

# Principles of Communications



Lecturer:

Weiyao Lin

Department of Electronic Engineering  
Shanghai Jiao Tong University

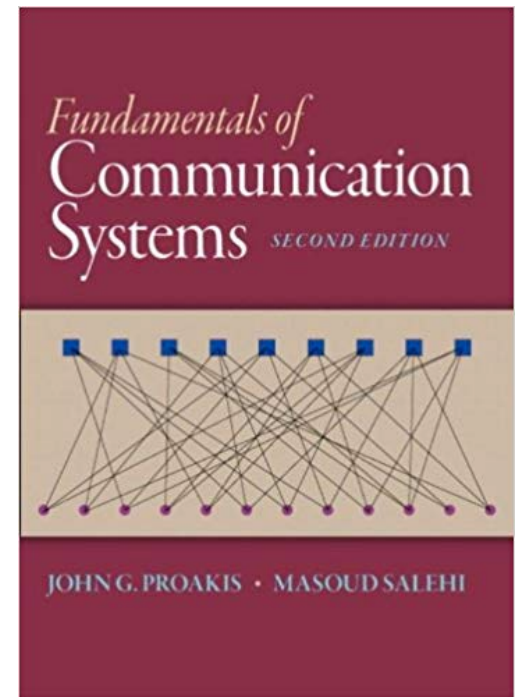
Chapter 1: Introduction

# Staff

- Lecturer:
  - Weiyao Lin (林巍骁)
  - Office: Room 1-301, SEIEE Buildings
  - Email: [wylin@sjtu.edu.cn](mailto:wylin@sjtu.edu.cn)
  - Web: <https://weiyaolin.github.io/>
- TA: To be confirmed
  - Xiaoyi He (何晓艺)
  - Office: Room 1-301, SEIEE Buildings
  - Email: [515974418@sjtu.edu.cn](mailto:515974418@sjtu.edu.cn)

# Textbook

- “Fundamentals of Communication Systems (2<sup>nd</sup> Edition)”, by J. G. Proakis and M. Salehi, Pearson prentice Hall 2013



- References:
  - “An introduction to analog and digital communications”, by Simon Haykin, 2<sup>nd</sup> edition, John Wiley & Sons, 2007
  - "Communications Systems Engineering", by John G. Proakis and Masoudsalehi, 2<sup>nd</sup> edition, Printice-Hall, 2002.
  - 《通信原理》，韩声栋、蒋铃鸽、刘伟编著，机械工业出版社，2008.6

# Textbook 2

- 《通信原理实验教程——基于NI软件无线电教学平台》，杨宇红、袁焱、田砾，清华大学出版社，2015



教育部高等学校电子信息类专业教学指导委员会规划教材  
高等学校电子信息类专业系列教材



Communication Principles and Exploration Lab Using  
the NI USRP™ Platform

## 通信原理实验教程

——基于NI软件无线电教学平台

杨宇红 袁焱 田砾 编著

Yang Yuhong Yuan Yan Tian Li



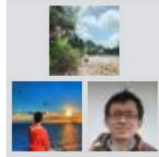
清华大学出版社

# Class Website and Lecture Notes

- Class Website:
  - <https://weiyaolin.github.io/comm/comm.html>
  - (backup) <https://oc.sjtu.edu.cn/courses/1476>
- Lecture notes can also be downloaded from:
  - <ftp://public.sjtu.edu.cn>
  - Username: 515974418
  - Password: public
    - Under the folder “communication system”

**Lecture notes are very important! The mid and final exam questions are designed based on the lecture notes!**

# Class WeChat Group



2018-19 通信英文班 (林  
巍骁)



该二维码7天内(9月14日前)有效，重  
新进入将更新

# Schedule 1

Week 1	Ch01: Introduction
Week 2	Ch02: Signal, Random Process, and Spectra
Week 3	
Week 4	Ch03: Analog Modulation
Week 5	Ch04: Analog to Digital Conversion
Week 6	Ch05: Signal Space Representation
Week 7	Ch06: Optimal receivers
Week 8	<b>Tutorial and Mid-term Test (To be confirmed)</b>

# Schedule 2

Week 9	Ch07: Digital Modulation Techniques
Week 10	
Week 11	Ch08: Digital Transmission Through Baseband Channels Ch09: Multicarrier Modulation and OFDM
Week 12	
Week 13	Ch10: Information Theory
Week 14	Ch11: Channel Coding
Week 15	
Week 16	Ch12: Advanced Topics and Course Review



