

Principles of Communications



Lecturer:

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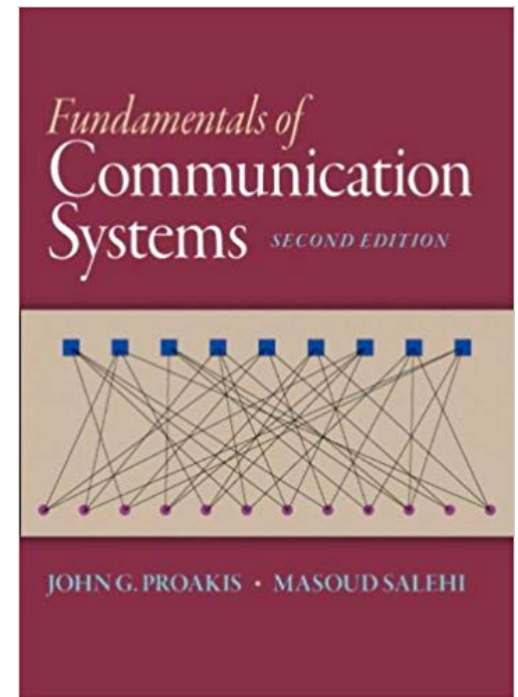
Chapter 1: Introduction

Staff

- Lecturer:
 - Weiyao Lin (林巍骁)
 - Office: Room 1-301, SEIEE Buildings
 - Email: 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

Textbook

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



- References:
 - “An introduction to analog and digital communications”, by Simon Haykin, 2nd edition, John Wiley & Sons, 2007
 - "Communications Systems Engineering", by John G. Proakis and Masoudsalehi, 2nd 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>
- 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!

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	Tutorial and Mid-term Test (To be confirmed)

