3rd International Conference on Communication and Information Processing (ICCIP-2021)
Available on: SSRN
(SSRN is an open-access online preprint community, owned by Elsevier.)

Simulation of M-ary QAM and M-ary PSK Modulation Techniques Using MATLAB GUI

Pranjal Dwivedi[a], Alok Ranjan[a], Ashish Srivastava[a]*

[a]*Department of Electronics &Telecommunication, MIT Academy of Engineering, Pune, India*

Abstract

The world has seen a transformation due to the recent pandemic. The field of education is drastically affected by it. There is a need to move from classroom teaching to online teaching, and the biggest hurdle is to impart practical knowledge. This paper attempts to study the concepts like M-ary Phase shift keying (PSK) and M-ary Quadrature amplitude modulation (QAM), used in modern-day communication systems, using a simulation platform. For this purpose, simulation using a graphical user interface (GUI) is proposed to study various M-ary PSK and M-ary QAM types. MATLAB is used to implement the GUI. The modulation, transmission, demodulation, and recovery of a signal implemented through the GUI will help learners understand the concepts better. Moreover, the constellation diagrams for M-ary PSKs and M-ary QAMs can be examined using the developed GUI.

Keywords- Phase Shift Keying (PSK), Quadrature Amplitude Modulation (QAM), Constellation diagram, Graphical User Interface (GUI)

1. Introduction

The field of digital communication is growing and evolving rapidly, modulation techniques and their enhancements have become important. The digital modulation techniques must be tested and analyzed using the latest mathematical simulation platforms for improvements and effectiveness. With the development of communication techniques, the demand for reliable and fast data transmission has increased, which is also a reason for the simulation and analysis of these modulation techniques. Now that we know about increasing the data rate by changing the envelope, phase, and frequency of the carrier signal, different digital modulation schemes based on keying techniques are used to implement digital communication systems. These modulation schemes map the baseband data into more than four possible carrier signals because the degrees of freedom are two, i.e., phase and amplitude. In M-ary signaling, two or more bits are grouped, and symbols have some energy associated with them, known as symbol energy. The number of signals that can be generated is given by $M=2^m$, where m is an integer indicating the number of bits. Different modulation types like amplitude shift keying,

* Corresponding author.
E-mail address: aksrivastava@entc.mitaoe.ac.in

frequency-shift keying, and phase-shift keying exist depending on whether the amplitude, phase, or frequency is changed. The modulation technique is called Quadrature Amplitude Modulation (QAM) when the amplitude and phase are varied.

These days communication systems are studied through the simulation environment Sadinov et al., 2017. Implementation and calculation of the BER of M-PSK and M-QAM can be done using the signal space approach Lu et al., 1999. Laboratory sessions can be conducted in three ways, first, the live hands-on sessions, second, through simulation, and third remote laboratories Nickerson et al., 2006. Conducting laboratory sessions for engineering education needs a careful lookout, with detailed dos and don'ts Krivickas et al., 2007. A different approach needs to have opted for teaching-learning in distance learning mode Tomei, 2010. Digital communication experiments can have a wide range of concepts from basics to complex like jamming Wickert, 2011. MATLAB is used as the simulation platform and is a suitable platform for explaining wireless communication concepts to undergraduate students Zheng et al., 2007. Simulink being graphical, this programming environment gives good visualization of the results Hirst et al., 2013. The advanced applications of digital communication can be designed using MATLAB Yuting et al., 2010. The GUI can be converted to a mobile application for ease of access. Also, GUI will help in increasing learning efficiency. Interactive learning software can improve the learning experience of the students Naim et al., 2016. The programming approach can help the learners to understand software engineering Douglas 2005. The further sections elaborate on the concerning theory and methodology that were undertaken to implement the idea presented in the paper. The second section describes the considered modulation technique along with the role of noise in the communication system. The third section deals with the discussion and interpretations of the developed GUI. The conclusion drawn through the implementation and execution of is the presented idea is elaborated in the fourth section.