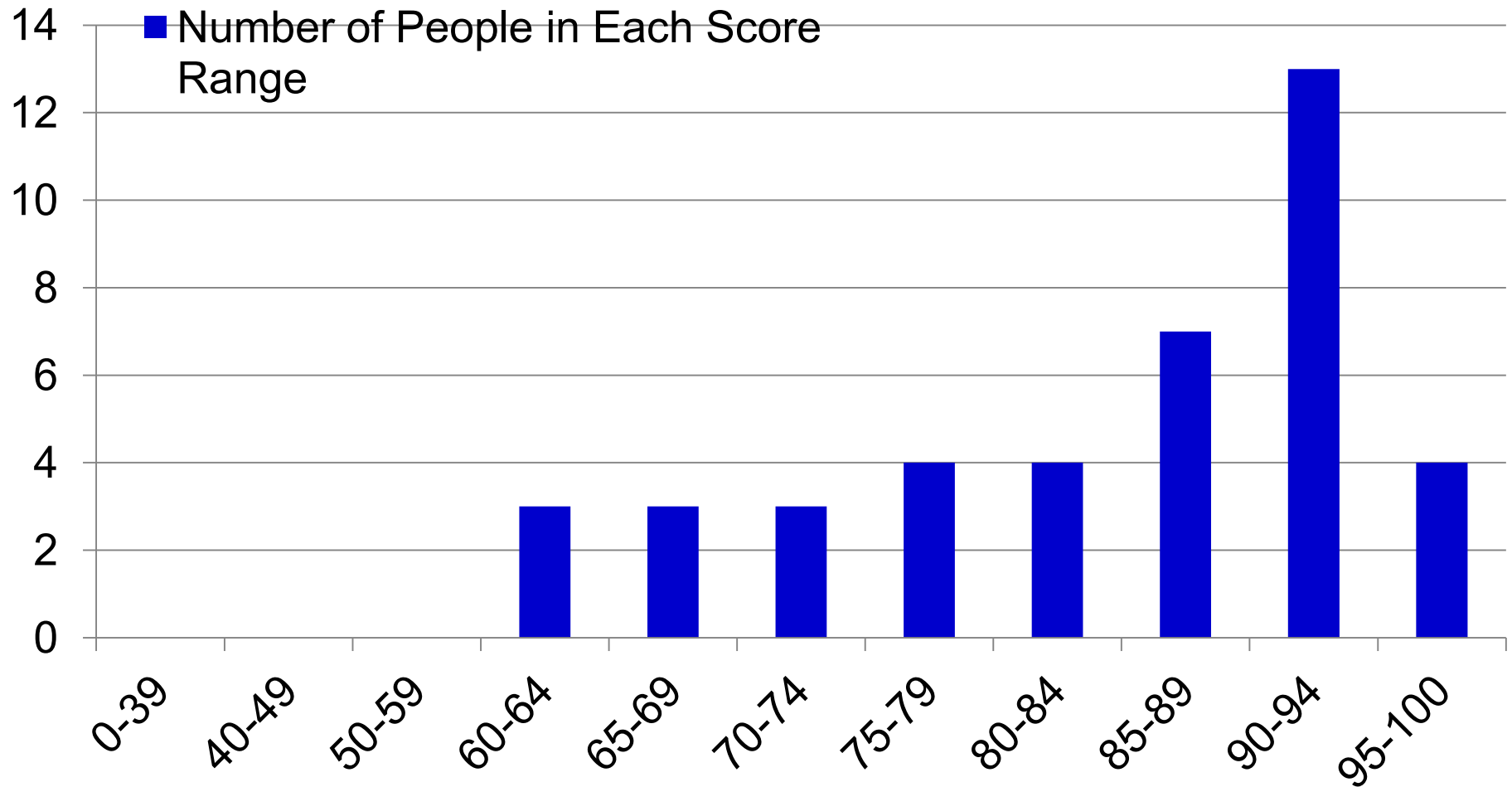
# Lab courses

- Yuhong Yang (杨宇红) [yangyuhong@sjtu.edu.cn](mailto:yangyuhong@sjtu.edu.cn)
- Schedule (To be confirmed):
  - **Week 6 Wednesday** (4:00-5:40 PM, 东上院100号)
    - labview介绍和模拟调制解调
  - **Week 11 Wednesday** (4:00-5:40 PM, 东上院100号)
    - 数字基带部分编程实验
  - **Week 14 Wednesday** (4:00-5:40 PM, 东上院100号)
    - 数字频带部分验证实验

# Assessment

- Homework: 10%
  - 5 sets of homework
  - 2 points for each homework
- Mid-term test: 10%
  - In-class open book test
- Lab project: 30%
- Final exam: 50%
- Bonus points

# Final score distribution in previous years



# Objective

---

- ❑ The primary objective of this course is
  - to introduce the basic techniques used in modern communication systems, and
  - to provide fundamental tools and methodologies in analysis and design of these systems
- ❑ After this course, the students are to expected to
  - Understand the principles and technique of modulation, coding and transmission.
  - Analyze the merits and demerits of current communication systems and to eventually design improved new systems

# Suggestion

---

- ❑ Prerequisites: signals and systems, random process
- ❑ The course focus on the methodologies of system design and analysis, rather than concrete circuits and implementation.
- ❑ Pay more attention to essential concepts and physical models

# Getting Help

---

- ❑ Attendance is essential
- ❑ Ask questions at any time during lecture
- ❑ Send an email to TA or myself in advance for consultation

# Overview of Comm Systems

---

- ◆ 1.1.Elements of a communication system.....●
- ◆ 1.2 Communication Channels.....●
- ◆ 1.3. Design tradeoffs of communication systems.....●

# What is communications?

---

## ❑ Communications

- The systems and processes that are used to convey information from a source to a destination, especially by means of electricity or radio waves.

## ❑ Telecommunications

- “tele” = distance
- The technology of sending signals and message over a distance using electronic equipment, for example, telegraph, telephone, radio, television and cellphone



# Historical Review

- ❑ 1838: telegraph
- ❑ 1876: telephone
- ❑ 1895: radio by Marconi
- ❑ 1901: trans-atlantic communication
  
- ❑ Early 20<sup>th</sup> century:
  - Most communication systems are analog.
  - Engineering designs are ad-hoc, tailored for each specific application



# Big Questions

---

- ❑ Is there a general methodology for designing communication systems?
- ❑ Is there a limit to how fast one can communicate?

