



## Review Article

# Comparative Study of Bit Error Rate of Different M-ary Modulation Techniques in AWGN Channel

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### To cite this article:

Bourdillon O. Omijeh, Ifiokabasi Eyo. Comparative Study of Bit Error Rate of Different M-ary Modulation Techniques in AWGN Channel. *American Journal of Networks and Communications*. Vol. 5, No. 5, 2016, pp. 82-90. doi: 10.11648/j.ajnc.20160505.11

Received: August 22, 2016; Accepted: August 31, 2016; Published: September 24, 2016

**Abstract:** This paper focuses on various digital modulation schemes and their effect on bit error rate (BER); and to ascertain which has the lowest bit error rate. Further analysis includes: to compare bit error rates of various digital modulation schemes using the M-ary modulation technique, analyse the effect of varying signal energy per bit to Noise ratio ( $E_b/N_o$ ) on the error rate of various digital modulation schemes, analyse graphically the relationship between  $E_b/N_o$  and BER, analyse graphically the relationship between BER and M-ary number. A model-based design methodology was employed in the research using MATLAB/SIMULINK. The comparison between different M-ary (M-PAM, M-PSK, and M-QAM) ( $M = 2, 4, 8, 16, 32$ , and  $64$ ) modulation schemes in normal AWGN channel was done. By analysing the graphical illustration of  $E_b/N_o$  vs BER of these M-PSK schemes it was strongly observed that increase in the value of  $M$  causes a correspondent increase in the error rate. Therefore, as the error rate increases with increasing  $M$ ; lower level should be used for long distance communication and vice versa. High level modulation techniques are always preferred for high data rate.

**Keywords:** Bit Error Rate, Digital Modulation, Additive White Gaussian Noise, Simulink

## 1. Introduction

Digital communication is employed for signals that are essentially analog and continuous-time, such as speech and images; and signals that are essentially digital such as text files [14]. In digital modulation, the baseband (modulating) signal is converted to a digital signal. It is preferred over analogue modulation for the following reasons: Greater noise immunity and robustness to channel impairments; accommodation of digital error control codes with detect/correct transmission errors. The basic digital modulation techniques are: Frequency shift keying, Phase shift keying, BPSK, QPSK and QAM. The choice of a particular digital modulation scheme depends on the quality factors such as: provision of low bit error rates at low received signal-to-noise ratios; good performance interference, multipath and fading environments; bandwidth occupation; easy and cost effective implementation [1-4, 14].

This paper focuses on various digital modulation schemes and their effect on bit error rate (BER) and to ascertain which has the lowest bit error rate. The objectives include: to compare bit error rates of various digital modulation schemes using the M-ary modulation technique, Analyse the effect of varying signal energy per bit to Noise ratio ( $E_b/N_o$ ) on the error rate of various digital modulation schemes, analyse graphically the relationship between  $E_b/N_o$  and BER, Analyse graphically the relationship between BER and M-ary number.

## 2. Theoretical Background

$S_1(t)$  and  $S_2(t)$  are the pairs of signals used to represent binary in BPSK system.

$$S_1(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t) \quad (1)$$

$$S_2(t) = \sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t + \pi) \quad (2)$$

$$S_2(t) = -\sqrt{\frac{2E_b}{T_b}} \cos(2\pi f_c t) \quad (3)$$

Where  $0 \leq t \leq T_b$  and  $E_b$  is the energy transmitted signal energy per bit [5-6]

The average probability of symbol error or, equivalently, the bit error rate for BPSK is

$$P_e = \frac{1}{2} \operatorname{erfc}\left(\sqrt{\frac{E_b}{N_n}}\right) \quad (4)$$

### 2.1. M-ary PSK

The modulated waveform of the carrier phase in an M-ary PSK system can be expressed as:

$$S_i(t) = A \cos(2\pi f_c t + \theta_i) \quad i = 1, 2, \dots, M \quad (5)$$

$$0 \leq t \leq T$$

Equation (5) can be rewritten as:

$$S_i(t) = \left\{ \cos[(i-1)\Phi_1(t) - \sin[(i-1)\Phi_2(t)] \right\} \quad (6)$$

Where  $I = 1, 2, \dots, M$

By choosing orthogonal basis signals

$$\Phi_1(t) = \sqrt{\frac{2}{T_s}} \cos(2\pi f_c t)$$

And  $\Phi_2(t) = \sqrt{\frac{2}{T_s}} \sin(2\pi f_c t)$  defined over the interval

$0 \leq t \leq T_s$ , the M-ary PSK signal set can be expressed as:

$$S_{\text{MPSK}}(t) = \left\{ \cos[(i-1)\Phi_1(t) - \sin[(i-1)\Phi_2(t)] \right\} \quad (7)$$

Where  $I = 1, 2, \dots, M$

Average symbol error probability of an M-ary PSK system [7-8] is given by

$$P_e \approx 2Q\left(\sqrt{\frac{4E_s}{N_o} \sin\left(\frac{\pi}{2M}\right)}\right) \quad (8)$$

### 2.2. M-ary QAM

Quadrature Amplitude Modulation (QAM) is a popular system of attaining high data rates in bandwidth channels that are limited. It is characterized by two data signals that are  $90^\circ$  out of phase with each other [6] [9]. M-ary QAM has become dominant over the years [10]:

