

Communication Engineering Term Project

(Simulation of 16QAM)

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ABSTRACT

A 16-QAM model for term project of communication engineering is presented. It has been simulated by MATLAB. The simulated performance of this 16-QAM system is measured by calculating the BER vs $1/N_0$, where N_0 is the variance of AWGN. The feature of AWGN is assumed that zero mean and N_0 variance. Calculated results of each part of 16-QAM system are presented by time domain figures.

1. Introduction

The QAM(Quadrature Amplitude Modulation) is the method using at the high speed digital modulation mainly. This method is used for improving the transmitting efficiency on the limited bandwidth. To achieve this performance the carrier signal in the QAM system is modulated by combination of amplitude and phase. It is also called Multi-level modulation. For example, in case of 16-QAM system the carrier signal is modulated by the types of 12 phase($\pi/6$) and then 4 types among these 12 phases have 2 types of amplitudes. Therefore it can present 16 types of information. Each symbol is distinguished as 16 levels and that is correspond to 4 bits.

The frequency efficiency of QAM is better than PSK(Phase Shift Keying) and QPSK(Quadrature Phase Shift Keying). And the transmitting rate is 4 times, 2 times better than PSK, QPSK, respectively. Also the realizatin of receiver and demodulation easy relatively. But it is sensitive about the error occur by something such as noise and fading.

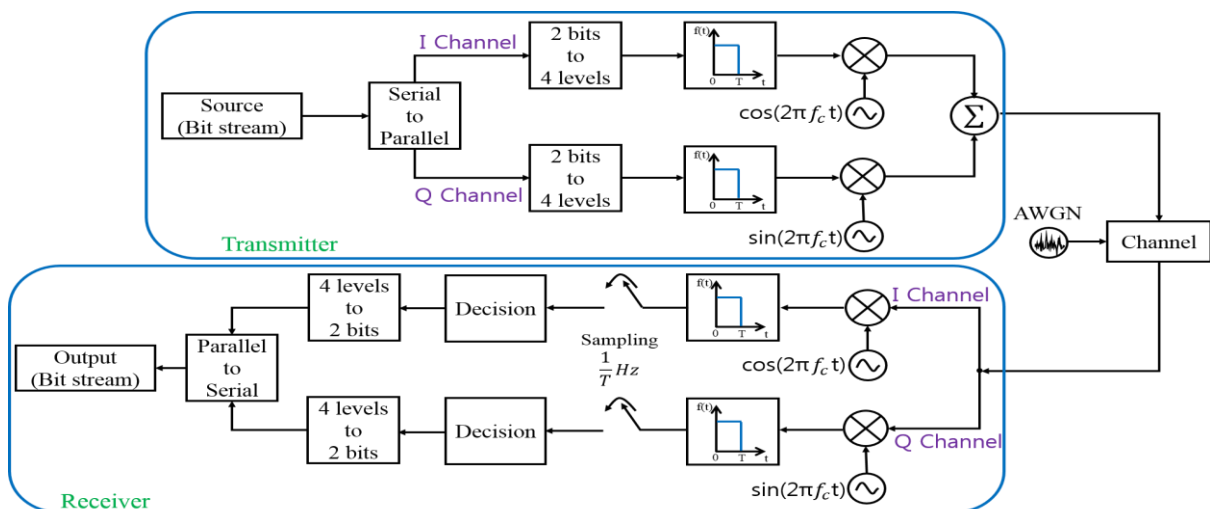


Fig. 1 Block diagram of 16-QAM system simulated in this paper

Fig. 1 shows that the whole 16-QAM system simulate in this paper.

In the following sections, the whole 16-QAM system simulated by using MATLAB is explained concretely.

2. Transmitter

The data generated from the source is bit stream. This data is splitted from serial to parallel by the ‘Serial to Parallel’ block. In case of 16-QAM system each 2 bits among 4 bits is splitted to 2 channels, I – channel and Q – channel. And these 2 bits are mapped to 4 levels at the each channel. This process is presented in Fig. 2.

