

An Undergraduate Guide to

Analog and Digital

**Communication
Principles**

An Undergraduate Guide to

Analog and Digital Communication Principles

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First Published 2025

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Published & Printed by:
Penerbit UTHM
Universiti Tun Hussein Onn Malaysia
86400 Parit Raja,
Batu Pahat, Johor
Tel: 07-453 7051
Fax: 07-453 6145

Website: <http://penerbit.uthm.edu.my>
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<http://e-bookstore.uthm.edu.my>

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Majlis Penerbitan Ilmiah Malaysia
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PREFACE

The aim of this book is to provide comprehensive knowledge of the fundamental concepts in analog and digital communication systems. Suitable for undergraduate students embarking on their first course in communication systems or individuals seeking to deepen their understanding of the subject, this guide serves as a valuable resource throughout the academic journey and beyond. By the end of this book, readers will not only grasp the theoretical knowledge and concepts of communication technologies but also gain insights into the societal impacts of communication engineering, offering a holistic view of both the academic and practical worlds. This book includes numerous examples and exercises to enhance comprehension of all major topics.

Chapter 1 introduces readers to the basic concepts of communication systems, including the building blocks of a communication system, the frequency spectrum and its regulation, common system parameters, signal classification, the societal impacts of communication, communication system efficiency, and noise. Additionally, this chapter provides a thorough discussion on dB calculations, which are crucial for assessing communication system performance.

Chapters 2 and 3 dig into analog communication systems, providing detailed explanations of amplitude modulation and frequency modulation. These chapters begin with an overview of general modulation concepts, followed by foundational discussions on general equations, time and frequency domain representations, bandwidth, and noise performances. The chapters conclude with discussions on generation and reception, including the superheterodyne concept.

Chapters 4 to 6 discuss the fundamental concepts of digital modulation and multiplexing. These chapters begin with the processes involved in analog-to-digital conversion and line encoding techniques and provide a thorough description of binary and multi-level digital modulation formats. Chapter 5 concludes with comprehensive explanations of the probability of error, bit error rate, and error performance comparison.

The final chapter, Chapter 7, on Applications in Emerging Wireless and Wired Communication Networks, demonstrates the practicality of the above modulation and multiplexing concepts in today's modern networks. The text also provides readers with the necessary technical foundations to understand the conversation on wireless and wired media.

Appendix A provides a basic guide for beginners to start using MATLAB for communication engineering purposes. Appendix B lists trigonometric identities and related formulas. Finally, Appendices C and D provide important tables such as the Bessel function and complementary error function, respectively.

ACKNOWLEDGEMENT

We are grateful to the technical reviewer Assoc. Prof. Dr. Nor Fadzilah Abdullah, Universiti Kebangsaan Malaysia for her constructive feedback. We are extremely grateful to the main editor for their invaluable support throughout the publication process. Additionally, we acknowledge the assistance and resources provided by our respective universities, Universiti Teknologi Malaysia and Universiti Tun Hussein Onn Malaysia, which facilitated a seamless writing process. We extend our heartfelt gratitude to our parents, spouses and children for their unwavering support and understanding during the development of this book. This publication has been made possible by the contributions of these individuals and institutions.

CHAPTER 1

INTRODUCTION TO COMMUNICATION SYSTEMS

LEARNING OUTCOMES

At the end of this chapter, you should be able to:

- Understand the concept of communication system and impact to the society.
- Analyze the noise in the communication system and its impact.

1.1 INTRODUCTION

Communication is the process of delivering information. In the past, information was delivered by direct conversation as well as using primitive methods such as fire, smoke, and drums for distance communication. However, those kinds of communications were not effective and time-consuming. The reliability and quality of transferring information evolved with the introduction of electricity and electromagnetics in the early 1800s. The successful demonstration of Samuel Morse, who used a system known as the Telegraph for delivering information electronically in 1844, has opened a new era in electronic communication. Nevertheless, the telegraph was limited to trained people who understood transmitting electronic signals using Morse code. Thus, research was carried out in the direction of transmitting sound rather than a code signal until Alexander Graham Bell came out with the invention of the telephone in the 1870s.

Then, communication technology expanded wirelessly after Guglielmo Marconi introduced the wireless telegraph in the 1890s. He managed to send a message wirelessly from Newfoundland to Cornwall in 1901. Wireless communication opened new paths to other inventions in the 1900s, such as audio broadcasting using radio communication, where amplitude modulation (AM) and frequency modulation (FM) techniques were introduced in broadcasting. Broadcasting is not only limited to sound; images can also be sent via radio communication. This was evident in the invention of the television in 1927. Radar and microwave communication were mainly used during World War II before satellite communication was introduced in the 1960s.

