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# Analog and Digital Modulation in Communication System

Md Masud Rana [1]
School of Electronic and Information Engineering,
Nanjing University of Information Science & Technology, Nanjing 210044, China.
Email: masudahnaf761@gmail.com

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## Abstract:

This paper examines the differences between baseband and broadband transmission, highlighting the necessity for modulation in communication systems. Baseband transmission uses the entire bandwidth of a medium without modulation, while broadband modulates signals across a frequency range for concurrent multiple signal transmission.

Analog modulation involves altering a sinusoidal carrier wave's amplitude, frequency or phase with an analog message signal enhancing transmission quality in applications like radio and television. Amplification modulation (AM), frequency modulation (FM), and phase modulation (PM) are important methods. In contrast, digital modulation uses techniques such as amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK) to alter the carrier based on digital data. Efficiency is increased by sophisticated methods like quadrature amplitude modulation (QAM) and quadrature phase shift keying (QPSK). Broadband systems utilize these digital techniques to achieve high data transmission rates, approaching the limits predicted by Shannon's capacity theorem, thus optimizing communication system performance.

*Key Words:* Simulink; Modulation; Communication System; Analog modulation and Digital modulation.

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## I. INTRODUCTION

In modern communication systems, information is transmitted using electromagnetic waves, which can be in the shape of either analog or digital signals. Analog signals are continuous waveforms that preserve the continuous nature of the original data by directly representing it. Digital signals, on the other hand, use discrete values, typically in binary form, allowing for more efficient processing and transmission [1]. Analog modulation is essential for transmitting analog signals over communication channels. This technique involves modulating a low-frequency analog signal onto a high-frequency carrier signal, which is typically a sinusoidal wave characterized by amplitude, frequency, and phase [2]. By altering these characteristics, the information from the analog signal is embedded into the carrier wave. The combined modulated signal is then transmitted, and demodulation at the receiver end extracts the original low-frequency signal.

There are various analog modulation techniques., each with distinct advantages and disadvantages. Amplitude Modulation (AM) varies the carrier wave's amplitude according to the analog signal. Frequency Modulation (FM) changes the carrier wave's frequency based on the analog input, while Phase Modulation (PM) alters the carrier wave's phase to encode the signal [3]. The choice of modulation technique depends on factors such as signal quality, bandwidth efficiency, and application requirements.

Analog modulation requires a bandpass channel, which allows a defined range of frequencies to pass while blocking unwanted frequencies. This is achieved using a bandpass filter, ensuring that only signals within the desired frequency range are transmitted, thereby reducing interference and noise [4]. Digital modulation converts digital data into a transmittable form by modulating a carrier signal with the digital data. Amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK) are among the methods employed. Digital modulation offers advantages over analog modulation, including longer transmission distances, greater accuracy, and robustness against noise and interference.

Modern wireless or wireline transmission devices use digital modulation techniques. This modulation technique is also used by direct video transmission systems. We also look at one of the most important digital modulation methods. This paper explores the principles of both analog and digital modulation, examining their techniques, advantages, disadvantages, and applications in various communication systems. It also discusses the different types of communication channels and the factors influencing signal quality.

  

## II. PURPOSE AND SIGNIFICANCE

The main purpose of analog modulation is to send analog signals like music, video, and voice over great distances with little deterioration. It achieves this by varying a carrier wave's amplitude, frequency, or phase, thereby translating baseband signals to higher frequency bands [5]. This frequency translation is essential for efficient transmission and preventing interference with other signals. Analog modulation also facilitates signal multiplexing, allowing multiple signals to be transmitted simultaneously on different carrier frequencies, thereby increasing the channel's capacity. Effective utilization of available bandwidth for services like AM and FM radio broadcasting is another key purpose of analog modulation.

On the other side, digital modulation is necessary for digital data transmission over analog media. This technique allows for efficient bit transmission, which is crucial for modern digital communication systems [6]. Digital modulation methods that provide enhanced resistance to noise and interference, such as Phase Shift Keying (PSK), Quadrature Amplitude Modulation (QAM), and Frequency Shift Keying (FSK), increase signal quality. Digital signals can also be compressed and encrypted, ensuring secure and efficient data transmission vital for applications like internet communications and secure wireless communications. Digital modulation also supports sophisticated error detection and correction techniques, enhancing data transmission reliability. Furthermore, it enables seamless integration with digital systems like computers, smartphones, and digital broadcasting.

### *A. Significance of Analog and Digital Modulation*

Analog modulation has historical importance as the foundation of early communication systems, including AM and FM radio and analog television. These developments paved the way for modern communication technologies. Analog modulation techniques are generally simpler and more cost-effective to implement with analog circuitry, making them suitable for certain applications. They are also well-suited for real-time applications like live radio and television broadcasting, where minimal latency is crucial.