The general expression of an M-ary QAM signal can be defined as:

$$S_i(t) = \{a_i \cos(2\pi f_c t) + b_i \sin(2\pi f_c t)\} \quad (9)$$

$$0 \leq t \leq T, i = 1, 2, \dots, M$$

Where  $E_{\min}$  is the energy of the signal with the lowest amplitude and  $a_i$  and  $b_i$  are a pair of independent integers. Specific values of  $S_i(t)$  is detected with higher probability than others because the energy per symbol of an M-ary QAM is not constant.

$$\begin{aligned} \Phi_1(t) &= \cos(2\pi f_c t); 0 \leq t \leq T_s \\ \Phi_2(t) &= \sin(2\pi f_c t); 0 \leq t \leq T_s \end{aligned} \quad (10)$$

The average probability of error in an AWGN channel for M-ary QAM, using coherent detection:

$$P_e \approx 4\left(1 - \frac{1}{M}\right) Q\left(\sqrt{\frac{2E_{\min}}{N_o}}\right) \quad (11)$$

In terms of average signal energy  $E_{\text{avg}}$ :

$$P_e \approx 4\left(1 - \frac{1}{M}\right) Q\left(\sqrt{\frac{2E_{\text{avg}}}{N_o}}\right) \quad (12)$$

### 2.3. Bit Error Rate (BER)

Bit Error Rate (BER) is the number of bit errors that occur for a given number of bits transmitted. It is related to the error probability because it is the ratio of bit errors to bits transmitted. The energy per bit is the amount of power in a digital bit for a given amount of time [10-11].

### 2.4. AWGN (Additive White Gaussian Noise)

The presence of Additive White Gaussian Noise (AWGN) in a channel distorts the quality of the received signal. The deviation of the received symbols with respect to the constellation set increases with respect to higher variance of the noise. And this leads to higher probability, demodulating a wrong symbol to make errors [12-13].

## 3. Model-Based Design Methodology

Three M-ary modulation schemes were considered in this work, namely: M-ary PAM, M-ary PSK and M-ary QAM. The model was designed using Simulink.

### 3.1. Design Steps for M-ary PAM

- Select the Random Data Sources from the communication sources block set.
- Select the AM Sub-folder in the Digital Baseband modulation block from the modulation blockset in the communication block set.
- Select the AWGN Channel block from the channel sub folder in the communication block
- Select the M-PAM Demodulator baseband module from the AM sub-folder in the modulation block set
- Select the Error Rate Calculation module from the comm. Sinks sub-folder and set the Received delay to 0 and computation delay to 0.
- Select the Discrete-Time Scatter Plot Scope modules

from *Comm Sinks* sub-folder.

- vii. Add the Power Spectral Density modules from *Additional Sinks* sub-folder. The entire design is as shown in Figure 1.

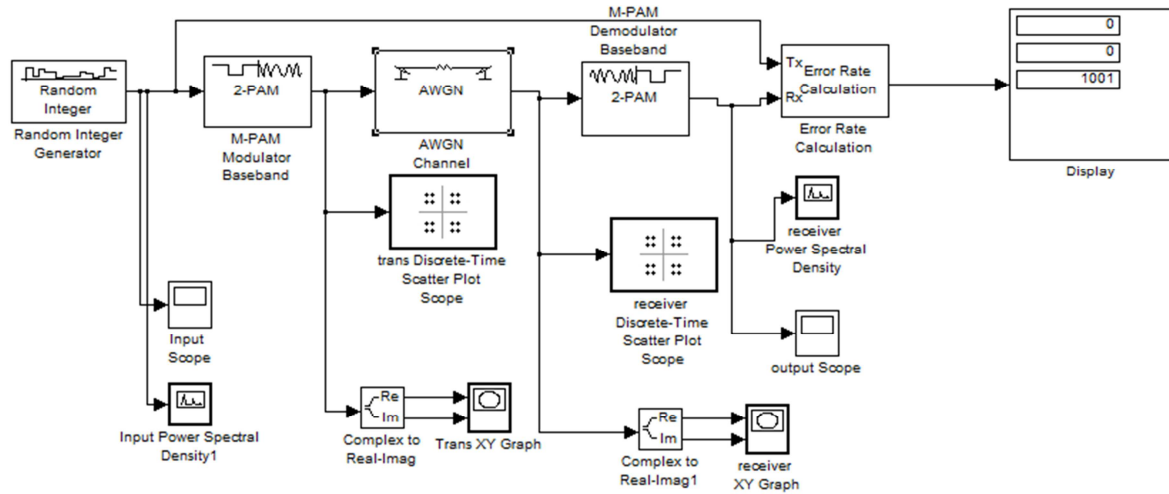


Fig. 1. Simulink model for 2-PAM Transmission.