# Harry Nyquist (1928)

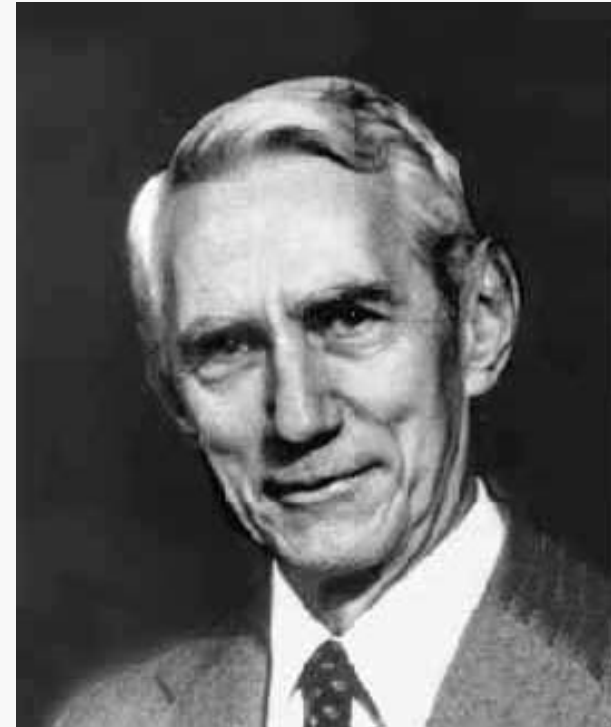
- ❑ Analog signals of bandwidth  $W$  can be represented by  $2W$  samples/second
- ❑ Channels of bandwidth  $W$  support transmission of  $2W$  symbols/second
- ❑ Nyquist transformed a continuous time problem to a discrete-time problem.
- ❑ But did he really solve the communication problems?



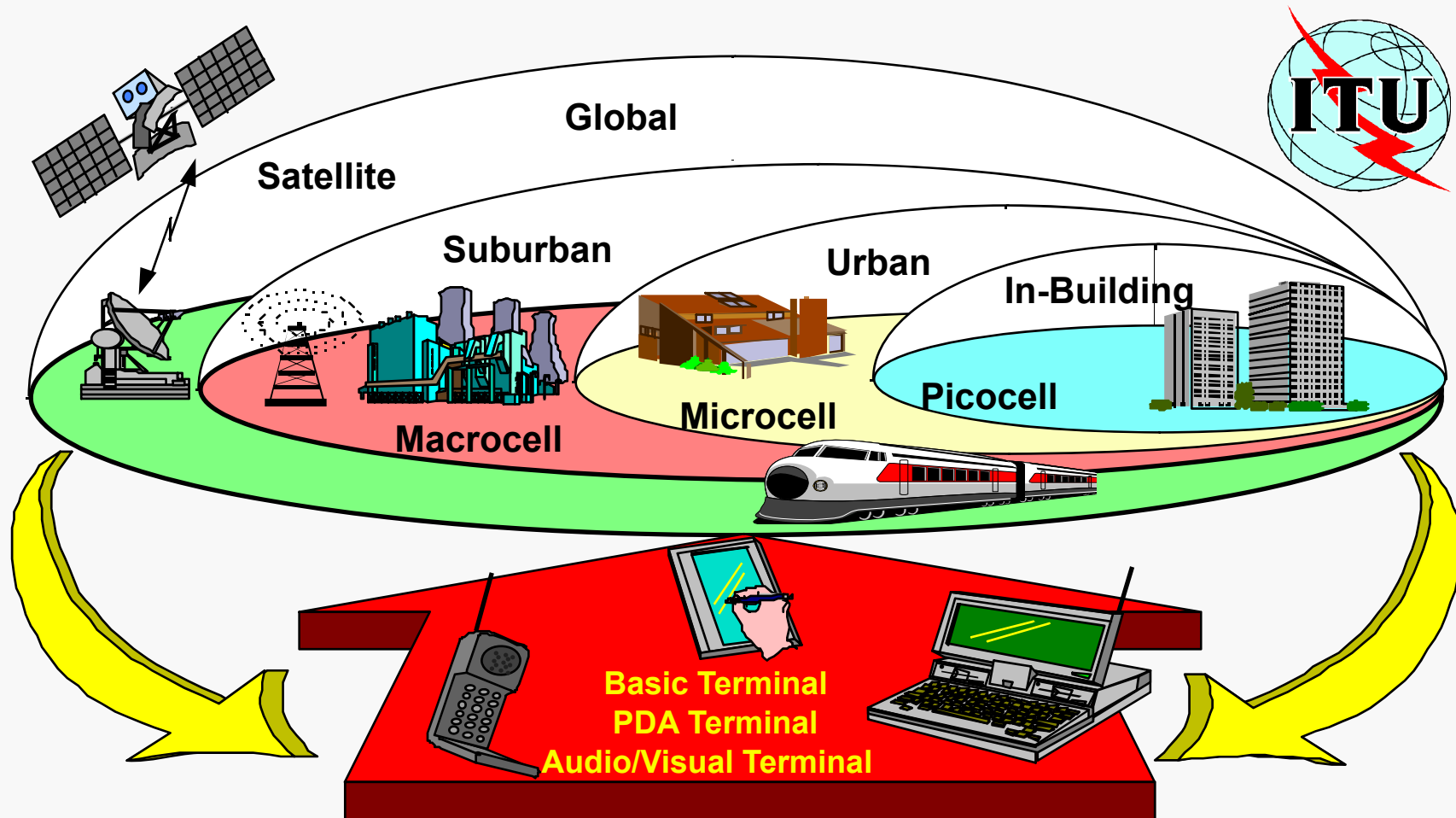
# Claude Shannon (1948)

