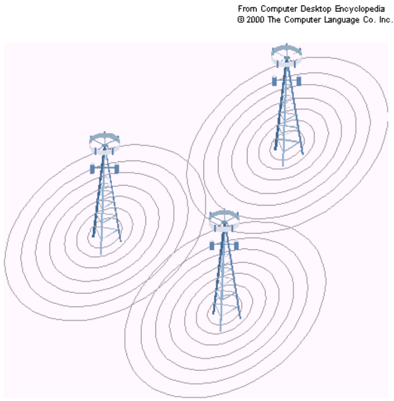
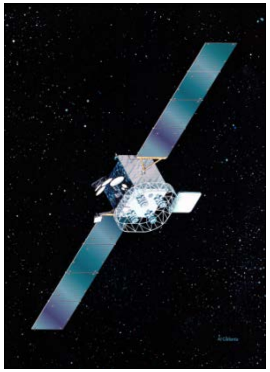
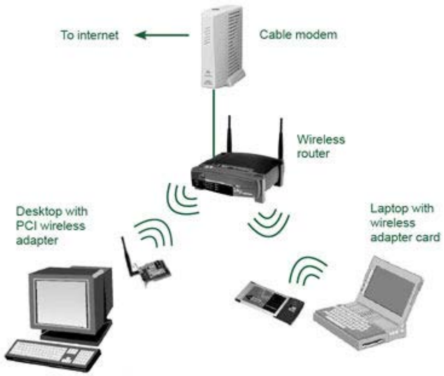
ELEC 3100: Signal Processing and Communications







Jun ZHANG

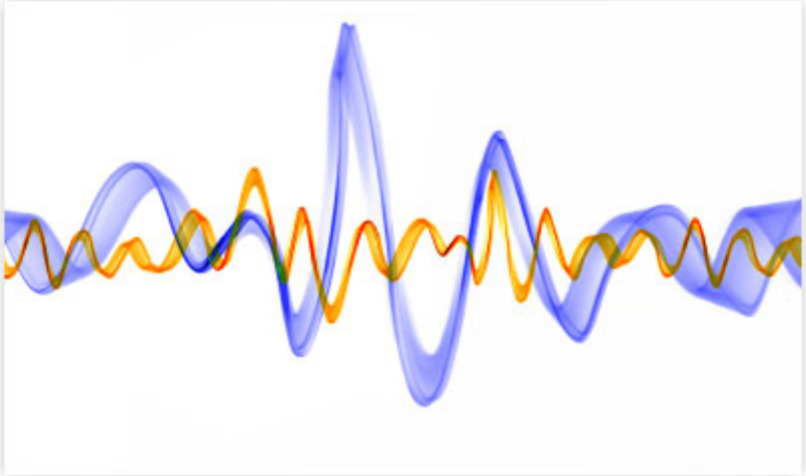
Department of Electronic and Computer Engineering

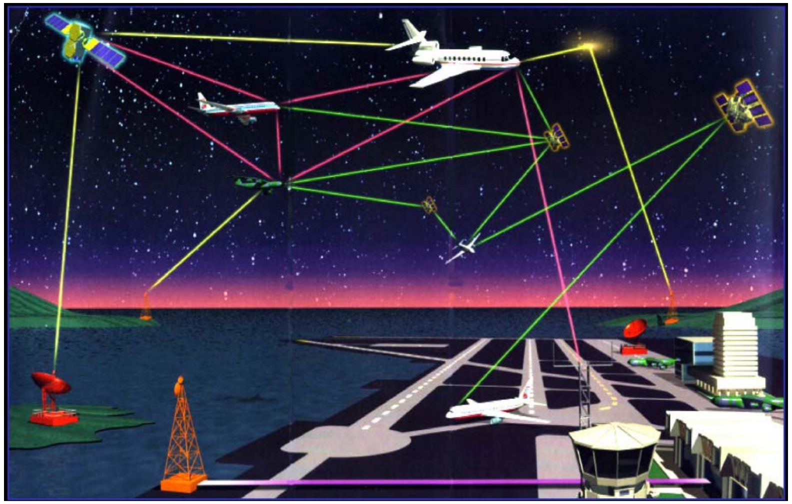
Hong Kong University of Science and Technology