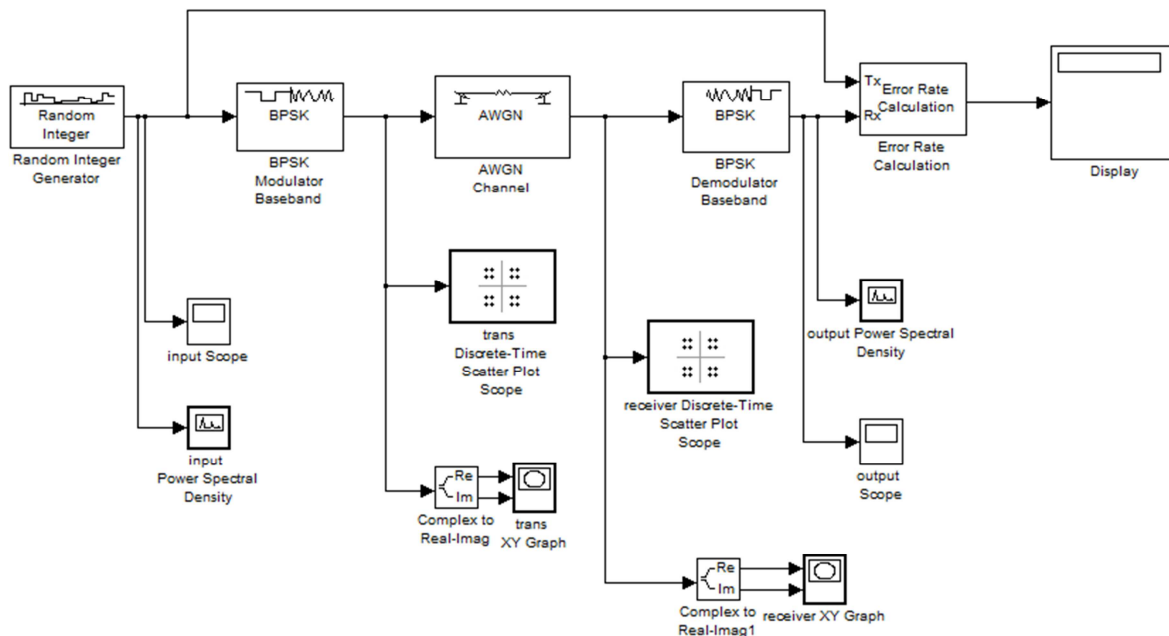


Fig. 2. Simulink model for BPSK Transmission.

- i. Set the simulation parameters (Simulation → Configuration Parameters) as follows:

- Start time to 0.0
- Stop time to 100.0
- Type to Variable-step
- Solver to discrete (no continuous states)
- Max. step size to auto

- ii. Run (Simulation → Start) the simulation and observe and save all plots and values in BER display for  $E_b/N_0$  set to 5db, 10db, 20db, and 30db.

- iii. Model and simulate again changing M- ary number of Random Integer Generator, M-PAM Modulator Baseband and M-PAM Demodulator Baseband modules to 4, 8, 16, 32 and 64.

### 3.2. Design Steps for M-ary PSK

- i. BPSK

- (1) Select the Random Integer Generator comm.
- (2) Select the BPSK modulator baseband module from the PM sub folder. Go to Communications Blockset → Modulation → Digital Baseband Modulation → PM sub-folder. Drag and drop BPSK Modulator Baseband module into the model and configure as in previous section.

The Simulink model for the BPSK Transmission is shown in Fig. (2)

- ii. Design steps for QPSK

- a Select the Random Integer Generator module from the Random data source block set

- b Select QPSK Modulator Baseband module and QPSK Demodulator Baseband module from *Digital Baseband Modulation* block set.

The Simulink model for QPSK is shown in Fig (3)

iii. Design steps for M-PSK

Model was designed using Simulink.

- (1) Select the Random Integer Generator module.
- (2) Select the M-PSK Modulator Baseband.
- (3) Select the M-PSK Demodulator Baseband.

Model and simulate again after changing M-ary number of Random Integer Generator, MPSK Modulator Baseband and M-PSK Demodulator Baseband modules to 4, 8, 16, 32 and 64. The MPSK design is shown in Fig (4)

### 3.3. Design Steps for M-ary QAM

- i. Select the Random Integer Generator module.
  - ii. Select the Rectangular QAM Modulator Baseband module.
  - iii. Select the Rectangular QAM Demodulator Baseband module.
- After running the simulation, observe and save all plots and values in BER display.

Model and simulate again changing M-ary number of Random Integer Generator, Rectangular QAM Modulator Baseband and Rectangular QAM Demodulator Baseband modules to 4, 8, 16, 32 and 64. The M-QAM Transmission Simulink model is shown in Fig (5)