---

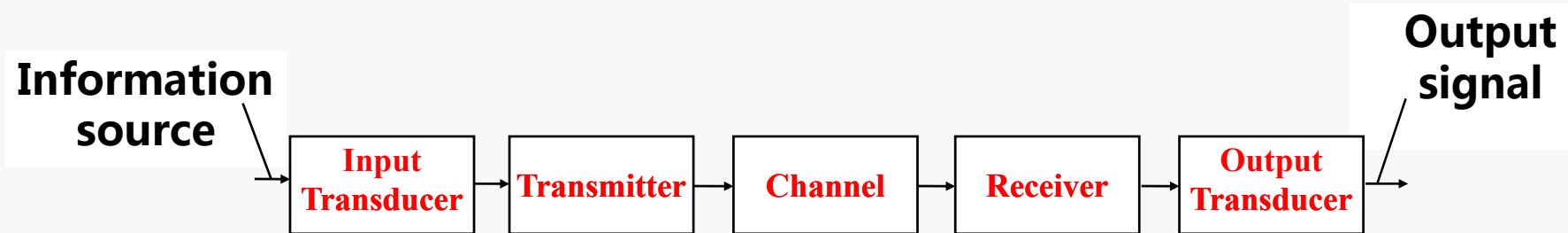
- ❑ Shannon's information theory solves all the big questions
- ❑ Shannon describes information source and channel with probability
- ❑ There exists an entropy rate  $H$  bits/sec for each source
- ❑ There exists a capacity  $C$  bits/sec for each channel
- ❑ If and only if  $H \leq C$ , the information can be transmitted over the channel almost error-free



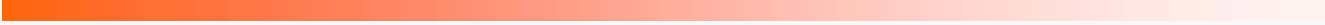
# 60 Years Later...



# Elements of Communication Systems

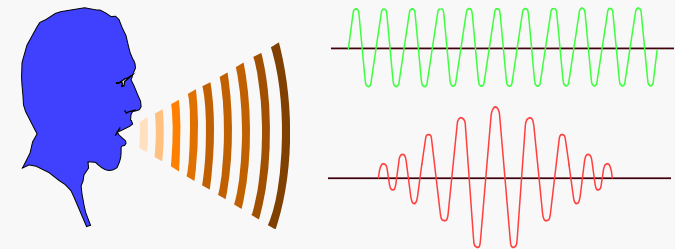


- ❑ Software
- ❑ Hardware
- ❑ Communication architecture, with coding and signal processing algorithms

- 
- ❑ **Source** : voice, picture, text, etc
  - ❑ **Input Transducer**: Converts the original message into an appropriate electrical form – e.g. microphone, video cameras
  - ❑ **Transmitter**: Couples the electric message to the channel
  - ❑ **Channel**: Medium carrying the message between the two points- twisted pair, coax, wireless or optical
  - ❑ **Receiver**: Extracts the original electric signal among many signals in the channel
  - ❑ **Output Transducer**: Recovers the message from the electric signal – e.g. loudspeaker

## ❑ Analog Communications

- The transmitter sends a waveform from an infinite variety of waveform shapes
- The receiver is to reproduce the transmitted waveform with high fidelity, which is usually measured in terms of SNR



## ❑ Digital Communications

- Signals made up of discrete symbols selected from a finite set
- Fidelity or Accuracy is specified in terms of bit error rate (Probability of making a bit error)