2. The Modulation Techniques

The section describes the theory behind the considered modulation technique and methodology opted to implement the GUIs. It is essential to emphasize the importance of M-ary encoding and the modulation techniques. The section concludes with a brief description of noise in the communication system in general and developed GUI in particular.

2.1. M-ary Encoding

To represent a signal using more than two bits, we use the word *M-ary*. The term M defines the number of bits being used to transmit one symbol, and it also gives an insight into the combinations and energy levels. M-ary encoding plays a critical role in digital modulation and communication. It improves the SNR, increases power and bandwidth efficiency in a modulation scheme. Different M-ary encoding is used in the digital world. Due to the features mentioned above, the encoding techniques are known with specific names. For instance, a 2-ary Phase Shift Keying modulation (2-PSK) is known as Binary Phase Shift Keying. Similarly, 4-PSK is known as Quadrature Phase Shift Keying.

In these modulation techniques, two or more bits are considered together to form a symbol, and the symbols $S_1(t)$, $S_2(t)$, ……, $S_m(t)$ are transmitted during the symbol period T. The possible number of signals depends on the value of M.

These modulation techniques find attractive application in the band-limited channels because of their higher bandwidth efficiency at the expense of power efficiency. There are certain drawbacks of these modulation techniques, like, poor error performance because of the minimal separation between the signals. Another

important point that needs to be taken into consideration is the bit rate and baud rate. Different modulation techniques result in different baud rates, which vary the bandwidth requirement of the signals.

As the value of M goes on increasing for a particular modulation scheme, the number of bits transmitted per symbol also increases, the resulting combination of bits forming a signal increases and, in turn, increasing the constellation points in a constellation diagram. With the rise in the constellation points, there tends to be some inter symbol interference (ISI) between the points. This results in distortion and corruption of the transmitted signal as the decision boundary of one symbol start interfering with the other symbols' boundary.

2.2. BPSK

It is a two-phase modulation. A binary message with 0 and 1 is represented by two different phase states, i.e., 0º and 180º for 0 and 1, respectively. For generating a BPSK signal, a basis function is chosen. Once we get the basis function, any vector present in the signal space can be represented as a linear combination of this function. In BPSK the modulation is done by varying the phase of the basis function depending on the message bits. The phase states of the carrier signal can be represented as follows:

$$S_1(t) = A_c \cos 2\pi f_c t\,, \qquad 0 \le t \le T_b \; for \; binary \; 1 \tag{1}$$

$$S_0(t) = A_c \cos(2\pi f_c t \pm \pi)\,, \qquad 0 \le t \le T_b \; for \; binary \; 0 \tag{2}$$

Here A_c represents the amplitude of the sinusoidal signal, f_c is the carrier frequency calculated in Hz, t is the instantaneous time in seconds, and T_b is the bit period in seconds. The signals S_0 and S_1 denote the modulated signal when information 0 and 1 are transmitted, respectively.

The BPSK transmitter can be implemented using the nonreturn to zero (NRZ) polar coding method and multiplying the output by a reference oscillator running at carrier frequency f_c. In this case, it is convenient to choose the oversampling factor as the ratio of sampling frequency (f_s) and the carrier frequency (f_c).

2.3. QPSK

In this modulation technique, two information bits that are combined as one symbol are modulated. The modulator is required to select one of the four possible carrier phase shift states. A QPSK signal with a symbol duration T is defined as:

$$S(t) = A_c \cos(2\pi f_c t + \theta_n), \qquad 0 \le t \le T \; for \; n = 1, 2, 3, 4 \tag{3}$$

and the signal phase is defined as:

$$\theta_n = (2n - 1)\pi/4, \tag{4}$$

Therefore, the possible phase outcomes are π/4, 3π/4, 5π/4 and 7π/4. Equation [4] above requires two orthogonal basis functions, which are in-phase and quadrature signaling points.

For the generation of a QPSK signal, a splitter is used to separate the odd and even bits from the generated information bits. The odd bits and even bits are converted to NRZ polar at the same time. It is to be noted here that the BPSK modulation requires a symbol duration same as that of bit duration, but when QPSK is used, the

symbol duration becomes twice as that of bit duration. Hence, QPSK sends a message at a rate that is twice as compared to the BPSK.