Digital modulation is significant for achieving higher data rates essential for modern applications such as high-speed internet, digital television, and mobile communications. It ensures more efficient use of the available spectrum, allowing more users and services to coexist within the same frequency bands. The flexibility and scalability of digital modulation are notable, as it can be adapted to different requirements like varying data rates and quality of service levels. This adaptability is vital for meeting the evolving needs of communication systems. Digital modulation also supports the convergence of various services, including voice, video, and data, into a single communication platform, enhancing the versatility and efficiency of communication systems. Additionally, digital modulation approaches operate better in difficult conditions, such as high electromagnetic interference urban regions, since they are more resilient to noise and interference.

## III. PRINCIPLE OF MODULATION

Modulation is a technique used to efficiently send information over a communication channel by altering a carrier signal. Usually a high-frequency sine wave, the carrier signal serves as a conduit for the information-bearing signal, which may be digital or analog. Modulation helps in translating the baseband signal to a frequency range that is suitable for transmission over long distances and reduces the potential for interference with other signals [7]. Here are the principles for both analog and digital modulation:

### *A. Analog Modulation*

1) ***Carrier Signal:*** A high-frequency signal that is used as the modulation foundation. Constant amplitude, frequency, and phase sine waves are often employed carriers.

2) ***Modulating Signal:*** The information signal, which may be an analog signal like music, video, or voice, must be sent.

3) ***Modulation Process:*** The process of altering the carrier signal's amplitude, frequency, or phase in response to the modulating signal's current value.

- **Amplitude Modulation (AM)**: This technique modifies the carrier signal's amplitude in proportion to the modulating signal's amplitude.

$$s(t)=[A+m(t)]\cos(2\pi f_c t)$$

where the modulating signal is denoted by m(t), the modulated signal by s(t), the carrier frequency by fc, and the carrier amplitude by A.

- **Frequency Modulation (FM)**: The modulating signal's amplitude determines the carrier signal's frequency.

$$s(t)=A\cos\left(2\pi f_c t + 2\pi k_f \int m(t)\,dt\right)$$

where $k_f$ is the modulator's frequency sensitivity.

- **Phase Modulation (PM)**: The modulating signal's amplitude is used to adjust the carrier signal's phase.

$$s(t)=A\cos\left(2\pi f_c t + k_p m(t)\right)$$

where $k_p$ is the modulator's phase sensitivity.

  

### B. Digital Modulation

*1) **Carrier Signal**:* Similar to analog modulation, a high-frequency sine wave is used as the carrier signal.

*2) **Modulating Signal**:* In the context of digital data, the information signal is usually a binary sequence.

*3) **Modulation Process**:* The digital data is used to adjust the carrier signal. Among the crucial methods are:

**Amplitude Shift Keying (ASK)**: The carrier signal's amplitude is adjusted between a range of distinct levels that correspond to binary data (0 or 1).

$$s(t)=\begin{cases} A\cos(2\pi f_c t) & \text{if binary 1} \\ 0 & \text{if binary 0} \end{cases}$$

- **Frequency Shift Keying (FSK)**: The carrier signal's frequency fluctuates among a range of distinct frequencies that match the binary data.

$$s(t)=\begin{cases} A\cos(2\pi f_1 t) & \text{if binary 1} \\ A\cos(2\pi f_0 t) & \text{if binary 0} \end{cases}$$

Where $f_1$ and $f_0$ are the frequencies representing binary 1 and 0 respectively.

- **Phase Shift Keying (PSK)**: The carrier signal's phase is adjusted based on the binary data.

$$s(t)=A\cos(2\pi f_c t+\theta)$$

where $\theta$ is shifted to represent binary data (e.g., 0° for binary 0 and 180° for binary 1 in BPSK - Binary Phase Shift Keying).

*4) **Advanced Digital Modulation**:* ASK and PSK are combined in techniques such as Quadrature Amplitude Modulation (QAM) to use both amplitude and phase fluctuations for larger data rates. QAM signals can be shown as follows:

$$s(t) = (A_I\cos(2\pi f_c t)+A_Q\sin(2\pi f_c t))$$

where $A_I$ and $A_Q$ are the amplitude components of the in-phase and quadrature signals.

A high-frequency carrier wave's amplitude, frequency, or phase can be changed to convey analog messages through analog modulation, which makes long-distance communication effective and eliminates interference. The following are common methods: phase modulation (PM), frequency modulation (FM), and amplitude modulation (AM).

In order to transmit digital data, digital modulation modifies the carrier wave's amplitude, frequency, or phase in discrete steps that correspond to binary data. Amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK) are important techniques. More complex approaches, such as Quadrature Amplitude Modulation (QAM), combine amplitude and phase fluctuations to achieve larger data rates..