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

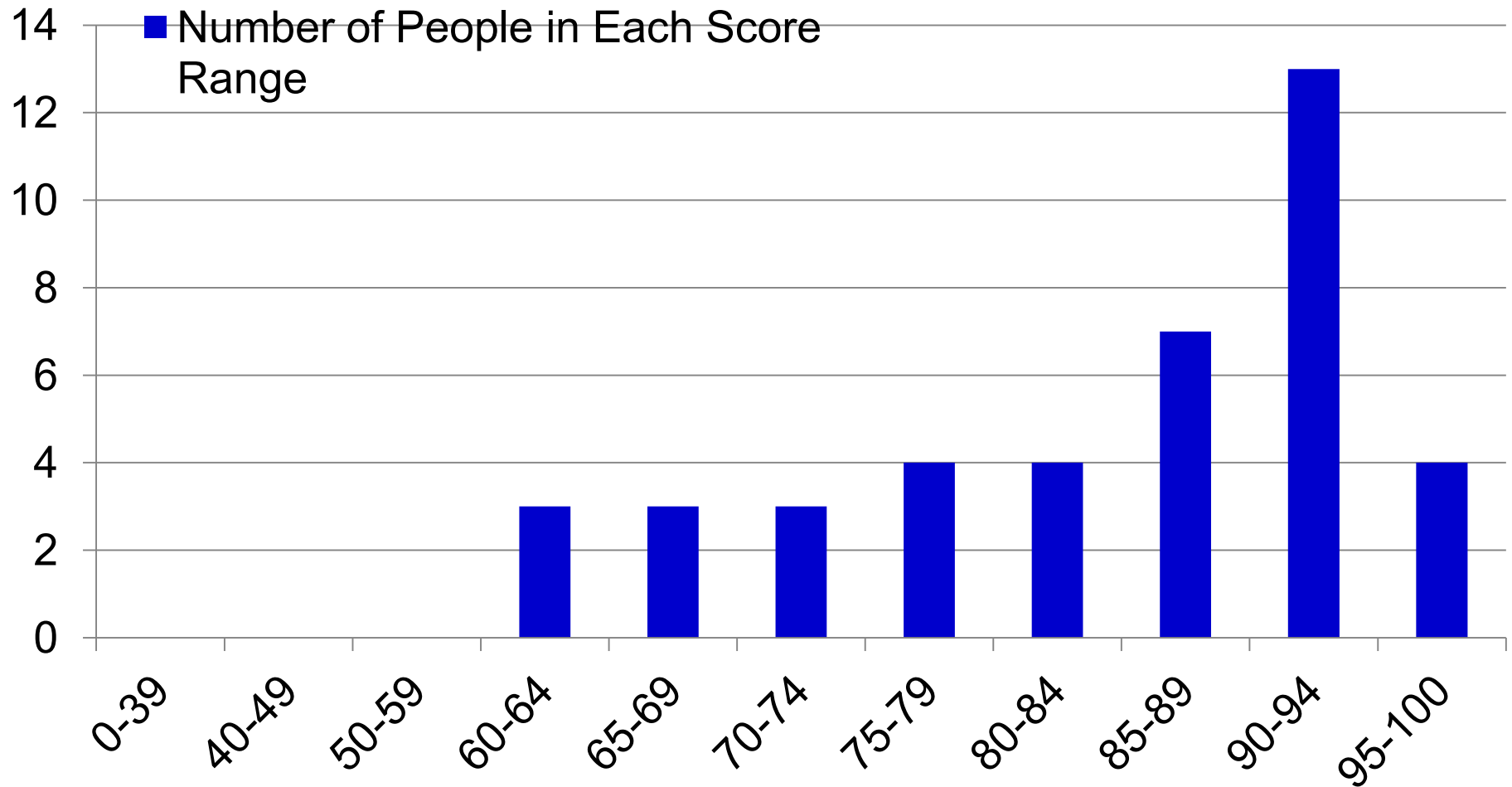
Lab courses

- Yuhong Yang (杨宇红) yangyuhong@sjtu.edu.cn
- Schedule (To be confirmed):
 - **Week 4 Wednesday** (4:00-5:40 PM, 东上院100号)
 - Introduction of LabView and Lab projects
 - **Week 9 Wednesday** (4:00-5:40 PM, 东上院100号)
 - Signal generator, Matched filter, Channel equalization
 - **Week 14 Wednesday** (4:00-5:40 PM, 东上院100号)
 - BPSK/QPSK etc
 - **Week 16 Wednesday** (4:00-5:40 PM, 东上院100号)
 - Exploration Project

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 20th 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?

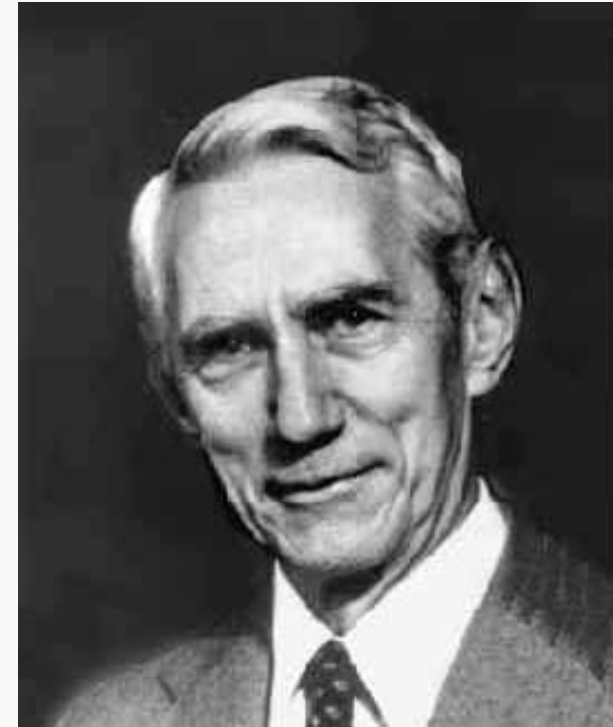
Harry Nyquist (1928)

- ❑ 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?

