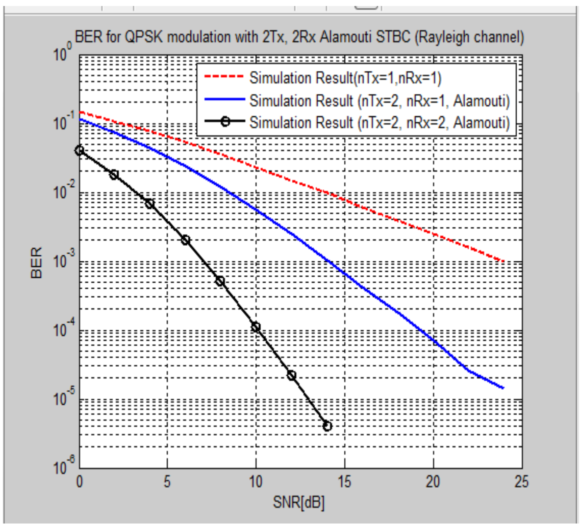


Fig8: BER for QPSK Modulation with 2x2 Alamouti STBC

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| SNR(dB) | SISO | 2x1 Alamouti | 2x2 Alamouti |
|---|---|---|---|
| 5dB | 6.4x10^-2 | 3.3x10^-2 | 3.7x10^-3 |
| 15(dB) | 7.8x10^-3 | 7.1x10^-4 | 3.0x10^-6 |
| 21(dB) | 1.9x10^-3 | 4.7x10^-5 | ------------------ |
| 25(db) | 7.8x10^-4 | 7.0x10^-6 | -------------------- |

Table 3: BER values for some of SNR_dB values of different schemes by using QPSK modulation

Figure 8 shows that graphical output of all systems and Table 3indicates BER values for some of SNR_dB values. As can be seen from graph and table, 2x2 Alamouti STBC has the smallest BER values for all of SNR_dB values. This result is expected because 2x2 Alamouti system has one more receiver when compared with 2x1Alamouti system and thanks to this one more receiver it increases its diversity. SISO system has the highest BER values for all of SNR_dB values because of no diversity.

## V.CONCLUSION

In this project we have learned theory of Space-Time Block Coding, feature of Alamouti STBC and differences between SISO systems. Also we have understood BPSK and QPSK modulation specialities and have learned how can be made Bit-Error-Rate analysis. , the system with BPSK modulation giver better BER result compare to QPSK modulation technique Furthermore thanks to this project we have developed MATLAB skill.

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