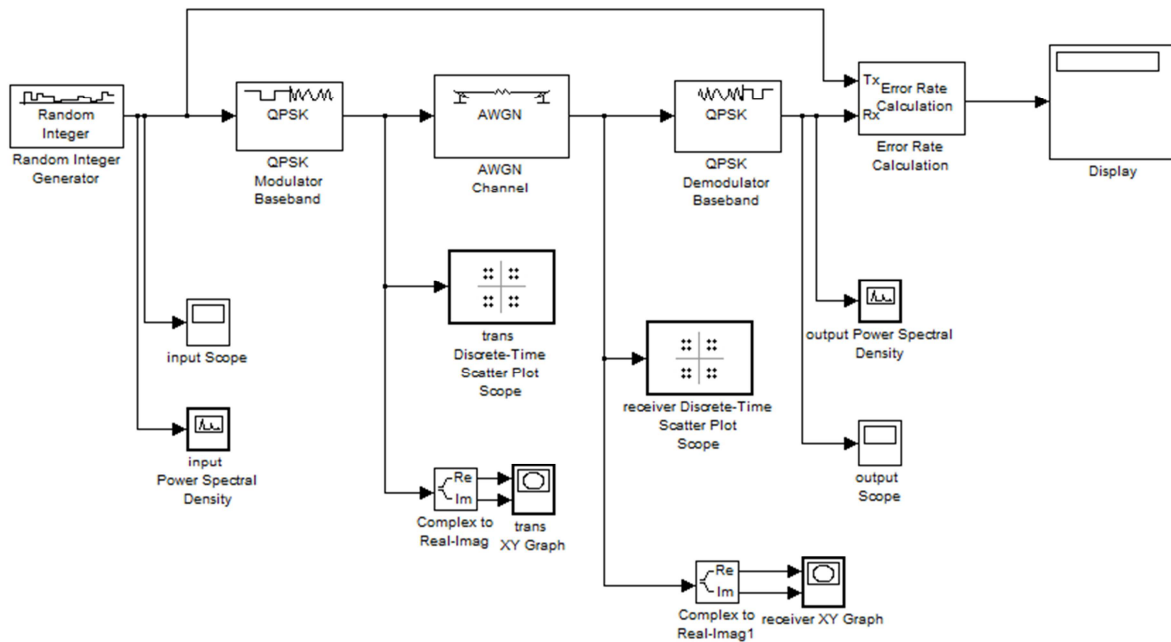


Fig. 3. Simulink model for QPSK Transmission.

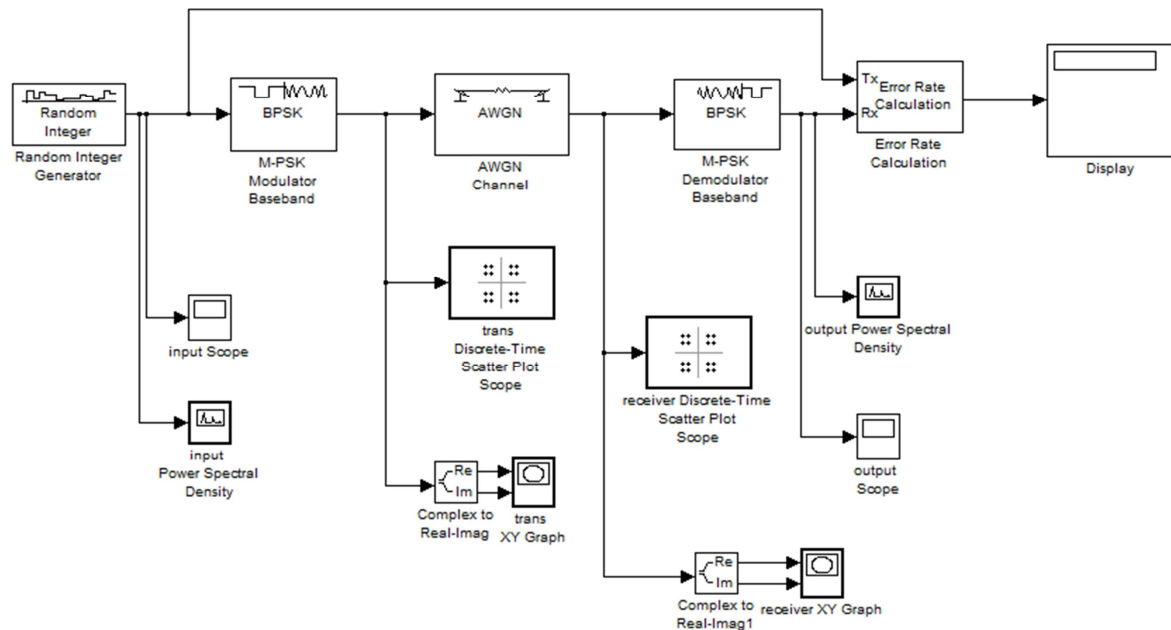


Fig. 4. Simulink model for MPSK Transmission.