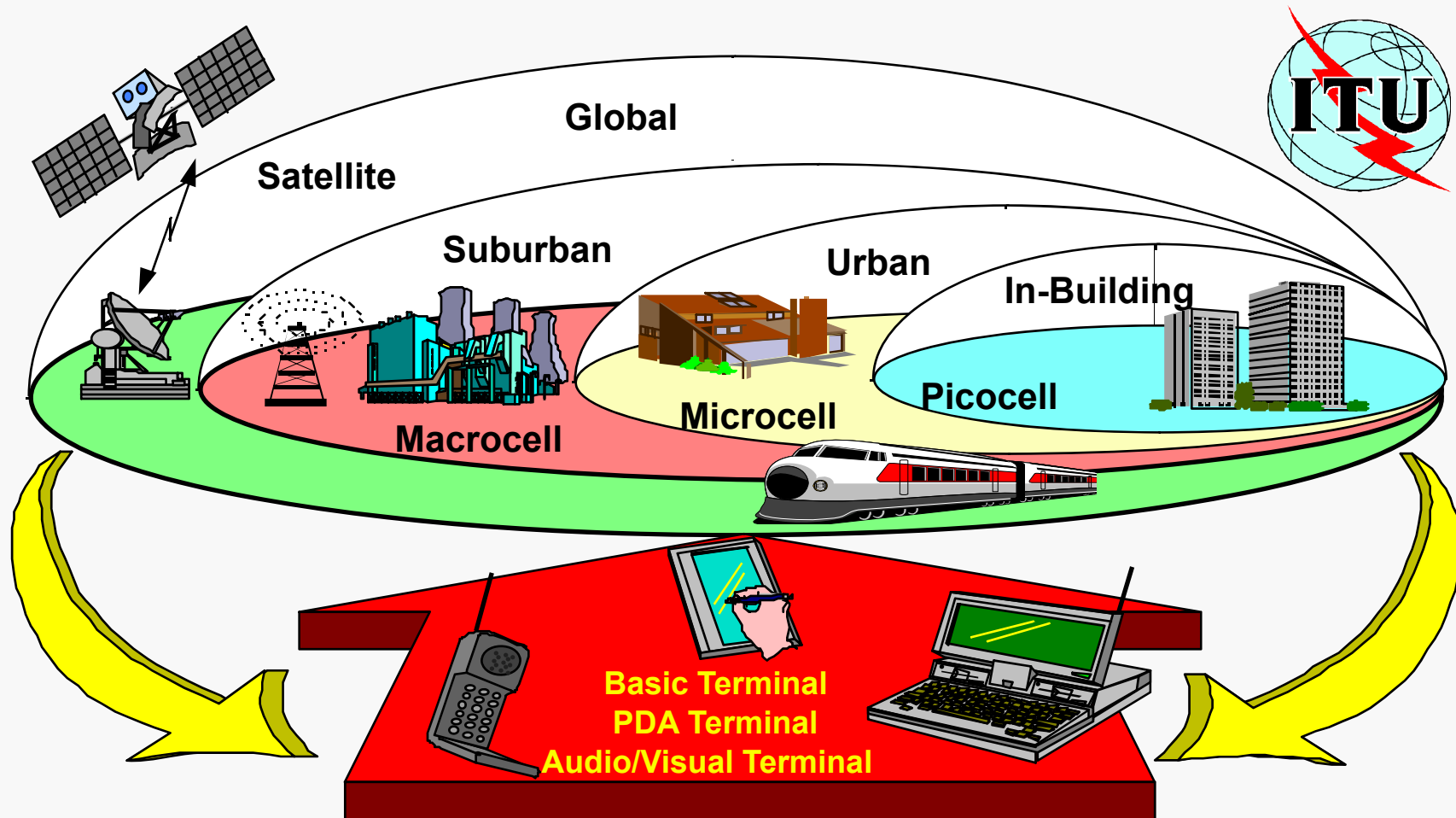


Claude Shannon (1948)