2.4. M-ary QAM

Quadrature amplitude modulation is a modulation technique that encodes the information or message signal with the carrier signal by varying the carrier signal's amplitude and phase. The carrier signal is subdivided into two signals which are 90^{o} out of phase from each other. These signals are termed In-phase and Quadrature phase signals. Since both the amplitude and phase are constantly varied, the signal envelope is not constant and has a higher bandwidth efficiency than other M-ary signaling schemes with the same power consumption. Suppose M_1 and M_2 represent the number of possible values of amplitudes and phases, respectively. The total number of bits per symbol transmitted is the combination of amplitude and phase modulation and is given by $log_2(M_1M_2)$.

Constellation diagram is used for graphical representation of the envelope of the state of the symbol and is considered an essential tool in analyzing the performance of QAM. The x-axis and the y-axis of the diagram represent the in-phase and the quadrature-phase components of the modulated signal, respectively. The separation between the signals in the constellation diagram tells us about the difference between the modulation schemes and how the receiver distinguishes them.

To measure the modulation schemes' performance, one needs to calculate the bit error rate (BER) while assuming that the systems contain additive white Gaussian noise (AWGN).

2.5. Noise

Noise is the unwanted electrical signal that is present in almost every electrical system. It interferes with the signal and leads to improper or distorted production and reception of the transmitted signal. Due to this, interference generates specific errors in the signal analysis and affects the sensitivity of receivers.

The noise is present in almost all communication systems and is the primary disturbance in those systems. AWGN has typically zero mean. The deviation of the received signals with noise increases with an increase in the variance. This noise is used to model any communication systems where the noise interferences are kept in check.

3. Results and Discussions

A Graphical User Interface Development Environment (GUIDE) can be used to create custom applications and user interfaces. A GUI can be made by dragging and dropping components. GUIDE generates two files, one contains layout information, and the other has implementation code. The simulation of discussed modulation techniques through GUIs was developed comprising a random signal, converting it into integer representation, modulation using inbuilt MATLAB functions, adding noise, simulation of the channel, demodulation using the inbuilt MATLAB function.

The GUI can also take desired inputs from the user and simulate the modulation and demodulation to show the results. Different parameters can be studied and analyzed through the developed GUI. Used parameters paved the way to compare the modulation techniques. The GUI of the modulation techniques along with constellation diagram was developed with the help of ‘push button’, ‘box’ and ‘axes’ widgets in MATLAB.

Various modulation techniques, including BPSK, QPSK, and QAM, can be learned using the options available on the GUI, as seen in Figure 1.

Figure 1 shows in-phase, and quad-phase components of the signal are depicted separately along with the combined modulated signal. From this figure, different phases can be observed at the message transitions from 0 to 1 or 1 to 0. Similarly, we can obtain BPSK, 8-PSK, and 16-PSK modulated signals by clicking on the corresponding push button on the GUI. On clicking the "Navigate to QAM" push button, the other GUI for QAM will open. In the second GUI, options for 4, 8, 16, and 64 QAM are provided. The learner can click on the desired technique to be studied. For example, on clicking the push button for 8-QAM, the results of this will pop up, as shown in Figure 2. A message signal is shown in the digital format (in terms of bits). The number of symbols is represented in terms of discrete signals in which there are M number of distinct amplitude levels. The symbols are separated by fixed symbol duration. Modulated signals in analog form can also be seen in the figure. In the same GUI for 8-QAM, the constellation diagram is also depicted. The reference constellation is adjusted to the desired constellation. Eight yellow points represent the transmitted symbol. The distance between each point and origin is different, which specifies the change in amplitude. Similarly, each point is located at a different location and specifies the phase change. With the help of the constellation diagram, the learner can easily find out the Euclidian distance for a particular modulation scheme.