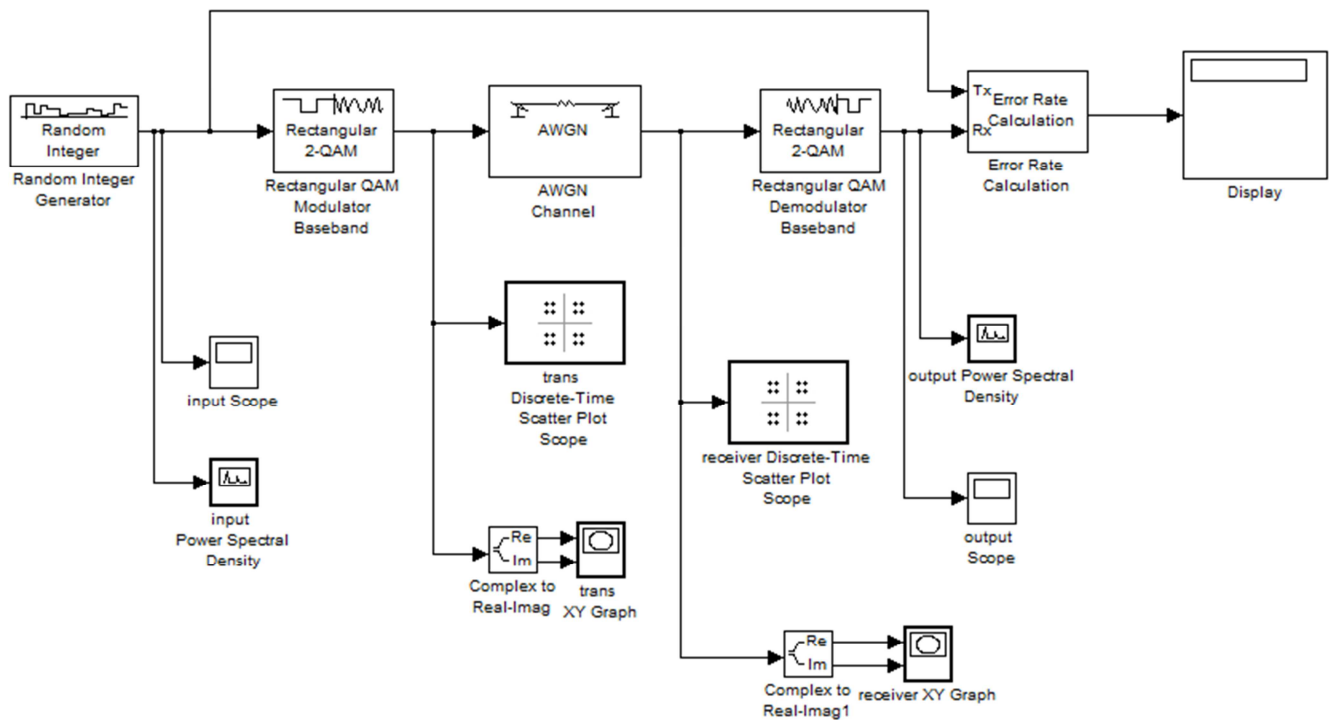


Fig. 5. Simulink model for M-QAM Transmission.

## 4. Results and Discussion

This section contains the designed systems experimentation, simulation and result analysis

### 4.1. Simulation Results of M-ary PAM

The BER for M-ary PAM for different values of  $E_b/N_0$  of the AWGN channel as obtained in this work is as shown in Table 1 below. The modified form is shown in Table 2. Fig 6 shows a graph of BER vs M-ary Number for M-PAM while Fig 7: A graph of BER vs  $E_b/N_0$  for M-PAM

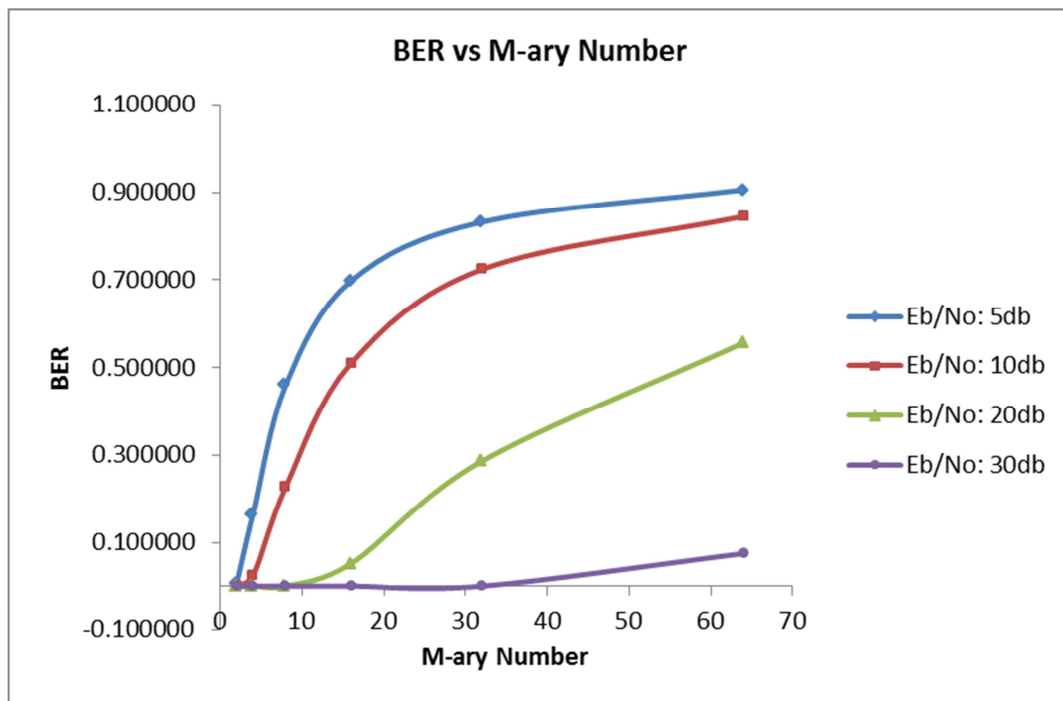


Fig. 6. A graph of BER vs M-ary Number for M-PAM.