Today's Lecture

- General Course Information

- Overview of Signal Processing and Communications Systems





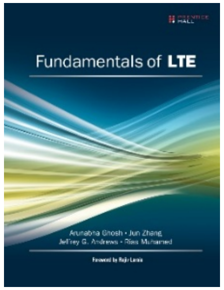
ELEC 3100

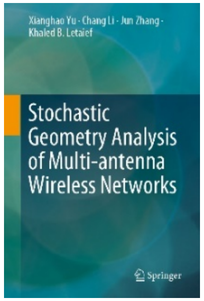
- **Instructor: Prof. Jun ZHANG**
  - **Office: 2430**
  - **Email: eejzhang@ust.hk**

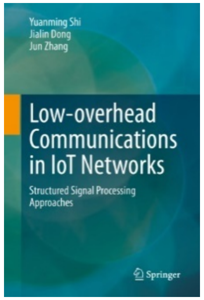
- **Available in Canvas**
  - **Course Syllabus**
  - **Notes for Lecture, Tutorial, and Labs**
  - **Homework and Solution**

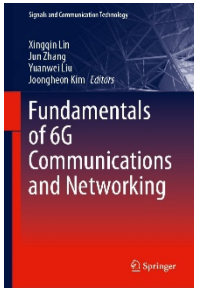
Background

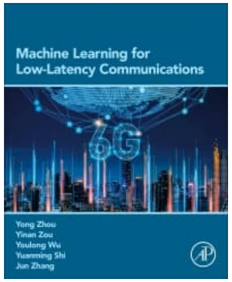
- **Prof. Jun ZHANG** (https://eejzhang.people.ust.hk/)
  - **IEEE Fellow**
  - **Distinguished Lecturer**, *IEEE Communications Society*
  - **PhD**, UT Austin
- Research interests
  - **Wireless communications and networking**
  - **Mobile edge computing and edge AI**
  - **Cooperative AI**
- Research awards
  - IEEE **Communications Society** & **Information Theory Society** Joint Paper Award, 2019
  - IEEE **Signal Processing Society** Young Author Best Paper Award, 2016, 2018
  - The Marconi Prize Paper Award in Wireless Communications, 2016
  - IEEE Communications Society Asia-Pacific **Best Young Researcher Award**, 2016











Course Schedule

- **Lecture: 3 hours per week**
  - 10:30am-11:50am, Tuesday, Thursday
  - LG3009, Lift 10-12

- **TAs:**
  - LIU, Zhening (zhening.liu@connect.ust.hk)
  - LI, Teng (tliby@connect.ust.hk)
  - ZHUANG, Yufan (yufan.zhuang@connect.ust.hk)
  - XUE, Yufei (yufei.xue@connect.ust.hk)

Timetable

ELEC3100	Mon	Tue	Wed	Thu	Fri
09:00 - 09:30					
09:30 - 10:00				T1	
10:00 - 10:30				2463	
10:30 - 11:00		L1		L1	T2
11:00 - 11:30	LA2				2503
11:30 - 12:00	4225C	LG3009		LG3009	
12:00 - 12:30					LA1
12:30 - 13:00					4225C
13:00 - 13:30					
13:30 - 14:00					
14:00 - 14:30					
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18:30 - 19:00					
19:00 - 19:30					
19:30 - 20:00					

Timetable

Tutorial schedule:

- Tutorial 1: Feb 13, Feb 14
- Tutorial 2: Feb 20, Feb 21
- Tutorial 3: Feb 27, Feb 28
- Tutorial 4: Mar 6, Mar 7
- Tutorial 5: Mar 13, Mar 14
- Tutorial 6: Mar 20, Mar 21
- Tutorial 7: Apr 10, Apr 11
- Tutorial 8: Apr 24, Apr 25
- Tutorial 9: May 8, May 9

Lab schedule:

- Lab 1: Feb 28, Mar 3
- Lab 2: Mar 14, Mar 17
- Lab 3: Apr 11, Apr 14
- Lab 4: Apr 25, Apr 28

Textbooks

- **Textbooks**

(1) **Sanjit K. Mitra**, “Digital Signal Processing,” McGraw-Hill, **4th Ed., 2011**.
(2) **John G. Proakis**, “Digital Communications,” **5th Ed., 2008**.

thick!