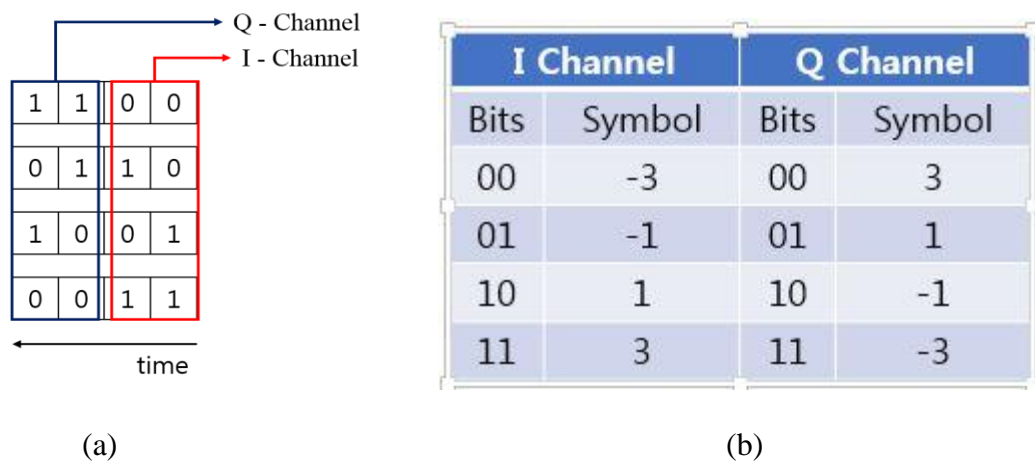


Fig. 2 The process of (a) Serial to Parallel block and (b) 2 bits to 4 levels block

As shown in Fig. 2 (a) the first 2 bits among the 4 bits are splitted to I – channel and then these 2 bits are mapped to 4 level symbols such as Fig. 2 (b). Based on the mapping like this we can expect the 16-QAM constellation plot as shown in Fig. 3.

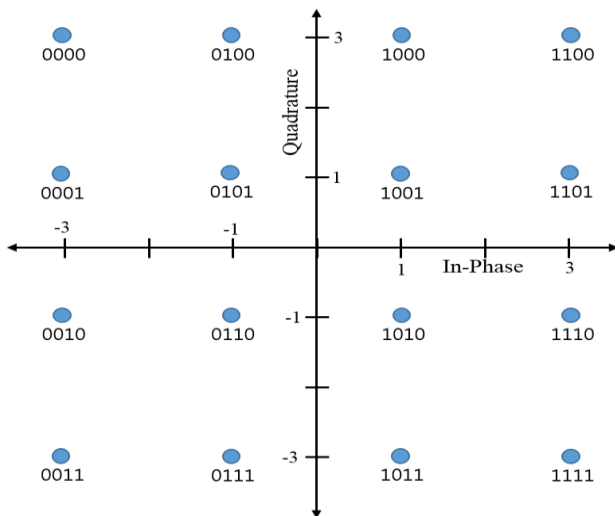


Fig. 3 The constellation plot of 16-QAM

As a result we can determine the symbol set a_n, b_n in I – channel, Q – channel

respectively :

$$a_n = \{-3, -1, 1, 3\}$$

$$b_n = \{-3, -1, 1, 3\}$$

We can decide in the receiver part of 16-QAM system by using this constellation plot Fig. 3. The result of the constellation plot is presented next section.

After mapping from the bits to symbols, the symbols are passed through the rectangular shape filter, $f(t)$. The result is the convolution between symbols and rectangular shape filter as shown in Fig. 4.

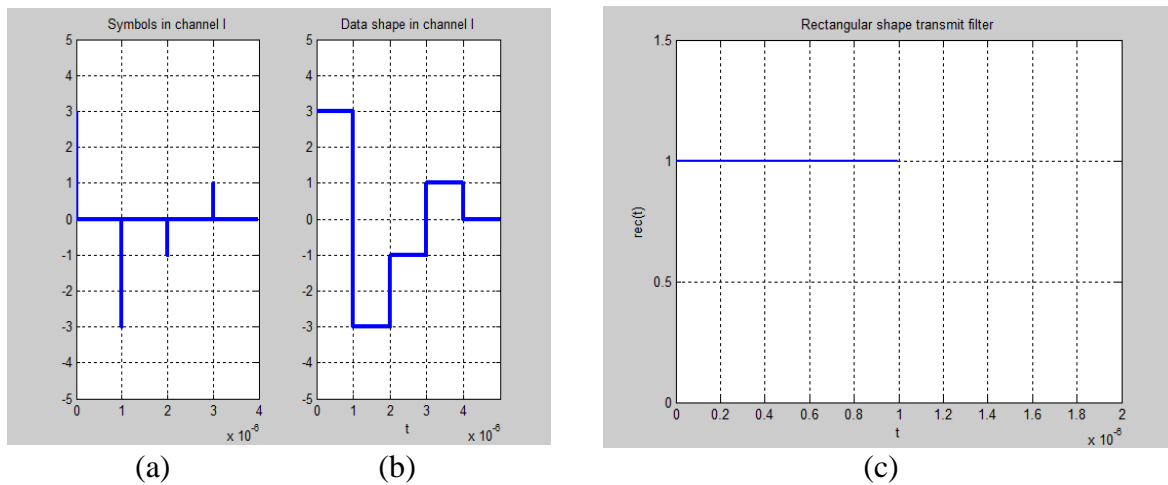


Fig. 4 The signal (b) is the result from convolution between symbols (a) and rectangular shape filter (c)