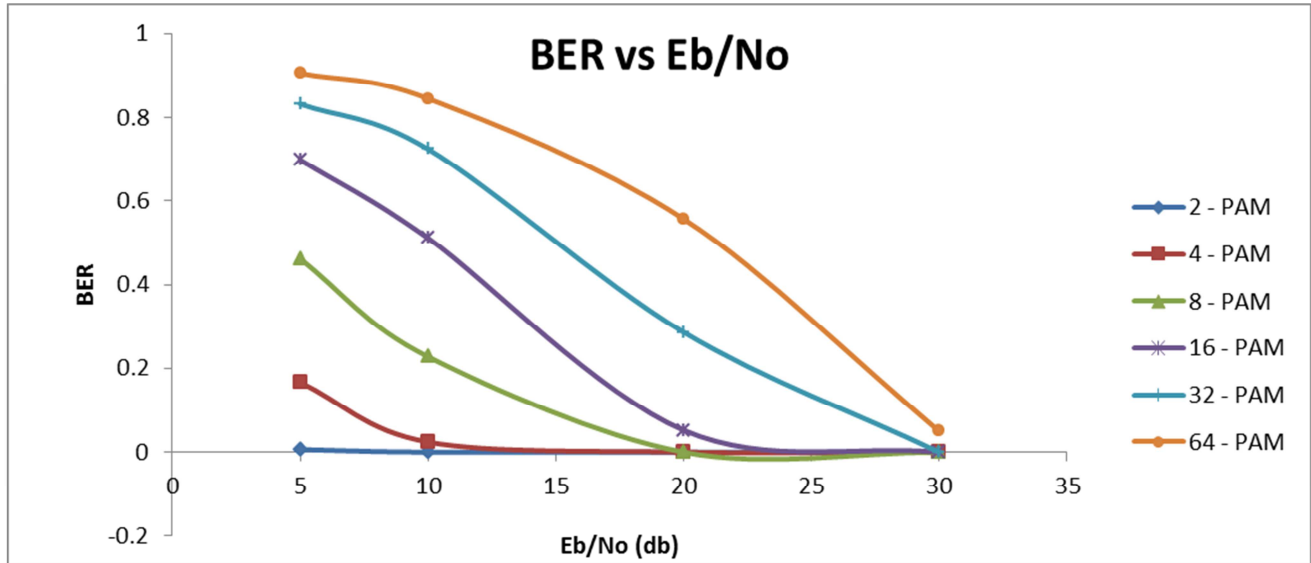


Fig. 7. A graph of BER vs Eb/No for M-PAM.

Table 1. BER values for M-ary PAM.

M-ary PAM: RESULT ANALYSIS								
M-ary Number	Bit Error Rate (BER)				Number of Errors (Ne)			
	Eb/No: 5db	Eb/No: 10db	Eb/No: 20db	Eb/No: 30db	5db	10db	20db	30db
2	0.005994	0	0	0	6	0	0	0
4	0.1658	0.02398	0	0	166	24	0	0
8	0.4605	0.2278	0	0	461	228	0	0
16	0.6983	0.5105	0.05195	0	699	511	52	0
32	0.8322	0.7243	0.2867	0	833	725	287	0
64	0.9061	0.8452	0.5564	0.07493	907	846	557	75

Table 2. Modified form of Table 1.

Eb/No	BER					
	2-PAM	4-PAM	8-PAM	16-PAM	32-PAM	64-PAM
5	0.005994	0.1658	0.4605	0.6983	0.8322	0.9061
10	0	0.02398	0.2278	0.5105	0.7243	0.8452
20	0	0	0	0.05195	0.2867	0.5564
30	0	0	0	0	0	0.0493

#### 4.2. Simulation Results from M-ary PSK Model

- (1) BPSK: The BER for M-ary BPSK for different values of  $E_b/N_o$  of the AWGN channel is shown in Table 3 below.
- (2) QPSK: The BER for Q-PSK for different values of  $E_b/N_o$  of the AWGN channel is shown in Table 4 below.
- (3) M-PSK: The BER for M-PSK for different values of  $E_b/N_o$  of the AWGN channel is shown in Table 5 below.

Table 3. BER values for BPSK.

M-ary Number	Bit Error Rate (BER)				Number of Errors			
	5db	10db	20db	30db	5db	10db	20db	30db
2	0.2028	0.06693	0	0	203	67	0	0

Table 4. BER values for QPSK.

M-ary Number	Bit Error Rate (BER)				Number of Errors			
	5db	10db	20db	30db	5db	10db	20db	30db
2	0.48651	0.29770	0	0	487	298	0	0
4	0.36863	0.15185	0	0	369	152	0	0

Table 5. BER values for M-PSK.

M-PSK: RESULT ANALYSIS								
M-ary Number	Bit Error Rate (BER)				Number of Errors (Ne)			
	Eb/No: 5db	Eb/No: 10db	Eb/No: 20db	Eb/No: 30db	5db	10db	20db	30db
2	0.2118	0.07393	0	0	212	74	0	0
4	0.3696	0.1459	0	0	370	146	0	0
8	0.5754	0.3556	0.002997	0	576	356	3	0
16	0.74426	0.5974	0.091908	0	745	598	92	0
32	0.85714	0.77123	0.34066	0.000999	858	772	341	1
64	0.91908	0.86114	0.59041	0.097902	920	862	591	98

Table 6. Modified form of Table 5.