CHAPTER 2

AMPLITUDE MODULATION

LEARNING OUTCOMES

At the end of this chapter, you should be able to:

- Understand the concept of amplitude modulation (AM) and distinguish the different types of AM.
- Calculate AM bandwidth and power performances.
- Describe the generation and detection methods of AM signals.
- Describe the effect of noise and SNR on an AM signal.

2.1 INTRODUCTION

Telecommunication refers to the transmission of information between two distant points. The information sources are normally in analog form, such as speech, images, and videos. The information signal is usually a baseband signal with a non-zero spectrum occupying a specific frequency range. The signal can be anything, such as when someone talks, and the voice can be heard for a certain distance. In order to transfer the information over a longer distance, a certain technique is needed to strengthen the signal without sacrificing the original information. The technique is called modulation, in which the source signal is modulated into a higher-frequency analog signal called a carrier.

2.1.1 MODULATION CONCEPT

Signal modulation is a fundamental concept in communication systems that involves altering the characteristics of a carrier signal to convey information. The process of modulation allows for an efficient transmission of data over communication channels, such as radio waves, optical fibers, or coaxial cables. It is a crucial aspect of various communication technologies, including radio broadcasting, television transmission, wireless communication, and more.

CHAPTER 3

ANGLE MODULATION

LEARNING OUTCOMES

At the end of this chapter, you should be able to:

- Understand the concept of instantaneous frequency, angle modulation, types of FM and FM bandwidth estimation.
- Describe generation and detection methods of FM signal.
- Describe the effect of noise and SNR on an FM signal.

3.1 INTRODUCTION

In this chapter, we will discuss another type of modulation technique, angle modulation which is also known as exponential modulation. This technique uses modulating signals to change the frequency and phase of the carrier signal. As frequency is closely related to phase, a direct change in frequency results in an indirect change to the phase, and vice versa. A more in-depth explanation of the relationship between frequency modulation (FM) and phase modulation (PM) can be found in Section 3.2. To have better understanding of angle modulation, we need to first generalize the function of a signal where its angle, may demonstrate linear (dotted line) or nonlinear (solid line) changes with time, as shown in Figure 3.1.

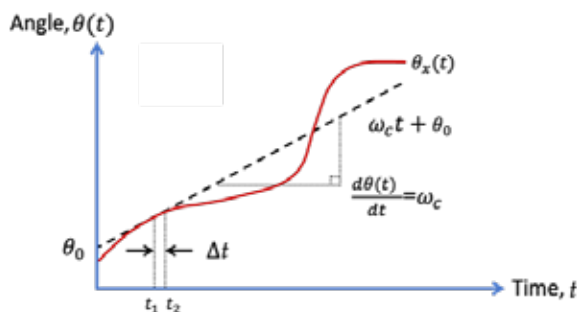


Figure 3.1: Nonlinear and linear signal angle variations with time

CHAPTER 4

PULSE MODULATION AND LINE ENCODING

LEARNING OUTCOMES

At the end of this chapter, you should be able to:

- Understand the concept of pulse modulation and the importance of sampling theory.
- Comprehend the processes involved in pulse code modulation (PCM) and conduct relevant PCM analysis.
- Describe specified pulse modulation techniques.
- Understand the important features of line encoding formats and the application of binary codes.

4.1 INTRODUCTION

Previous chapters dealt with analog modulation, in which both the modulating and the carrier waves are in analog form. The analogous form of modulating signals suits the nature of signals that exist around us, such as temperature and vibration, that can be represented by any value within a certain range. Thus, in the early years, electronic communication systems were largely based on analog systems. However, when the digital concept was introduced in the late 1990s with the advent of large to very large-scale integrated circuits, analog communication systems were replaced by digital systems. Now, digital communication systems are present in most of today's applications and services, such as smartphones, digital television, and smart homes.

In this chapter, we will discuss the advantages of digital modulation, and readers will be introduced to the concept of pulse modulation, particularly the conversion of an analog signal to its digital form. The processes involved in this conversion until signals are channeled to the transmission line are described in depth. These processes encompass sampling, quantization, coding, and line encoding.