As a result we can determine the symbol rate, baud [symbols/sec]:

$$\text{baud [symbols/sec]} = \frac{1}{T}, \quad \text{where } T = 10^{-6} \text{sec}$$

This rectangular shape filter will be used in the receiver part for processing before the sampling and decision. It is discussed next section. The signal of Fig. 4 (b) is multiplied by carrier signal to transmit over the wireless channel. By multiplying with the carrier signal, we can implement the frequency up-conversion. The carrier signal is different according to the channel. The I – channel and Q – channel are multiplied by $\sqrt{\frac{2}{T}}\cos(2\pi f_c t)$ and $\sqrt{\frac{2}{T}}\sin(2\pi f_c t)$, respectively where $\sqrt{\frac{2}{T}}$ is energy factor to make the energy of carrier to unity and the frequency f_c is 20 times more than symbol rate. In case of I – channel, the result of multiplying with carrier signal is shown in Fig. 5 (a). The transmitting signal is generated by adding the signals from I – channel and Q – channel. The transmitting signal is

$$\text{Tx Signal} = a_n \sqrt{\frac{2}{T}} \cos(2\pi f_c t) + b_n \sqrt{\frac{2}{T}} \sin(2\pi f_c t)$$

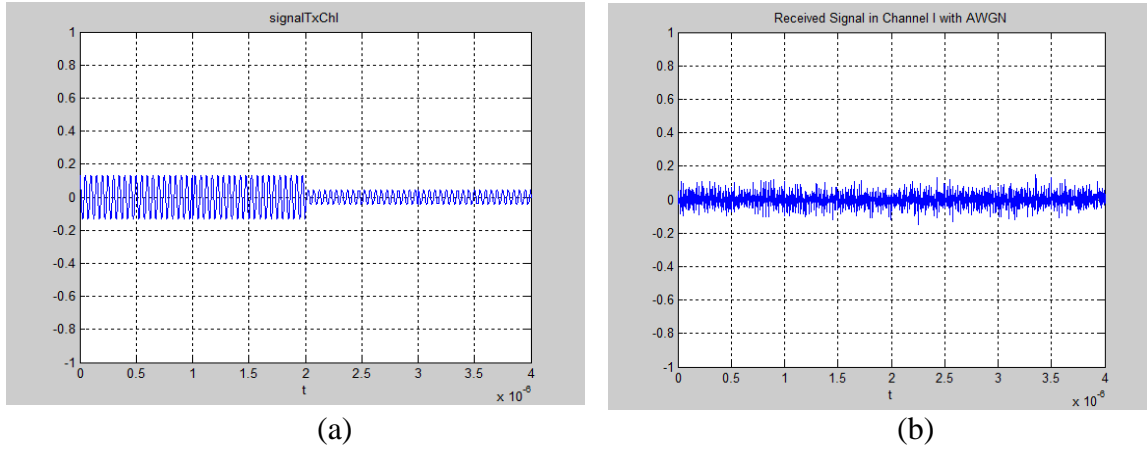


Fig. 5 (a) The result signal of multiplying with carrier signal (the energy of carrier signal is 1), (b) the signal after multiplying with carrier signal in part of receiver

This signal of Fig. 5(a) pass through the noisy channel that the mean and variance are zero and N_0 respectively. The channel noise, AWGN affect the decision of signal in the receiver part. Therefore it can occur error of communication system.

3. Receiver

The received signal added AWGN is splitted to 2 channel, I – channel and Q – channel. And then signal is mutiplied with carrier signal, $\sqrt{\frac{2}{T}}\cos(2\pi f_c t)$ and $\sqrt{\frac{2}{T}}\sin(2\pi f_c t)$ in the I – channel and Q – channel, respectively. The result of this process is shown in Fig. 5(b). As shown in Fig. 5(b) the signal is distorted by AWGN. In cae of Fig. 5(b), the characteristic of noise is that zero mean and $\frac{1}{N_0} = 1\text{dB}$. The received signal is

$$\text{Rx Signal} = a_n\sqrt{\frac{2}{T}}\cos(2\pi f_c t) + b_n\sqrt{\frac{2}{T}}\sin(2\pi f_c t) + n(t) , \text{ where } n(t) \text{ is AWGN}$$