Both analog and digital modulation are essential for their respective applications, enabling effective and reliable transmission of information across various communication systems.

## IV. SIMULATION

**Amplitude Modulation:** This simulation depicts an amplitude modulation (AM) process. The message signal, a low-frequency sine wave that represents the data to be conveyed, is displayed in the top figure. The carrier signal, a high-frequency sine wave that transmits the message signal, is seen in the middle plot. The modulated signal, which is produced by altering the carrier signal's amplitude in line with the message signal, is depicted in the bottom plot. This combination makes it possible to use the higher frequency carrier wave to send the message signal across long distances.

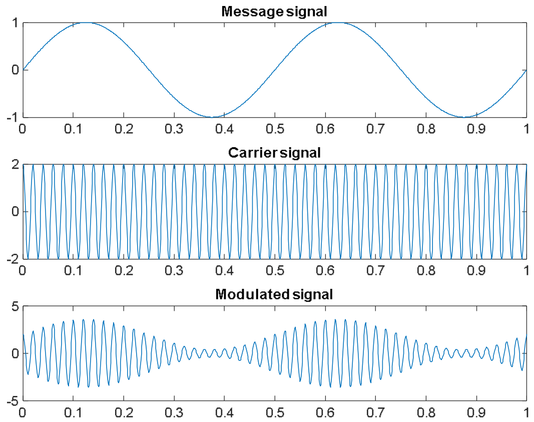


**Figure 1 Amplitude Modulation**

**Frequency Modulation:** The frequency modulation (FM) process is illustrated in this simulation. The message signal, a low-frequency sine wave that represents the data to be delivered, is shown in the top graph. The carrier signal, a high-frequency sine wave that transmits the message, is depicted in the middle graph. The frequency-modulated signal is depicted in the bottom graph, where the amplitude of the message signal determines the frequency of the carrier signal. With this technique, the message signal can travel great distances while being very resistant to interference and noise.

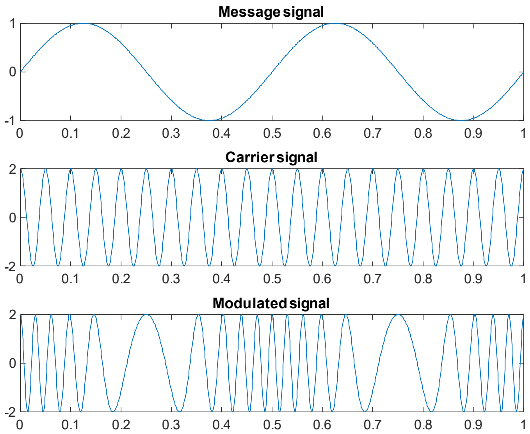


**Figure 2 Frequency Modulation**

**Phase Modulation:** This simulation illustrates a Phase Modulation (PM) process. The top plot shows the message signal, a binary waveform conveying digital data. The carrier signal, a high-frequency sine wave, is shown in the middle plot. The BPSK modulated signal, which is displayed in the bottom figure, shifts the carrier wave's phase by 180 degrees each time the message signal switches between binary states. This modulation technique is used in digital communications to transmit binary data over radio frequencies, providing robustness against noise and interference.

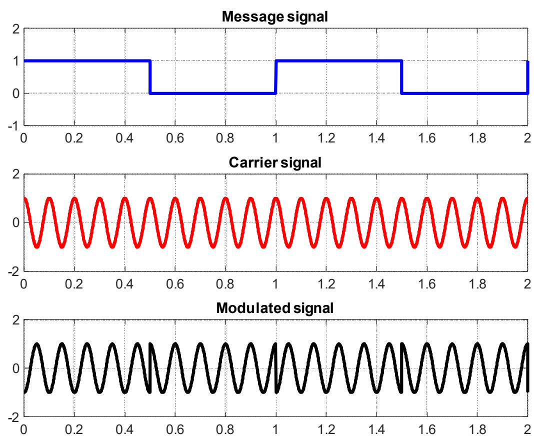


**Figure 3 Phase Modulation**

**Amplitude Shift Keying Modulation:** An Amplitude Shift Keying (ASK) modulation mechanism is shown in this simulation. The modulated signal, where the carrier wave's amplitude changes in accordance with the binary message signal, is displayed in the top plot. The carrier signal, a high-frequency sine wave, is shown in the middle plot. The binary message signal, which alternates between two levels (0 and 1), is depicted in the bottom plot. To represent binary data, the carrier amplitude is changed in ASK; one amplitude corresponds to binary 1 and another (usually zero) to binary 0. This modulation technique is used in digital communication systems to transmit data efficiently.