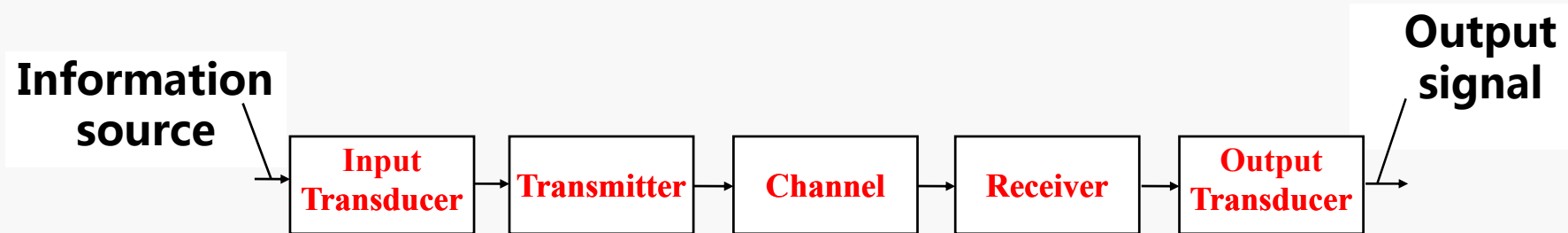
- ❑ Shannon's information theory solves all the big questions
- ❑ Shannon describes information source and channel with probability
- ❑ There exists an entropy rate H bits/sec for each source
- ❑ There exists a capacity C bits/sec for each channel
- ❑ If and only if $H \leq C$, the information can be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



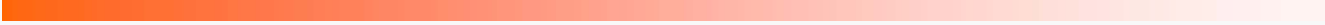
60 Years Later...



Elements of Communication Systems

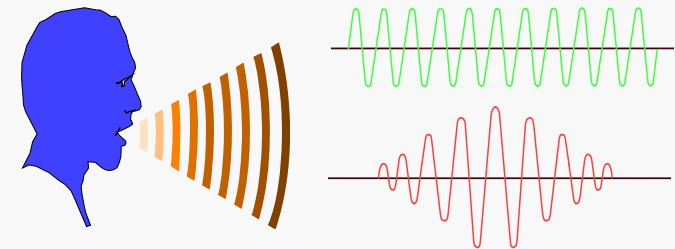


- ❑ Software
- ❑ Hardware
- ❑ Communication architecture, with coding and signal processing algorithms

- 
- ❑ **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



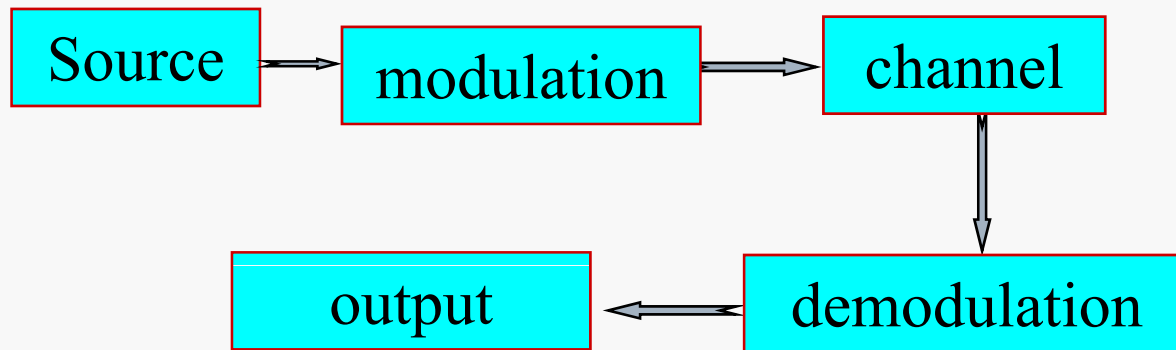
□ Digital Communications

- 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)