In the case of I – channel, the signal after multiplying with $\sqrt{\frac{2}{T}}\cos(2\pi f_c t)$ is

$$a_n\frac{2}{T}\cos^2(2\pi f_c t) + b_n\frac{2}{T}\sin(2\pi f_c t)\cos(2\pi f_c t) + n(t)\cos(2\pi f_c t)$$

The signal after multiplying with carrier signal, Fig. 5(b) is passed through the matched filter same as the rectangular shape filter using part of transmitter Fig. 4(b). The result of this process is the convolution between the signal, Fig. 5(b) and the matched filter, Fig. 4(b). This result is represented in Fig. 6(a).

And then we can obtain the symbols by sampling the signal passing through the matched filter. The sampled value at each $T(10^{-6}\text{sec})$ is represented as sum of the amplitude over the period $T(10^{-6}\text{sec})$. Therefore we can obtain the symbol set a_n, b_n using the equation (1). In the equation (1), the term of b_n is zero by orthogonal property. Therefore the a_n term and noise term are remained. Similarly in case of Q – channel, b_n term and noise term are

remained. The result of this process is shown in Fig. 6(b).

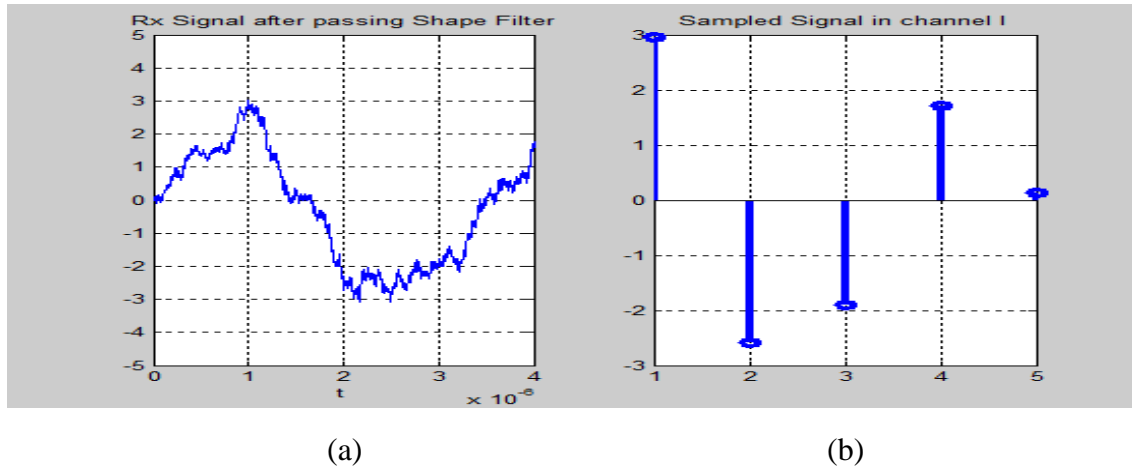


Fig. 6 (a) the signal after matched filter (convolution between signal and matched filter), (b) the signal after sampling the signal (a) at each $T(10^{-6}sec)$

$$\begin{aligned}
 \text{Sampled signal} = & a_n \int_0^T \frac{2}{T} \cos^2(2\pi f_c t) dt \\
 & + b_n \int_0^T \frac{2}{T} \sin(2\pi f_c t) \cos(2\pi f_c t) dt \\
 & + \int_0^T n(t) \cos(2\pi f_c t) dt \dots\dots\dots(1)
 \end{aligned}$$

We can plot the constellation plot of 16-QAM by based on these sampled symbols in several changes of variance of AWGN. The plot of the constellation is shown in Fig 7.