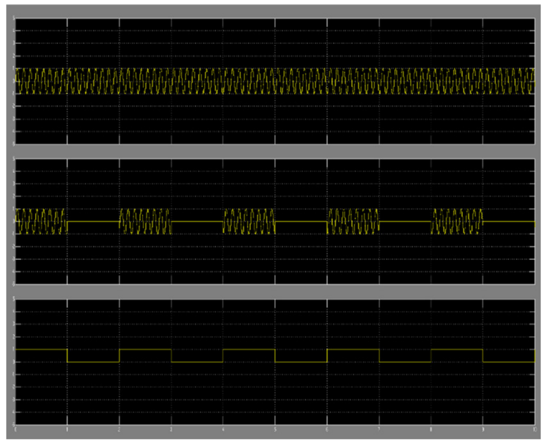

**Figure 4 ASK Modulation**

**Frequency Shift Keying Modulation:** This simulation illustrates a Frequency Shift Keying (FSK) modulation process. The top plot displays the modulated FSK signal, where the frequency changes according to the input digital data. To illustrate the various frequency components utilized to represent binary '1' and '0', the middle plot displays the appropriate demodulated signal. The original message signal, a binary waveform, used for the modulation, is shown in the bottom plot. Due to its resilience to noise and signal deterioration, FSK modulation is frequently utilized in digital communication systems.

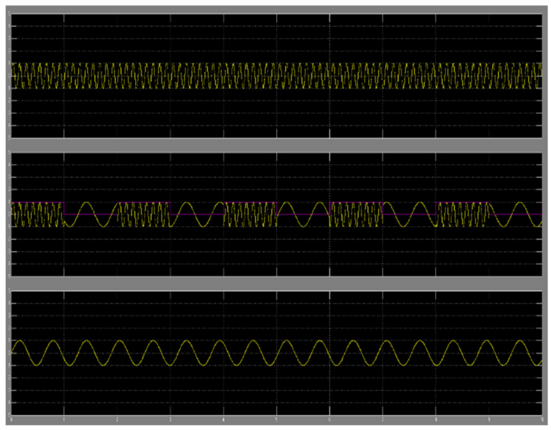

**Figure 5 FSK Modulation**

  

**Phase Shift Keying Modulation:** A simulation that demonstrates Phase Shift Keying (PSK) modulation is provided. The PSK modulated signal, which represents binary data by altering the carrier wave's phase, is displayed in the top plot. The demodulated signal is shown in the middle plot, with phase shifts representing the binary "1"s and "0"s in the original message. The original binary message signal utilized for modulation is seen in the bottom plot. PSK is a digital modulation technique that is commonly used in digital communications because it encodes data by changing the phase of a carrier signal, making it resistant to noise.

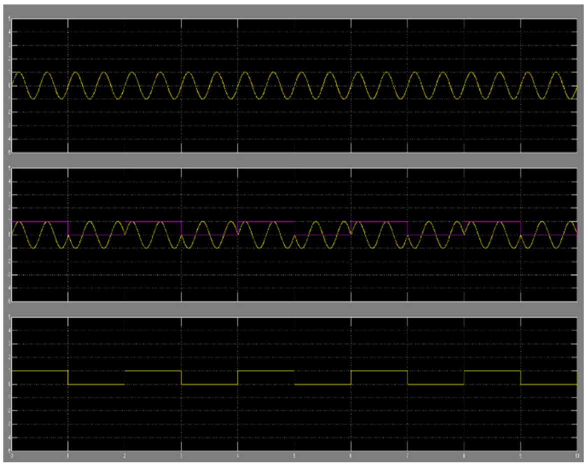

**Figure 6 PSK Modulation**

## V. CONCLUSION

The use of both digital and analog modulation is essential in communication systems, to sum up. Modulation enables the transfer of information over long distances without the need for wires. Analog signals that can convey information through changes in amplitude, frequency, or phase can be transmitted via analog modulation techniques including amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM). However, the transfer of digital signals which are more secure and offer faster data rates is made possible by digital modulation techniques such as amplitude shift keying (ASK), frequency shift keying (FSK), and phase shift keying (PSK). In communication systems, modulation is an essential procedure that uses two signals: a high-frequency carrier signal and a low-frequency baseband signal. We can wirelessly send data over long distances by combining the baseband signal with the carrier signal. Modulation has revolutionized communication technology and allowed for the development of wireless devices such as mobile phones, which have become an essential part of our lives. Modulation has brought about a technological revolution, allowing humans to communicate wirelessly and transfer information across the globe in seconds. With the use of modulation, we can now send voice, video, and data signals over long distances, leading to the development of various communication systems like cell phones, satellite communication, and radio and television broadcasting. The future of communication systems is bright, and modulation will continue to be a critical technology in enabling faster, more secure and reliable communication.

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