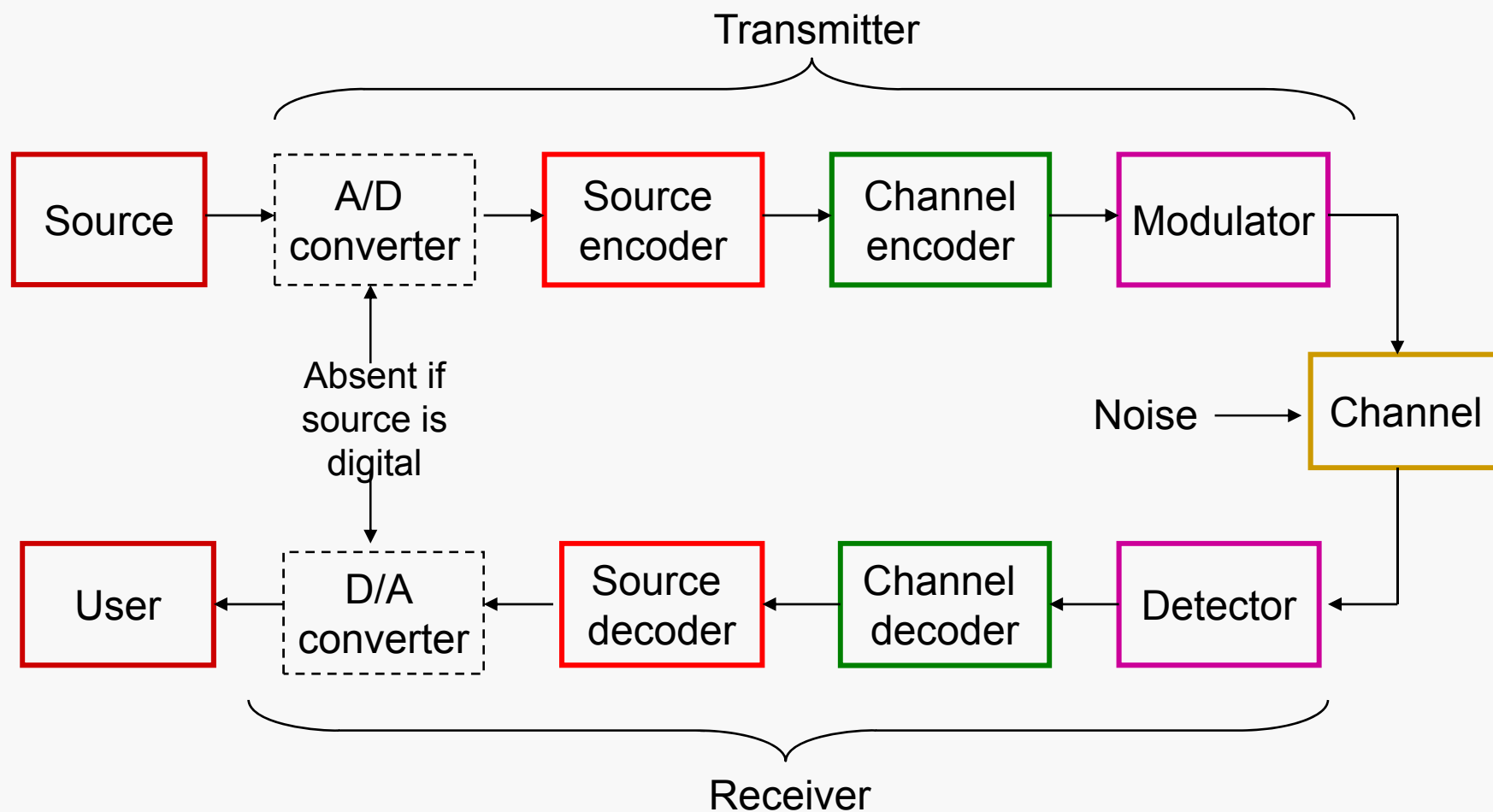


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Analog Communication Systems



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?