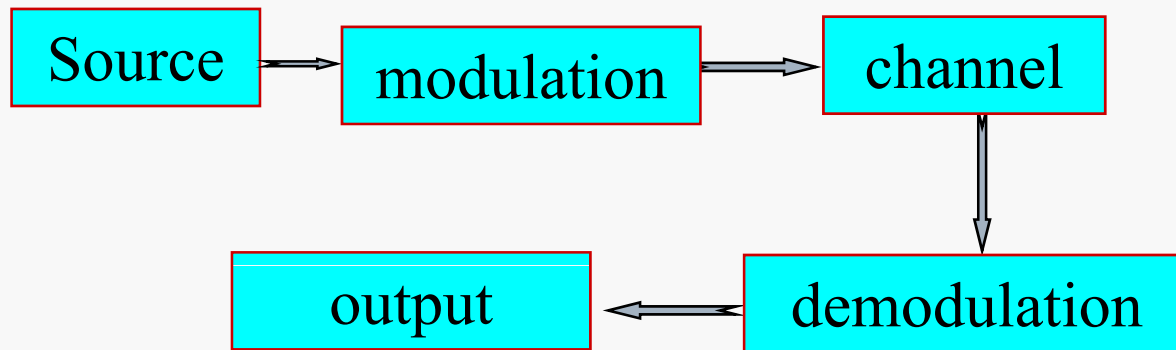


00011011110

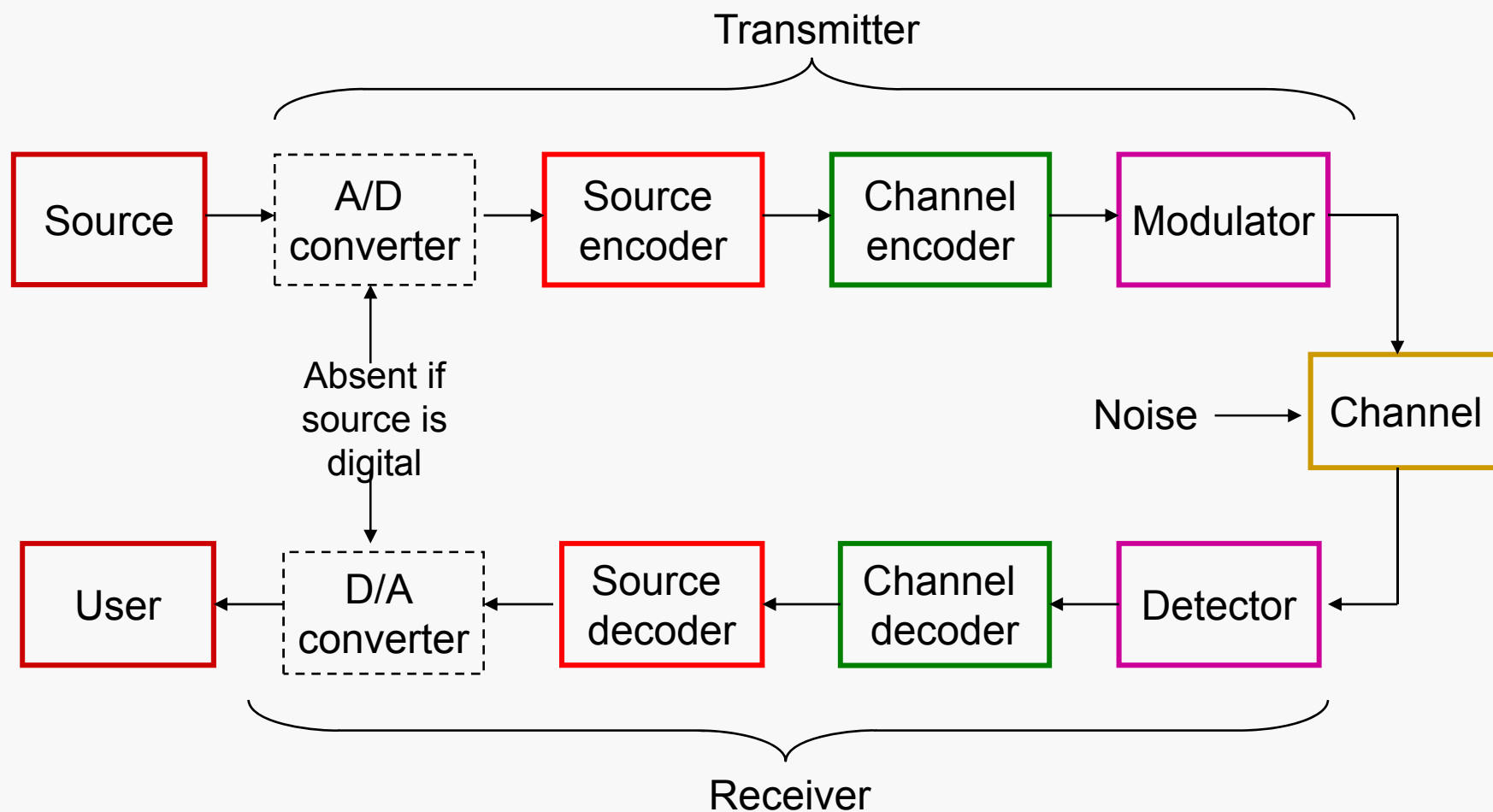


# Analog Communication Systems

---



# Digital Communication Systems



## ❑ Source coding

- **Source encoder** maps the digital signal generated at the source output into another signal in digital form
- The objective is to eliminate or reduce redundancy so as to provide an **efficient representation** of the source output

## ❑ Channel coding

- **Channel coding** provides protection against transmission error. This is done by inserting redundant data in a prescribed fashion
- **Channel encoder** inserts redundant information in a very selective manner.

- ❑ Thus, in source coding, we remove redundancy, whereas in channel coding, we introduce controlled redundancy.

# Why Digital Communications?

---

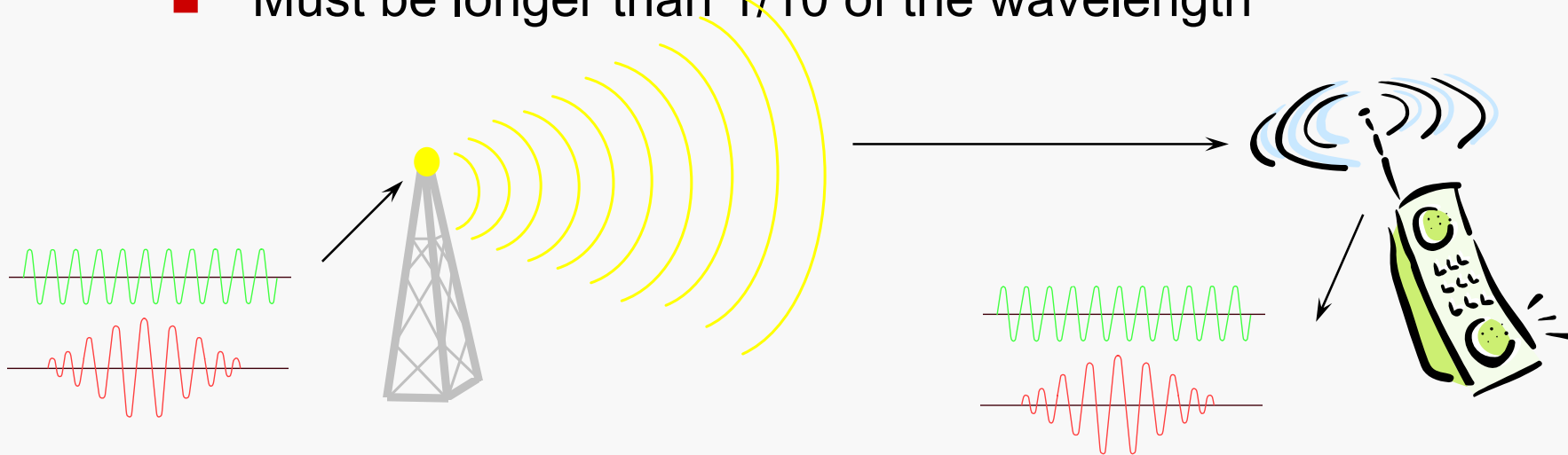
- ❑ **Robustness** to channel noise and external Interference
  - Many signal processing techniques are available to improve system performance: source coding, channel (error-correction) coding, equalization
- ❑ **Security** of information during its transmission from source to destination
  - various encryption, coding techniques available
- ❑ **Integration** of diverse sources information into a common format
  - Allow integration of voices, video, and data on a single system
- ❑ **Low cost DSP chips**
  - Very cheap VLSI designs