- **References**

(3) **R.E. Ziemer and W.H. Tranter, “***Principles of Communications*: *Systems, Modulation, and Noise,*” **Wiley, 6th Ed., 2009.**
(4) **F.G. Stremler**, “*Introduction to communication systems”,* **Addison-Wesley, 3rd Ed., 1990.**
(5) **S. Haykin, “***Communication Systems***”, 4th Ed., Wiley, 2001**
(6) **S. Haykin, “***An Introduction to Analog & Digital Communications***”, Wiley, 1989.**
(7) **A.B. Carlson, “***Communication Systems: An Introduction to Signals and Noise in Electrical Communication***”, 5th Ed., McGraw Hill, 2010.**

- **Books (1) and (2) are on reserve at the library.**
- **Books (3), (4), (5), (6) and (7) are on book collection at the library.**

Course Grading

- **Final grade will be determined as a weighted combination of the homework, lab, midterm, final exam according to the following:**

Midterm (7pm-9pm, Mar 25, 2025)	**30%**
Final	**45%**
Lab x4	**10%**
Homework x3	**15%**

- **Exams: 1 Midterm & 1 comprehensive Final**
  - **Closed book and notes**
  - ✓ **For final, 1 A4 size cheat sheet (handwritten)**
  - **Formulas, equations, tables will be provided**

Homework

- **Homework will be posted in Canvas regularly with stated due dates. No late homework will be accepted.**
- **It is very important that you do the homework in order to understand the material covered in class.**
- **You will benefit most from the homework if you attempt to do the problems before consulting your friends, instructor and TAs.**
- **The homework should be your own and not a copy of your friend's.**

Laboratory

- **Matlab-simulation based**
- **If you will be unable to attend a lab during the course of the semester, you are required to make prior arrangements with TA.**
- **No make-up lab will be arranged unless a strong reason can be provided.**

MATLAB®
The Language of Technical Computing

Overview

- This course provides a broad treatment of signal processing and communications: discrete time signals and systems, filter design, source coding, channel coding, digital modulation theory, channel models, and noise effects.

- The objective is to:
  - Comprehend the basic theory about signal processing including discrete-time signals and systems, and filter design.
  - Have a basic understanding of communications systems including source coding, channel coding, digital modulation, detection theory, and error analysis.

Necessary Background

ONLY Top 5 >.<

Prerequisite: ELEC2100 + ELEC2600

focus Discrete!

- It is assumed that students taking this course are familiar with signal + systems and probability. - noise

  2100 2600 後半

- Important concepts will be explained qualitatively using real-life examples.

- However, as an engineering student, extensive use of mathematics is necessary for accurate system modeling and analysis.