CHAPTER 5

CONTINUOUS WAVE DIGITAL CARRIER MODULATION

LEARNING OUTCOMES

At the end of this chapter, you should be able to:

- Describe three basic digital modulation schemes: ASK, FSK, and PSK.
- Describe the M -ary modulation scheme, particularly QPSK and 8-QAM.
- Describe the equations, waveforms, and signal constellation diagrams of representative digital modulation formats.
- Explain the modulator and demodulator implementations.
- Evaluate and compare the performance of different modulation schemes.

5.1 INTRODUCTION

As discussed in Chapter 4, digital signals are represented as a stream of binary bits that can be transmitted as pulse signals. This kind of baseband signal transmission is possible because the channel allows the low-frequency digital pulse signals to pass through the digital channel, in this case a link cable, as shown in Figure 5.1.

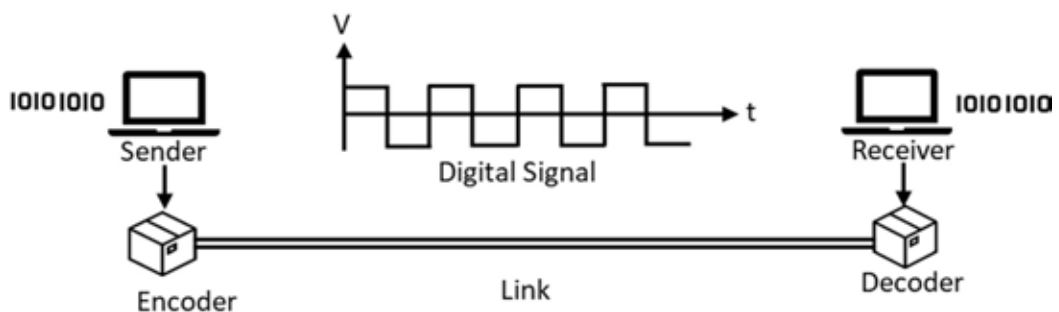


Figure 5.1: Baseband digital signal transmission

CHAPTER 6

MULTIPLEXING

LEARNING OUTCOMES

At the end of this chapter, you should be able to:

- Understand the concept of multiplexing and its importance in a communication system.
- Understand the concepts of frequency division multiplexing (FDM), time division multiplexing (TDM), space division multiplexing (SDM), and wavelength division multiplexing (WDM).
- Analyze and design two basic multiplexing techniques, FDM and TDM.
- Explore the use of modern multiplexing techniques in communication to demonstrate lifelong learning.

6.1 INTRODUCTION

Previous chapters dealt with important concepts in communication systems such as modulation and noise, which involve both analog and digital transmission systems. The transmission process also requires the analog or digital data to be converted into electromagnetic signals, where different voltage values, polarity, and patterns are used to distinguish symbols to represent the information signal.

In this chapter, we will discuss a new topic, multiplexing, that offers better resource utilization through the sharing of transmission resources. The concept, hierarchy, and standard of basic multiplexing techniques (FDM and TDM) are discussed, followed by other techniques such as SPM and WDM. Additionally, we will introduce readers to the modern multiplexing techniques utilized in optical and wireless transmission systems.

CHAPTER 7

APPLICATIONS IN EMERGING WIRELESS AND WIRED COMMUNICATION NETWORKS

LEARNING OUTCOMES

At the end of this chapter, you should be able to:

- Understand the fundamental concepts of wireless and wired communication; transmitter, modulator, receiver, signal propagation and communication link.
- Understand how the key communication concepts such as modulation and multiplexing are applied in modern wireless and wired communication networks.
- Describe the emerging wireless and wired networks such as the 5G and 6G wireless networks, and optical fronthaul technologies for 5G and beyond.

7.1 INTRODUCTION

In previous chapters, we explored essential concepts in communication systems, including modulation, multiplexing and noise, which underpin both analog and digital transmission methods. The transmission process requires converting data—whether analog or digital—into electromagnetic signals, where variations in voltage, polarity, and patterns help distinguish symbols that represent the information. In this closing chapter, we will examine how these foundational principles are applied in the context of emerging wireless and wired networks.

Telecommunication systems have evolved significantly to meet the growing demand for connectivity, reaching even the most remote areas. Modern communication encompasses a wide array of applications beyond traditional data, voice, and video. It includes Internet of Things (IoT) devices, augmented and virtual reality experiences, real-time data analytics, remote healthcare services, and smart city infrastructure, all of which require seamless connectivity. However, as speed and capacity become critical for efficient data transfer, challenges persist.

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BIOGRAPHY



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