# Communication Channels

- ❑ Carries signal – could be a pair of wires, optical fiber, free space, underwater acoustic channel
- ❑ Presents distorted signal to the receiver
- ❑ Effects include
  - Attenuation: signal power typically decreases as distance
  - Noise (e.g. additive white Gaussian noise or AWGN)
  - Filtering:
    - channel can have a bandwidth that is small compared to the signal bandwidth (e.g. in a telephone channel)
    - Transmitted pulses will be changed in shape and smeared out in time causing Inter-Symbol Interference or ISI
  - Fading
    - Signal amplitude can change in a random fashion
    - Fading is very important in wireless communications

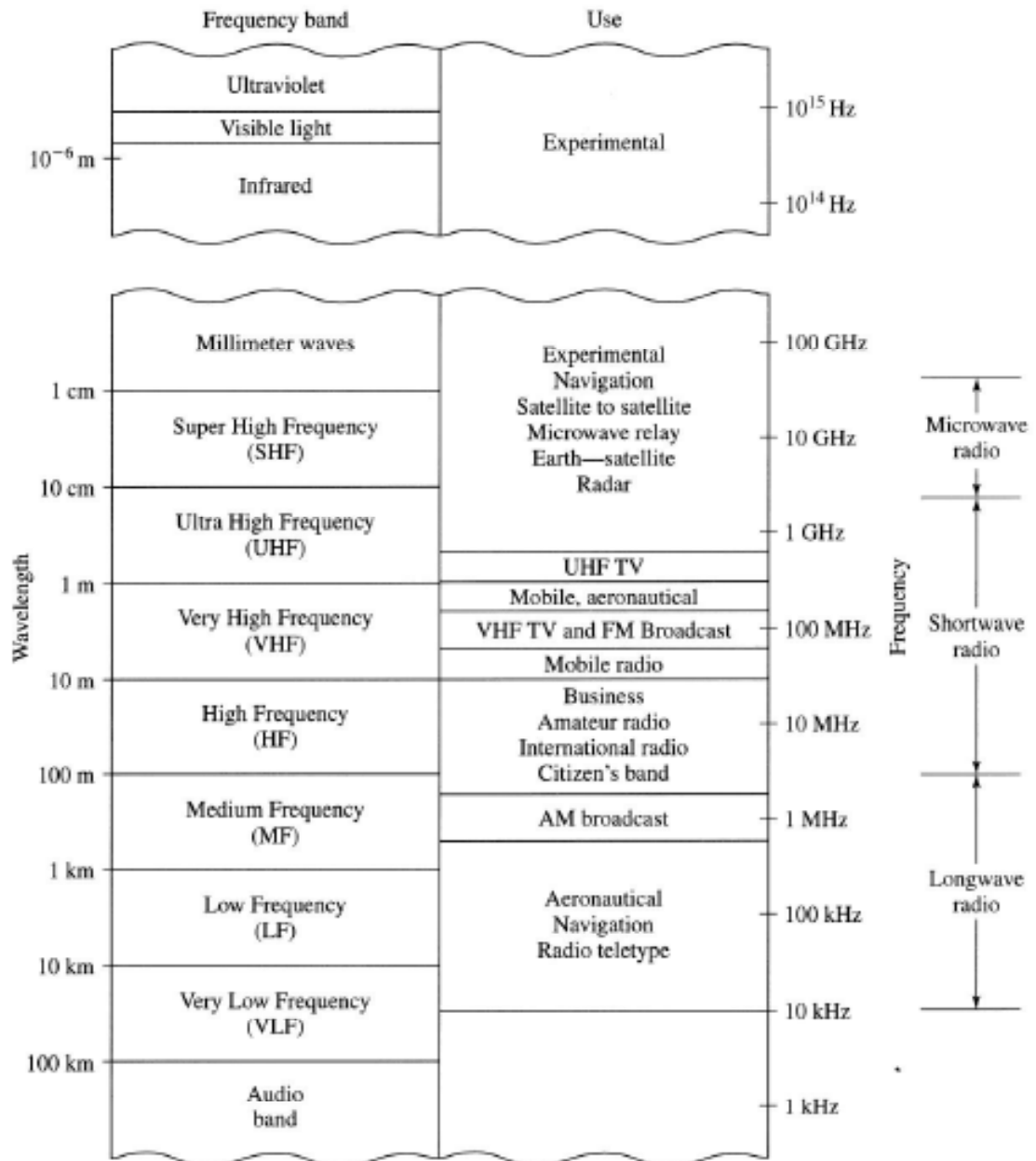
# Wireless Electromagnetic Channels

- ❑ EM energy is radiated to the propagation medium (e.g. free space) by an **antenna**
- ❑ The size and configuration of the antenna depends on the frequency of operation
  - Must be longer than  $1/10$  of the wavelength