$P[X < x]$

X: RV

x: Threshold

eg. SNR 雜訊比，噪音的比例

SNR $\downarrow$, noise $\uparrow$

$= \int_0^{x_0} p(x)\,dx$ if X is continuous

$p(x)$: pdf

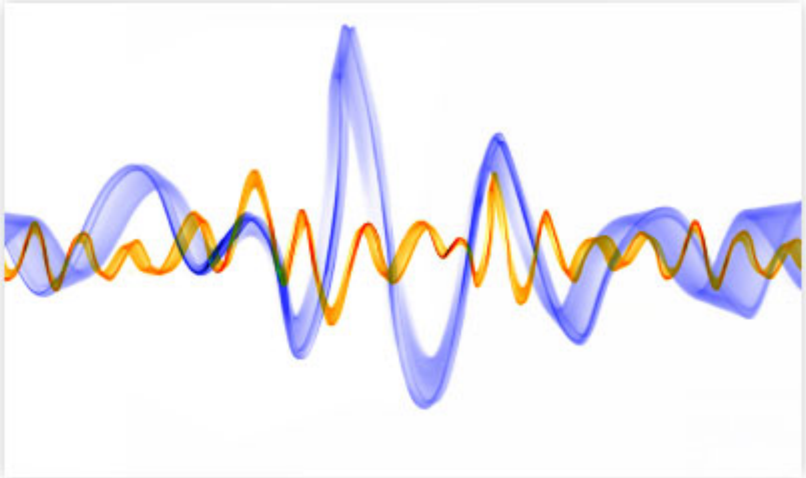
e.g. $X \sim N(m, \sigma^2)$

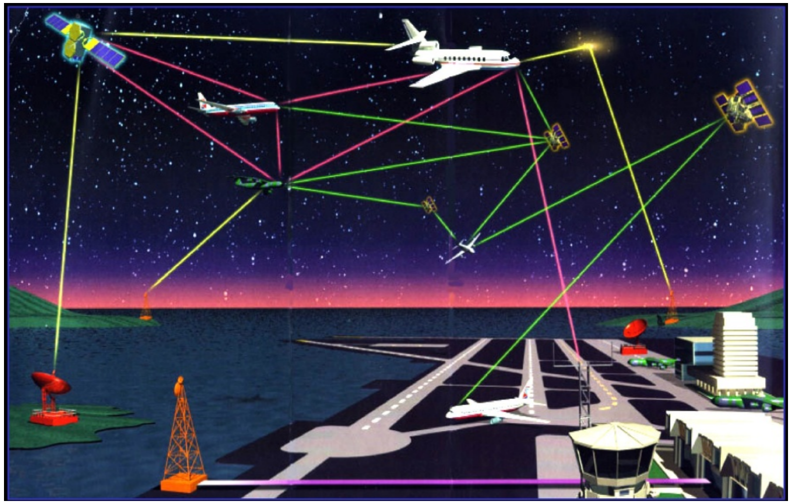
$= \sum_x p[x]$ if X is Discrete

$p[x]$: pmf

Today's Lecture

- General Course Information
- **Overview of Signal Processing and Communications Systems**