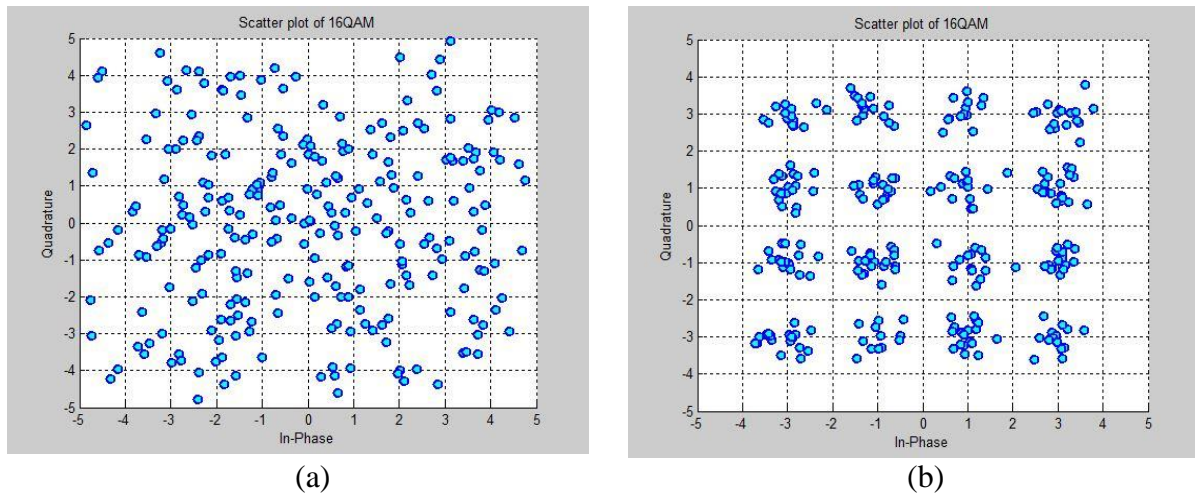


Fig. 7 The constellation plot of 16-QAM (a) $\frac{1}{N_0} = 1dB$, (b) $\frac{1}{N_0} = 10dB$

As shown Fig. 7 when the $\frac{1}{N_0}$ is 1dB Fig. 7(a), the points lie around. Therefore we can't decide the right value of symbols. We can say there exist lots of noise which interfere the accurate communication. On the contrary to this when the $\frac{1}{N_0}$ is 10dB Fig. 7(b), the points are concentrated at the points shown in Fig. 3. It means that there are small number of error in

the 16-QAM communication.

4. Result

We have discussed about the each composition of 16-QAM system simulated in this paper so far. And we have seen the result of constellation plot for measurement of communication performance according to $\frac{1}{N_0}$. In this section we will see the other performance measurement, plot of $P(e)$ vs $\frac{1}{N_0}$. $P(e)$ is the probability of making bit errors. This $P(e)$ is measured as

$$P(e) = \frac{\text{the number of bit decision errors}}{\text{the total number of bits}}$$

We will compare the $P(e)$ vs $\frac{1}{N_0}$ plot between the result of simulation and theoretical result. The results are shown in Fig. 8.

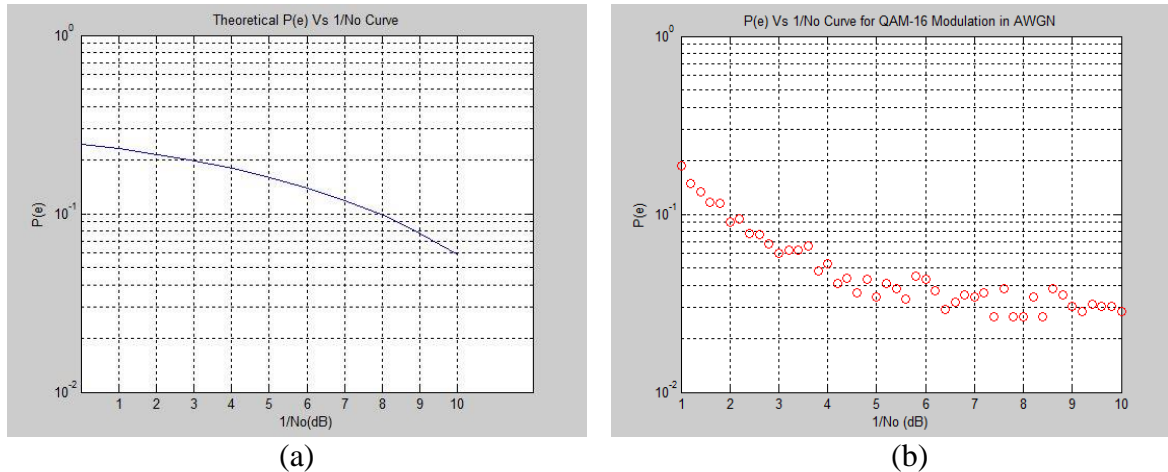


Fig. 8 The plots of $P(e)$ vs $\frac{1}{N_0}$ (a) theoretical result, (b) simulation result

As shown in Fig. 8, the plot of simulation result Fig. 8(b) is similar to the plot of theoretical result Fig. 8(a). It means that this simulation is operating as well. Therefore this simulation of 16-QAM system has good performance than PSK and QPSK about the frequency efficiency and transmitting rate.