Through Figure 3, the 16-QAM can be studied, and it gives the learner a better insight for understanding the modulated signal and the constellation diagram. The different information signal in digital format is considered as an input for the 16-QAM. Here also one can observe sixteen different amplitude levels in symbol representation in discrete form. Continuous, modulated signal can also be seen in Figure 3.

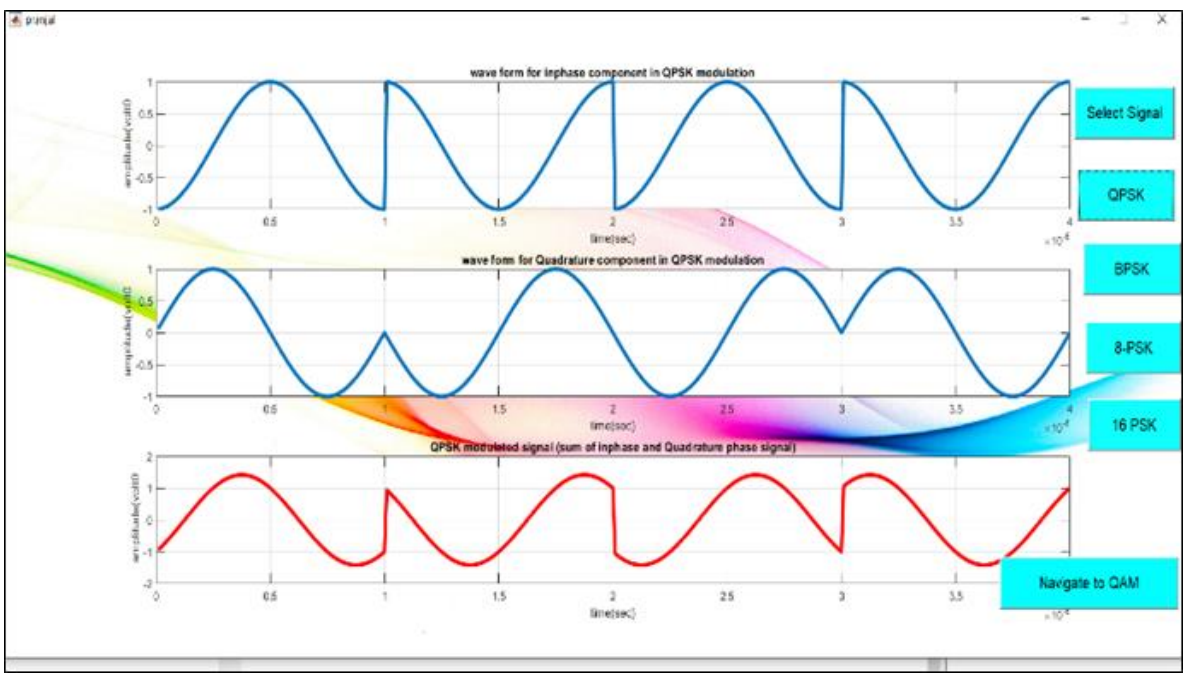

Fig. 1. In-phase, Quad-phase, and Modulated QPSK Signal

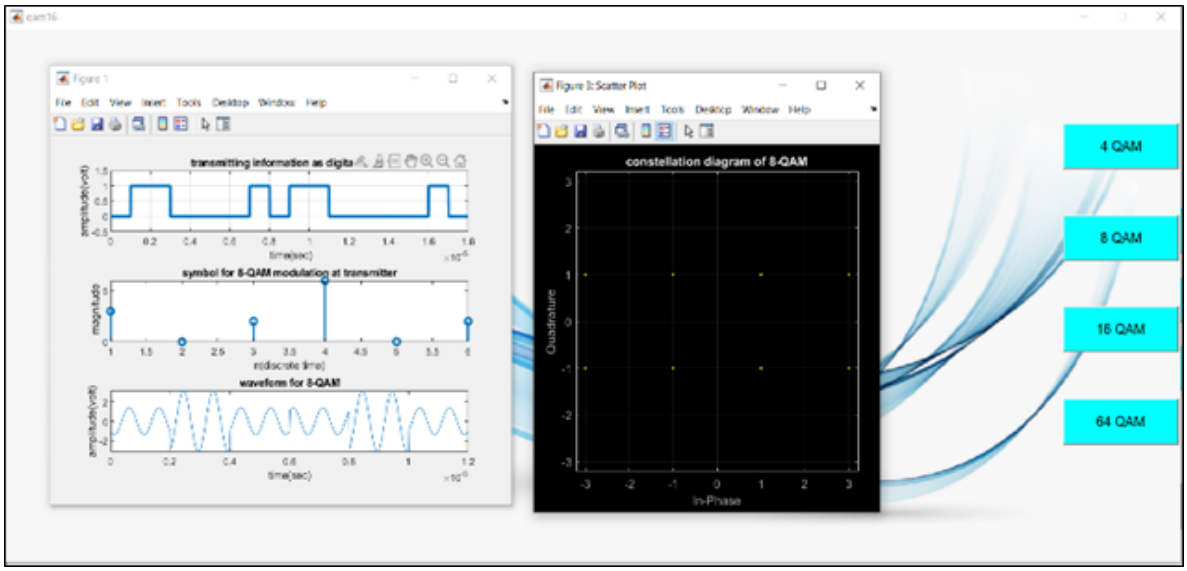

Fig. 2. 8-QAM Modulated Signal with Constellation Diagram

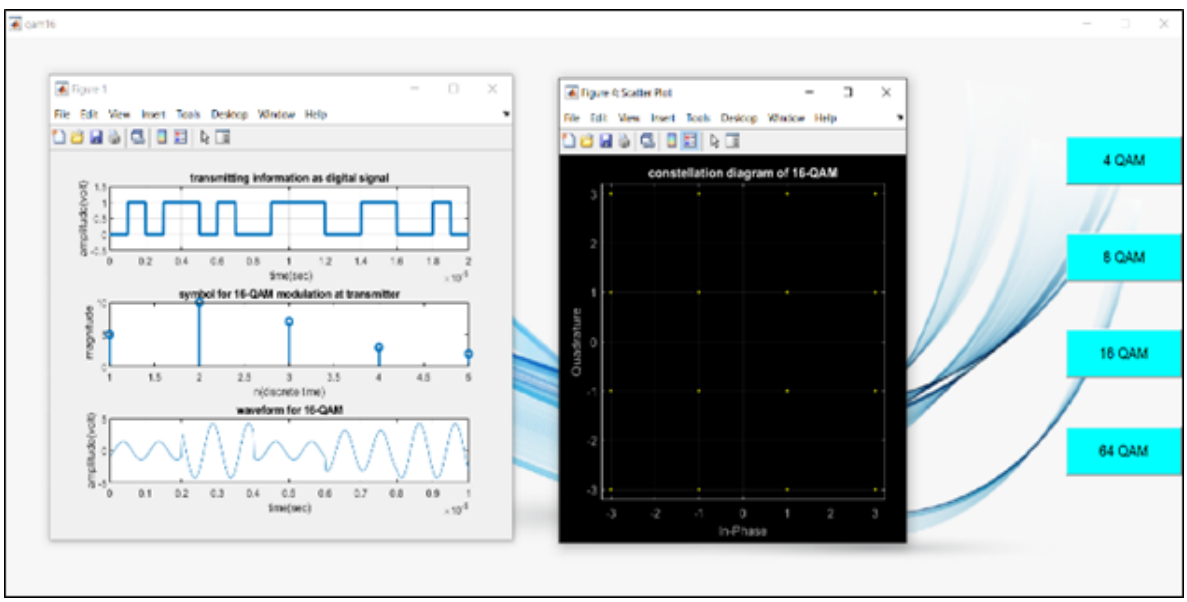

Fig. 3. 8-QAM Modulated Signal with Constellation Diagram

4. Conclusions

The paper elaborates the M-ary modulation techniques using MATLAB environment. The motivation for the paper's central theme was employed from the fact that practical teaching has been very difficult in pandemic situations and will raise an alarming situation if something is not done. Teaching-learning through the use of the developed GUI will efficiently help the students to visualize and understand different modulation schemes. The modulations considered are phase shift keying variants (BPSK, QPSK, 8-PSK, 16-PSK) and Quadrature Amplitude Modulation (4-QAM, 8-QAM, 16-QAM, 64-QAM). The developed GUIs will provide a better learning experience to the learner. The results show different stages of modulation of the message signal. The constellation diagram of the received signal after passing through the channel in the presence of noise can also be observed. With the increase in modulation order, Euclidian distance decreases; thus bit error rate increases. The lower value