## Radio spectrum:

The set of all frequencies from 0Hz to infinity is known as the **radio spectrum** and is used for many different applications



# Spectrum Regulation

---

- ❑ Radio waves travel or propagate through a common channel that everybody shares
- ❑ That is for a particular frequency only one person, user or company can use it – otherwise there will be interference and chaos!
- ❑ The government effectively owns the radio spectrum and regulates it
- ❑ The government of different countries must coordinate the regulation of the spectrum
  - ITU (International Telecommunication Union)



# Spectrum Regulation – Licensed

Service/system	Frequency span
AM radio	535-1605 kHz
FM radio	88-108 MHz
Broadcast TV	54-88 MHz, 174-216 MHz, 470-806 MHz
Broadband wireless	746-764 MHz, 776-794 MHz
3G systems	1.7-1.85MHz, 2.5-2.69 MHz
1G and 2G cellular phones	806-902 MHz, 1.85-1.99 GHz
Satellite digital radio	2.32-2.325 GHz
Multichannel multipoint distribution service (MMDS)	2.15-2.68 GHz
Digital broadcast satellite (Satellite TV)	12.2-12.7 GHz
Local multipoint distribution service (LMDS)	27.5-29.5 GHz, 31-31.3 GHz
Fixed wireless services	38.6-40 GHz

# Spectrum Regulation– Unlicensed

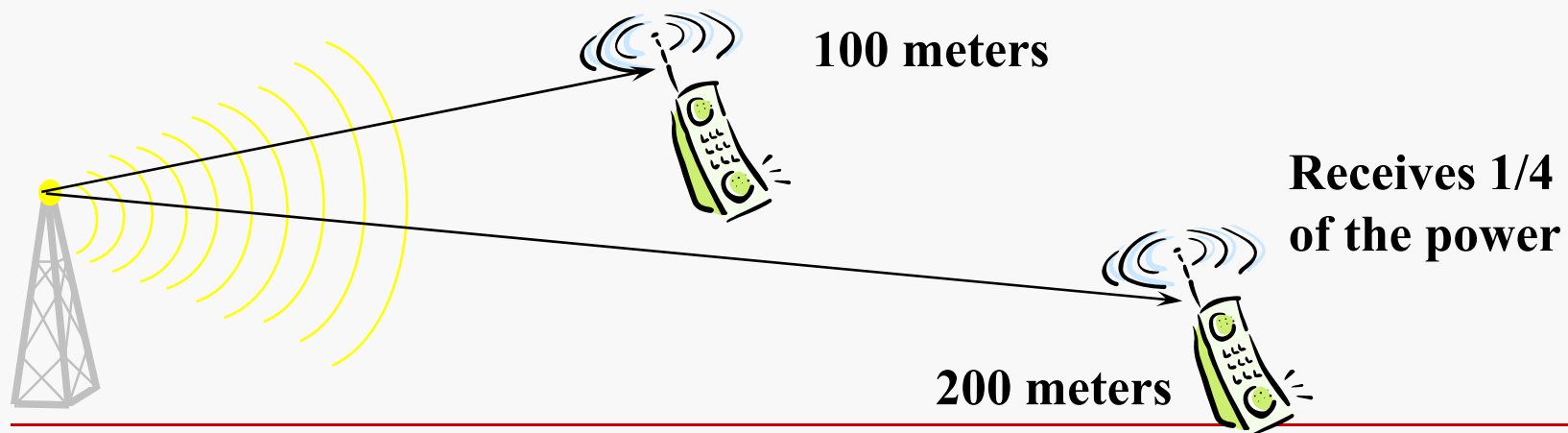
Band	Frequency
ISM band I (Cordless phones, 1G WLAN)	902-928 MHz
ISM band II (Bluetooth, 802.11b/g WLAN)	2.4-2.4835 GHz
U-NII band I (Indoor systems, 802.11a WLAN)	5.15-5.25 GHz
U-NII band II (short-range outdoor systems, 802.11a WLAN)	5.25-5.35 GHz
U-NII band II (Long-range outdoor systems, 802.11a WLAN)	5.725-5.825 GHz

# Propagation

## Free-space propagation model

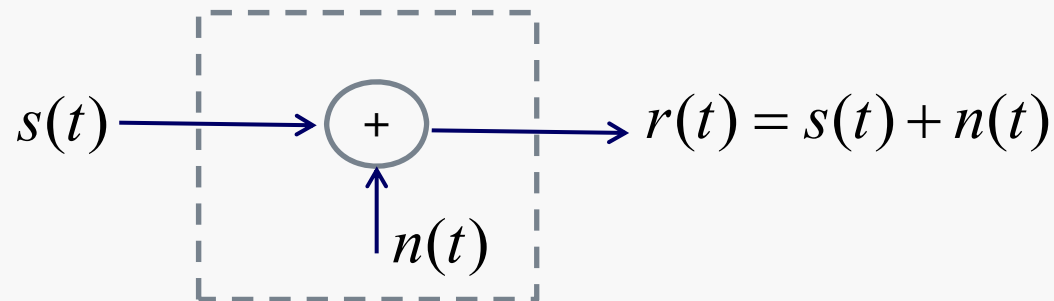
$$P_r = P_t G_t G_r \left( \frac{\lambda}{4\pi d} \right)^2$$