Eb/No	BER					
	2-PSK	4-PSK	8-PSK	16-PSK	32-PSK	64-PSK
5	0.2118	0.2696	0.5754	0.74426	0.85714	0.91908
10	0.07393	0.1459	0.3556	0.5974	0.77123	0.86114
20	0	0	0.002997	0.091908	0.34066	0.59041
30	0	0	0	0	0.000999	0.097902

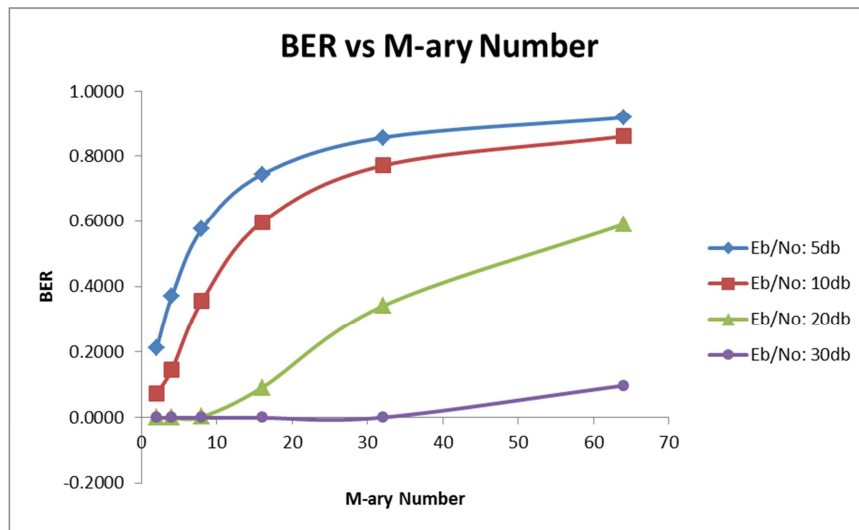


Fig. 8. A graph of BER vs M-ary Number for M-PSK.

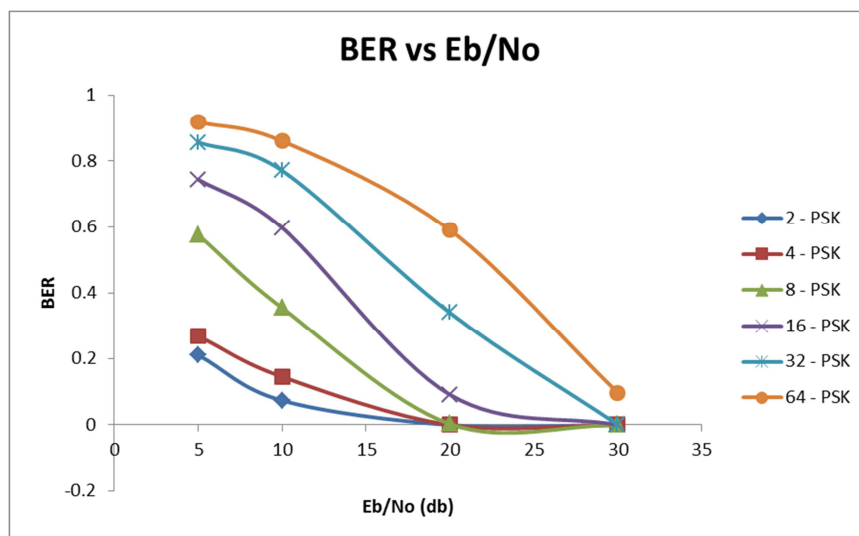


Fig. 9. A graph of BER vs Eb/No for M-PSK.



#### 4.3. Simulation Results from M-ary QAM Model

The BER for M-QAM for different values of  $E_b/N_0$  of the AWGN channel is shown in Table 7 below.

Table 7. BER values for M-QAM.

M-ary QAM: RESULT ANALYSIS								
M-ary Number	Bit Error Rate (BER)				Number of Errors (Ne)			
	$E_b/N_0$ : 5db	$E_b/N_0$ : 10db	$E_b/N_0$ : 20db	$E_b/N_0$ : 30db	5db	10db	20db	30db
2	2.2278E-01	7.8921E-02	0	0	223	79	0	0
4	3.7263E-01	1.5584E-01	0	0	373	156	0	0
8	6.7832E-01	4.8452E-01	2.1978E-02	0	679	485	22	0
16	7.9920E-01	6.1439E-01	6.4935E-02	0	800	615	65	0
32	8.6613E-01	7.3427E-01	1.5185E-01	0	867	735	152	0
64	9.2707E-01	8.7512E-01	4.0959E-01	9.9900E-04	928	876	410	1

Table 8. Modified form of Table 7.

$E_b/N_0$	BER					
	2-QAM	4-QAM	8-QAM	16-QAM	32-QAM	64-QAM
5	2.2278E-01	3.7263E-01	6.7832E-01	7.9920E-01	8.6613E-01	9.2707E-01
10	7.8921E-02	1.5584E-01	4.8452E-01	6.1439E-01	7.3427E-01	8.7512E-01
20	0	0	2.1978E-02	6.4935E-02	1.5185E-01	4.0959E-01
30	0	0	0	0	0	9.9900E-04

#### 4.4. Discussion of Results

In all the digital modulation schemes experimented on, it is observed from tables 1 - 8 and figures 6 – 11, BER decreases with the increase in the  $E_b/N_0$  value. Increasing the  $E_b/N_0$  value means increasing the signal power with respect to noise energy. The error rate is increasing as the value of M increases for the same  $E_b/N_0$  value that is,  $BER_{64\text{-PSK}} \geq BER_{32\text{-PSK}} \geq BER_{16\text{-PSK}} \geq BER_{8\text{-PSK}} \geq BER_{4\text{-PSK}} \geq BER_{2\text{-PSK}}$  for the same  $E_b/N_0$  value. This also applies to the other M-ary modulation schemes considered in this report. The error rate becomes constant after a certain value of  $E_b/N_0$  in all the modulation

schemes considered for this study through the normal AWGN channel. The value of M increases means more number of bits are combined to make a symbol and these bits are packed more closely in signal constellation. From this experiment, it is proven that between the different M-ary modulation schemes experimented with, M-PAM has the lowest bit error rate within the same  $E_b/N_0$  value of the AWGN channel used with the other modulation schemes considered in the study. Between BPSK, QPSK, and M-PSK, BPSK has the lowest bit error rate within the same  $E_b/N_0$  values. Based on the results obtained from this research, for digital amplitude modulation, M-PAM offers a better BER than M-QAM. This in turn, translate to better transmission of the integrity of the signal.