of modulation has disadvantages such as transmission problems, lesser bandwidth efficiency, and lesser power efficiency. The theoretical concepts of digital modulation techniques can be taught to a learner using the developed GUI for an improved learning experience without compromising on practical aspects in online or distance learning mode.

References

S. M. Sadinov, May 22- 26, 2017, "Simulation Study of M-ARY QAM ModulationTechniques using Matlab/Simulink." MIPRO 2017, Opatija, Croatia

Jianhua Lu, K. B. Letaief,, Justin C-I Chuang, and Ming L. Liou, 2nd February 1999, "M-PSK and M-QAM BER Computation Using Signal-Space Concepts", IEEE Transactions On Communications, Vol. 47, No.

J. Ma and J. Nickerson, pp. 1-24, 2006, "Hands-On, Simulated, and Remote Laboratories: A Comparative Literature Review," Journal of ACM Computing Surveys, vol. 38, no. 3.

R. Krivickas and J. Krivickas, 2007, "Laboratory Instruction in Engineering Education," Global Journal of Engineering Education, vol. 11, no. 2, pp. 191-196.

Lawrence A. Tomei, 2010, Designing Instruction for the Traditional, Adult, and Distance Learner: A New Engine for Technology-Based Teaching, Information Science Reference, New York, USA.

M. Wickert, 2011 IEEE, 2011, "Digital Communication with Jamming Experiments for a Signal Processing First Course," Digital Signal Processing Workshop and IEEE Signal Processing Education Workshop (DSP/SPE), pp.101-106.

J. Z. Zhang, R.D. Adams & K. Burbank,2007 UICEE, "Using MATLAB to Improve Learning Effectiveness and Quality in an Undergraduate Course on Wireless Communications and Systems," Global J. of Engng. Educ., Vol.11, No.1, Australia, pp. 45-54.