- $P_t$  : transmit power
- $P_r$  : receive power
- $G_t$  : transmit antenna gain
- $G_r$  : receive antenna gain
- $\lambda$  : wavelength
- $d$  : distance

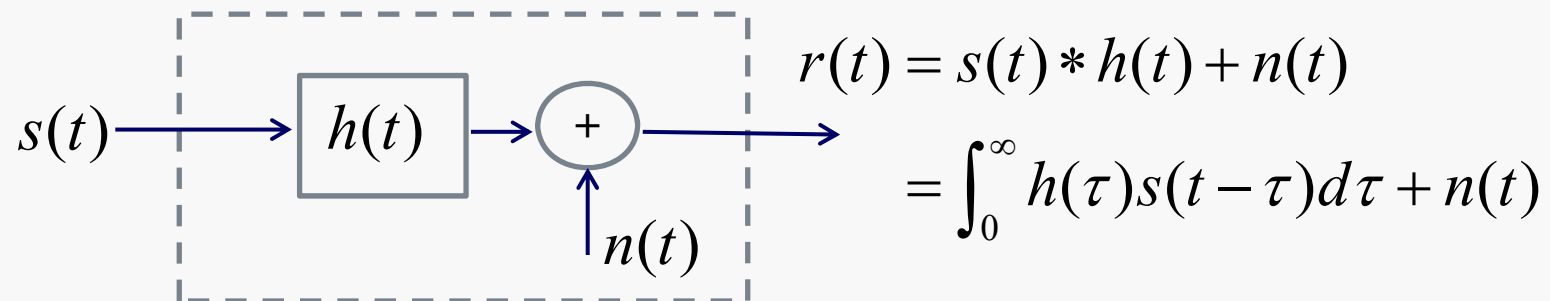


# Mathematical Models

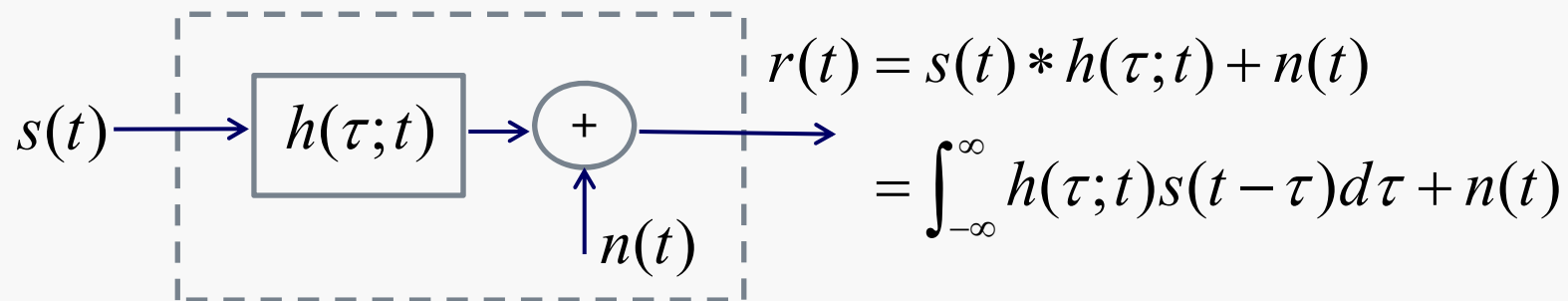
## □ The additive noise channel



## □ Linear filter channel



## □ Linear time-variant filter channel



### ■ Consider a multi-path signal propagation

$$h(\tau; t) = \sum_{k=1}^L a_k(t) \delta(t - \tau_k)$$

These three channel models are used throughout this course for the analysis and design of communication systems

# What are the Features of a Good Communication System?

---

- ❑ Small signal power (measured in Watts or dBW)
- ❑ Large data rate (measured in bits/sec)
- ❑ Small bandwidth (measured in Hertz)
- ❑ Low distortion (measured in SNR or bit error rate)
- ❑ Low cost – with digital communications, large complexity does not always result in large cost

In practice, there must be tradeoffs made in achieving these goals

# Tradeoff (1): Data Rate vs. Bandwidth

## ❑ Bandwidth efficiency

$$\text{bandwidth efficiency} = \frac{\text{data rate } R}{\text{bandwidth } W} \text{ bits/sec/Hz}$$

- ❑ We want large bandwidth efficiency
- ❑ Increased data rate leads to shorter data pulses which leads to larger bandwidth
- ❑ This tradeoff cannot be avoided
- ❑ Some modulation schemes use bandwidth more efficiently than others

# Tradeoff (1): Fidelity vs. Signal Power

## ❑ Energy Efficiency

$$\text{energy efficiency} = \frac{\text{bit energy}}{\text{noise power spectral density}} = E_b/N_o$$

- ❑ We want small  $E_b/N_o$  to save power
- ❑ One way to get an error free signal would be to use huge amounts of power to blast over the noise – not practical
- ❑ Some types of modulation achieve relative error free transmission at lower power than others



## Tradeoff (3): Bandwidth Efficiency vs. Energy Efficiency

---

- ❑ It is possible for a system designer to trade between bandwidth efficiency and energy efficiency
  - Binary modulation sends only one bit per use of the channel; M-ary modulation can send multiple bits, but is more vulnerable to errors
  - Error correction coding: inserting redundant bits improves bit error rate, but increases bandwidth
- ❑ This is the **fundamental tradeoff** in digital communications.