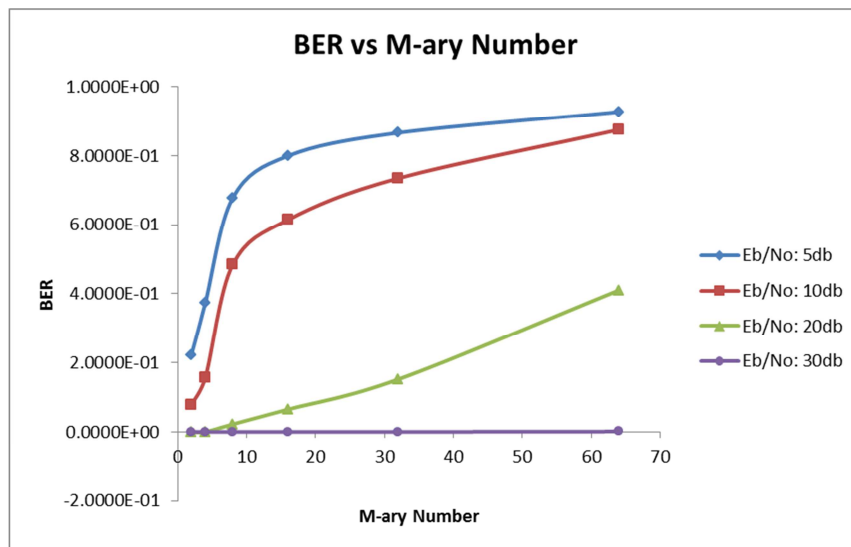


Fig. 10. A graph of BER vs M-ary Number for M-QAM.



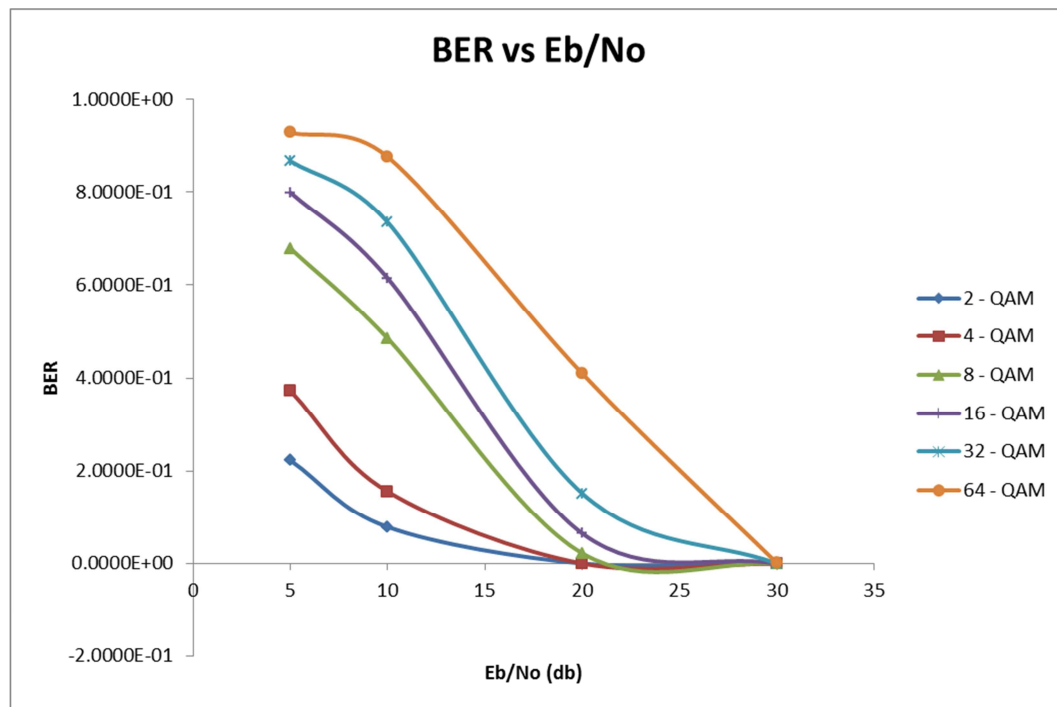


Fig. 11. A graph of BER vs  $E_b/N_o$  for M-QAM.

## 5. Conclusion

This paper has successfully dealt with the digital modulation schemes and their effect on bit error rate (BER); and to ascertain which has the lowest bit error rate. The bit error rates of various digital modulation schemes using the M-ary modulation technique were compared, the effect of varying signal energy per bit to Noise ratio ( $E_b/N_o$ ) on the error rate of various digital modulation schemes was analysed. From this research, M-PAM and BPSK offer better BER and better coverage integrity of the signal as it is transmitted along an AWGN channel.

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