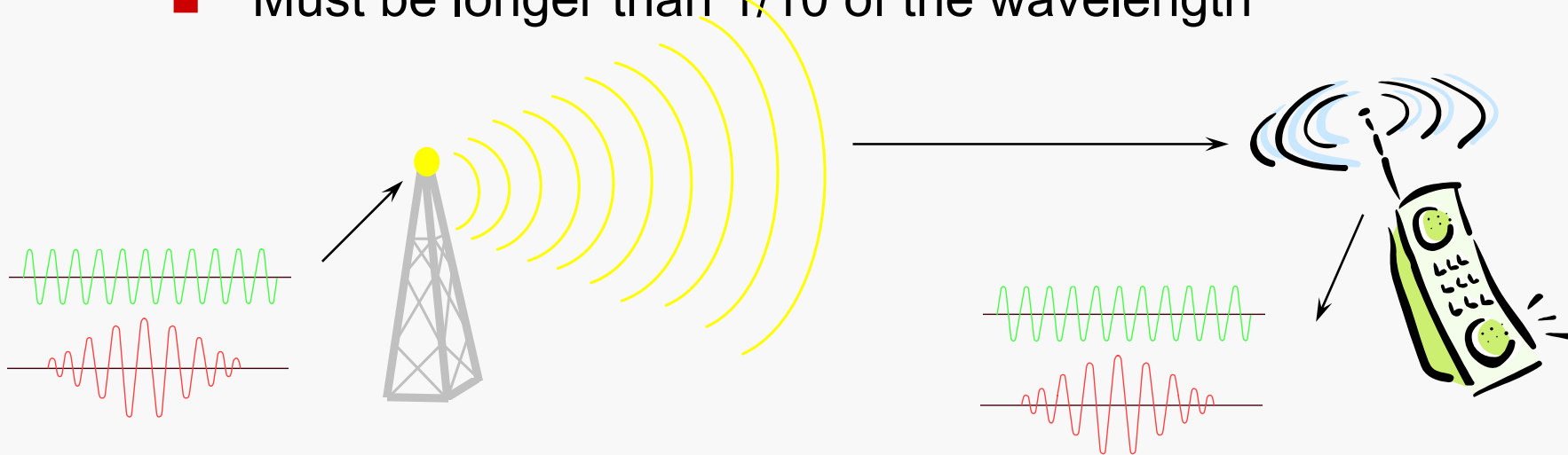
- ❑ **Robustness** to channel noise and external Interference
 - Many signal processing techniques are available to improve system performance: source coding, channel (error-correction) coding, equalization
- ❑ **Security** of information during its transmission from source to destination
 - various 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