Brice A. Hirst and Yahong R. Zheng, 2013, "Utilization of MATLAB Simulink Exercises for an Undergraduate Communications Course," Proceedings of the 2013 American Society for Engineering Education Annual Conference & Exposition, American Society for Engineering Education.

D. Yuting and F Lijun, 2010, "The Simulation Design of MATLAB applied to the Mode Technology of Digital Communication System," Third International Symposium on Information Science and Engineering, IEEE Computer Society, pp.438-441.

Naim, Nani Fadzlina, et al. "Interactive Learning Software for Engineering Subjects Based on MATLAB-GUI." Journal of Telecommunication, Electronic and Computer Engineering (JTEC) 8.6 (2016): 77-81.

Douglas Bell, 2005., Software Engineering for Students: A Programming Approach. 4th Edition, Pearson Education Limited, Harlow, England.

Pranjal Dwivedi is a student in the Department of Electronics and Telecommunication Engineering, School of Electrical Engineering, MIT Academy of Engineering Pune. He had been working in the field of wired and wireless communications as a research enthusiast.

Alok Ranjan is a student in the Department of Electronics and Telecommunication Engineering, School of Electrical Engineering, MIT Academy of Engineering Pune. For the last two years, he has been working in the communication domain and has a firm grip over the simulation platforms and latest technical tools.

Ashish Srivastava is working as an Assistant Professor in the Department of Electronics and Telecommunication Engineering, School of Electrical Engineering, MIT Academy of Engineering Pune. He is a Doctoral candidate in the National Institute of Technology Patna. Ashish's research interest lies in the field of communication engineering.