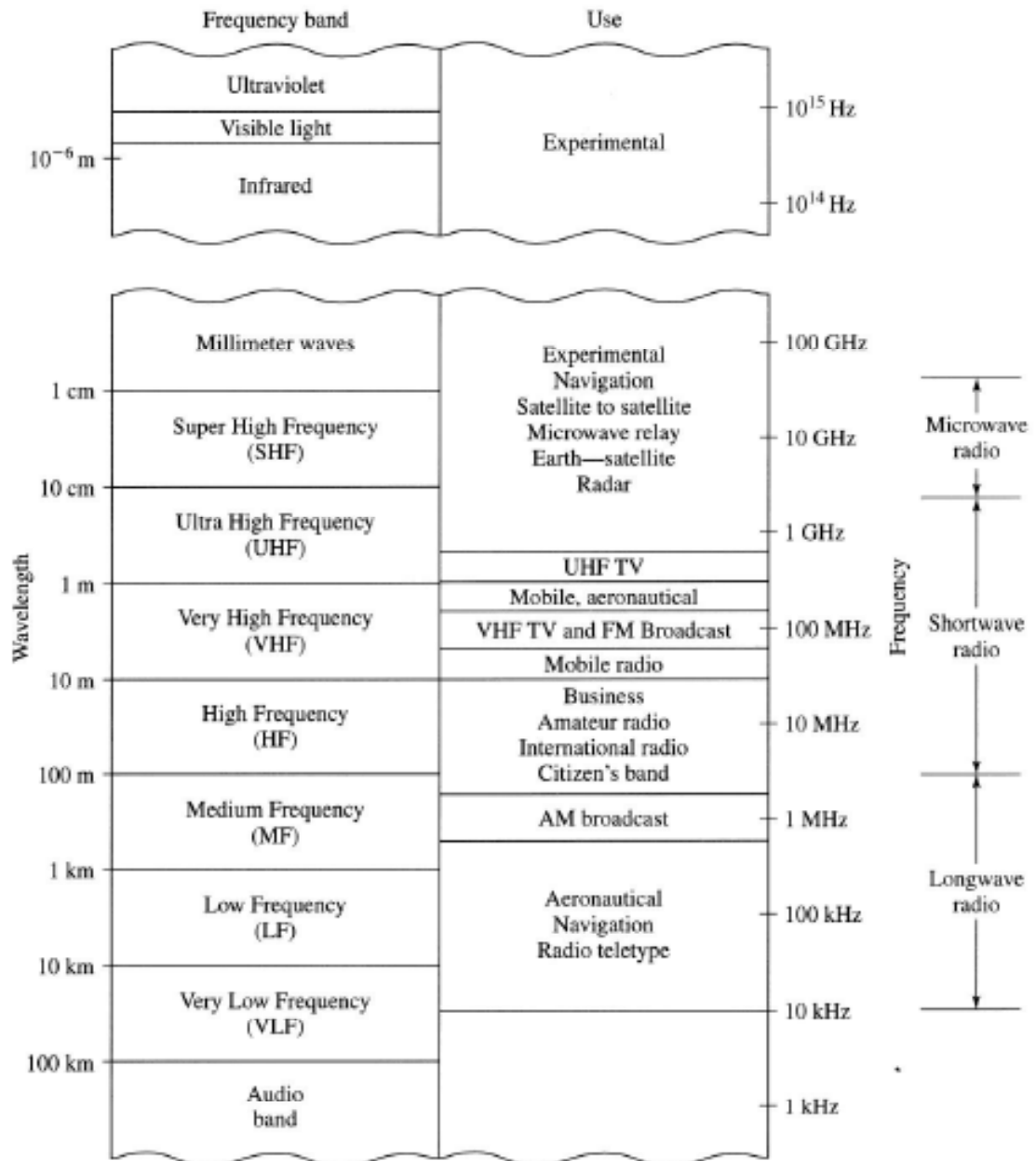
Wireless Electromagnetic Channels

- ❑ 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

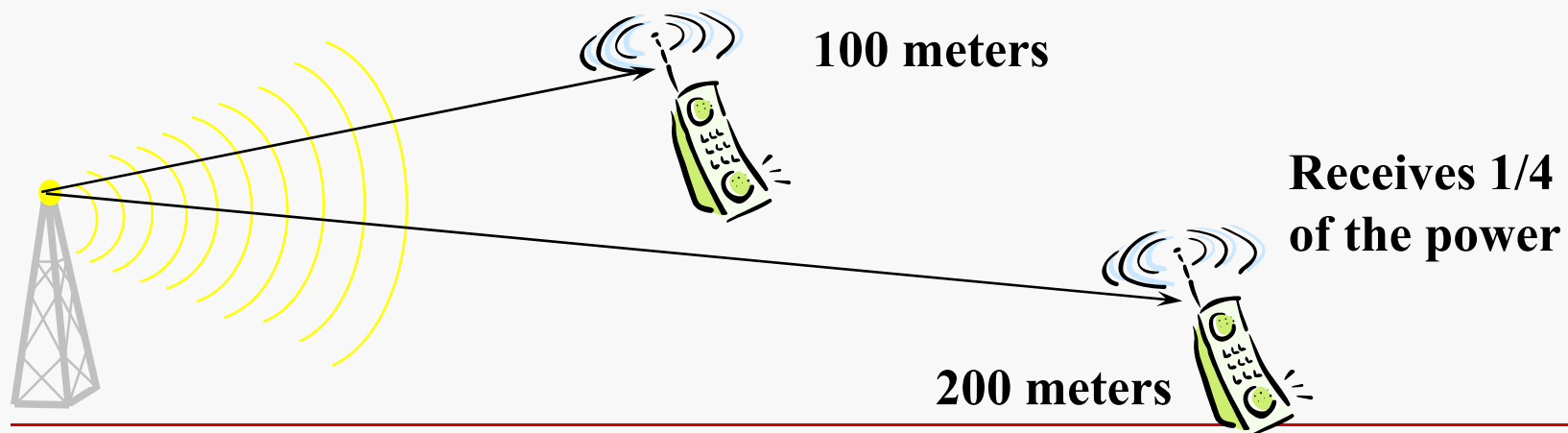
Band	Frequency
ISM band I (Cordless phones, 1G WLAN)	902-928 MHz
ISM band II (Bluetooth, 802.11b/g WLAN)	2.4-2.4835 GHz
U-NII band I (Indoor systems, 802.11a WLAN)	5.15-5.25 GHz
U-NII band II (short-range outdoor systems, 802.11a WLAN)	5.25-5.35 GHz
U-NII band II (Long-range outdoor systems, 802.11a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

Propagation

Free-space propagation model

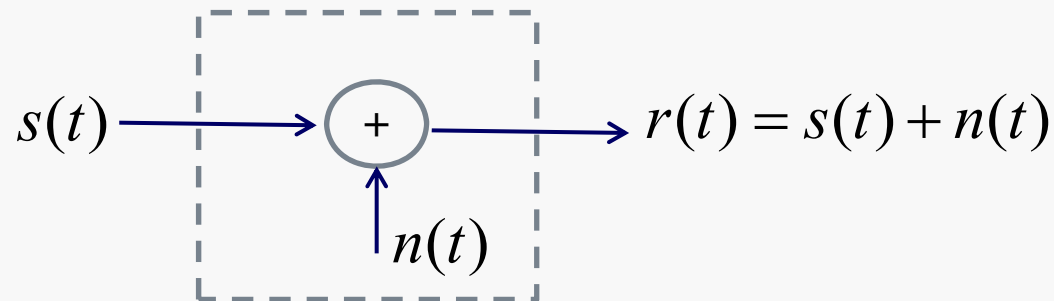
$$P_r = P_t G_t G_r \left(\frac{\lambda}{4\pi d} \right)^2$$

- P_t : transmit power
- P_r : receive power
- G_t : transmit antenna gain
- G_r : receive antenna gain
- λ : wavelength
- d : distance

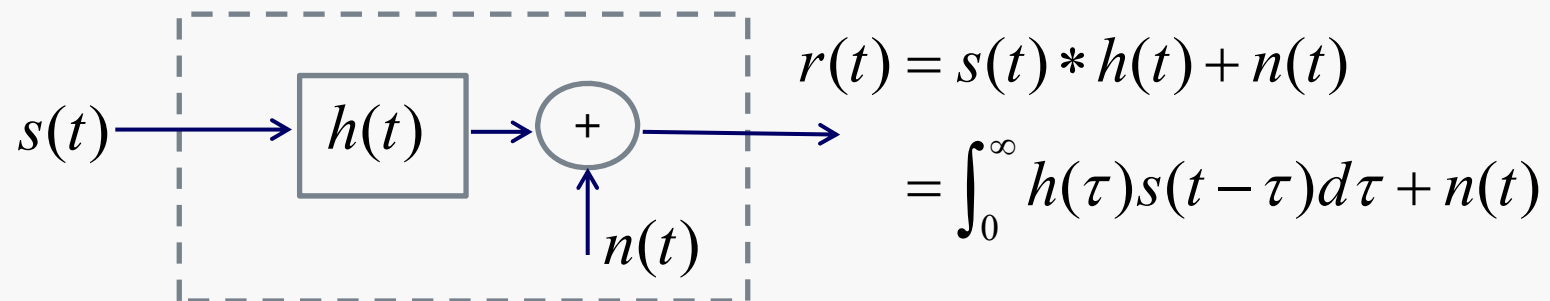


Mathematical Models

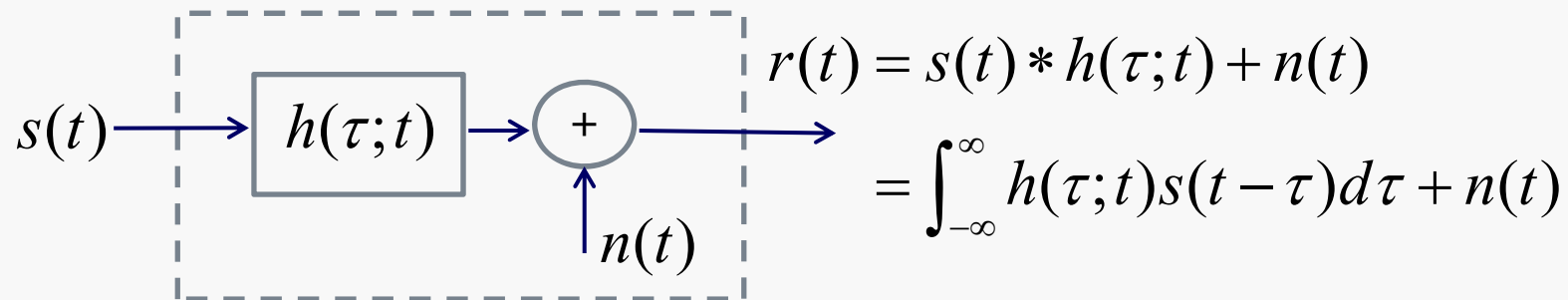
□ The additive noise channel



□ 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.