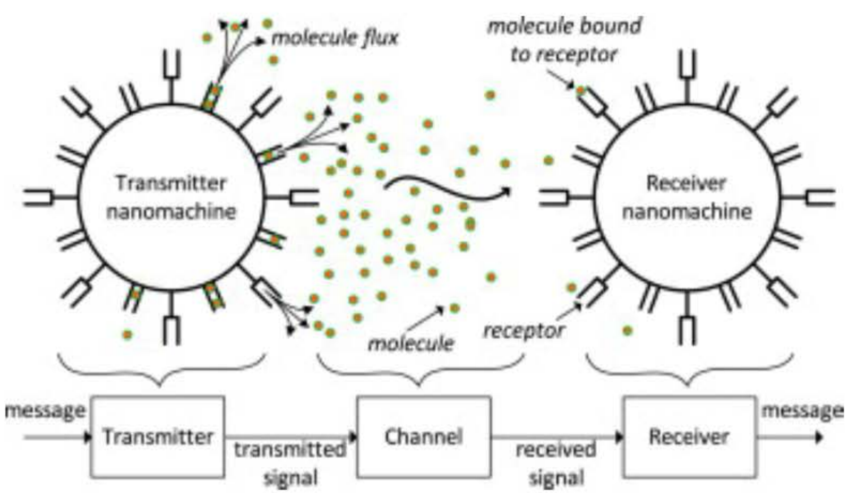




Communication

→ formulae this system to mathematical term

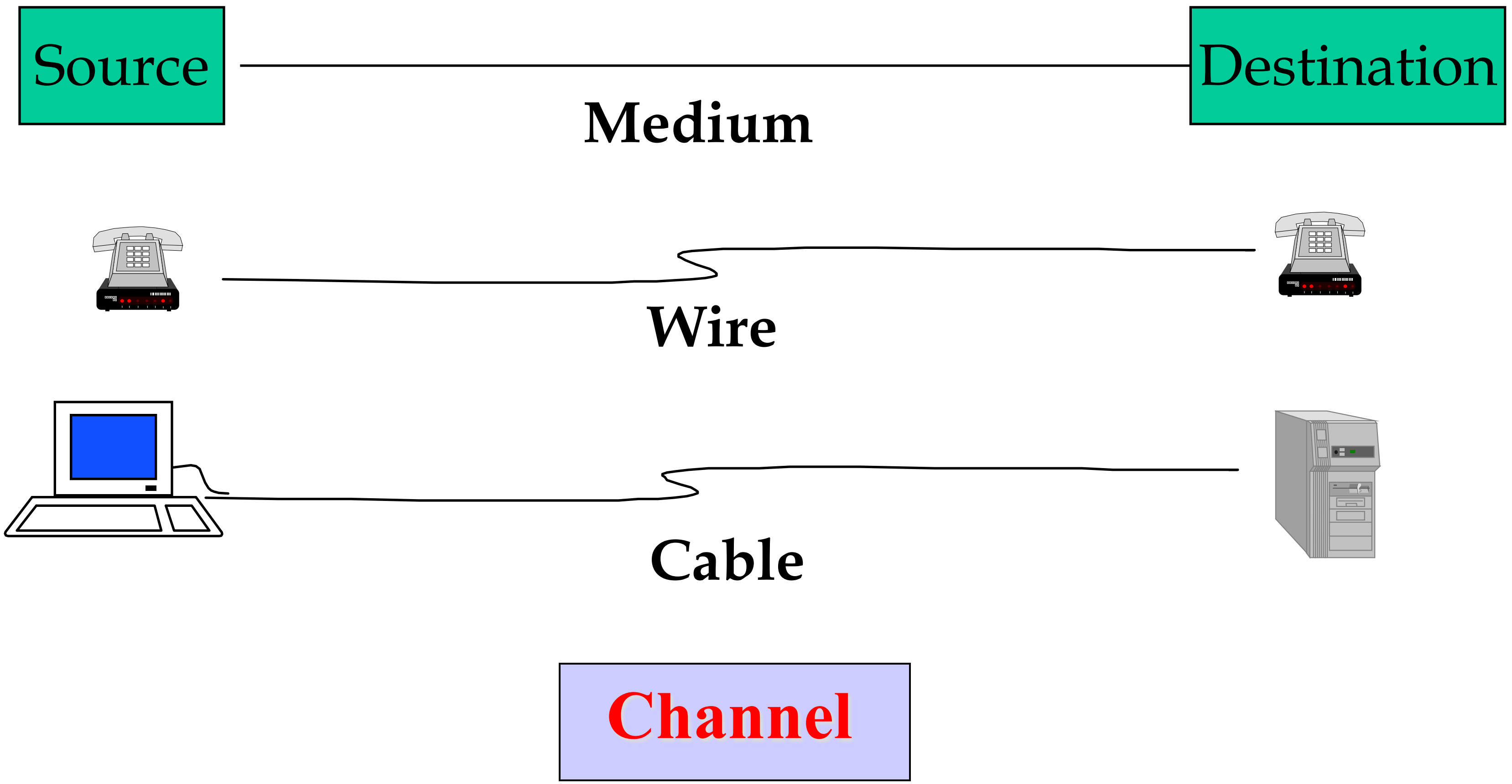
- What is "communication"?
  - Transfer of "information" from one location to another location
- Examples
  - Telecommunication
  - Short-range communication
  - Molecular communications



Why this is not a practical means of telecommunication?

Efficiency
Reliability

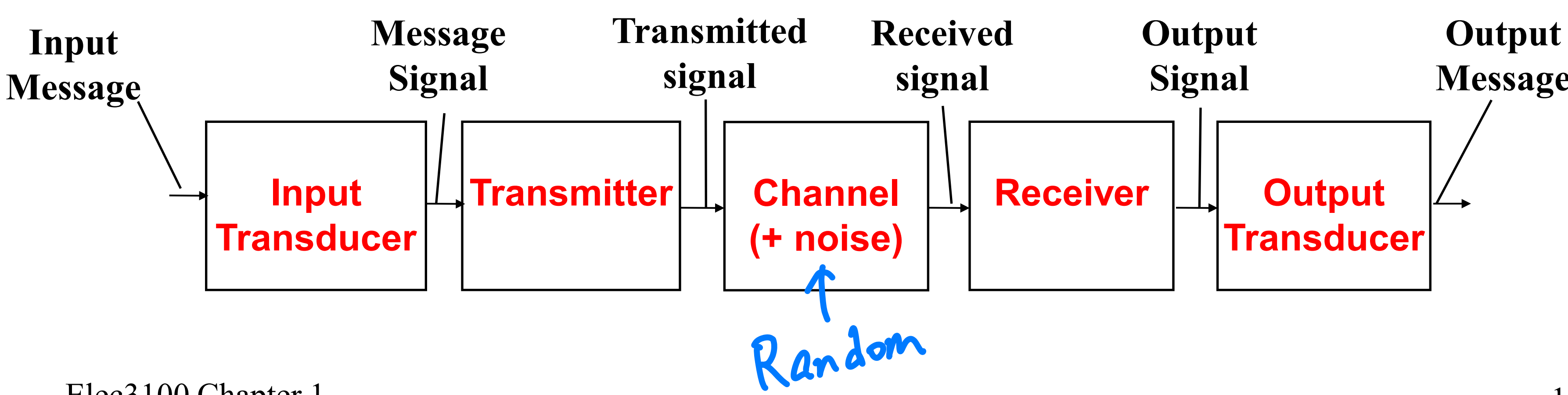
Communications Systems



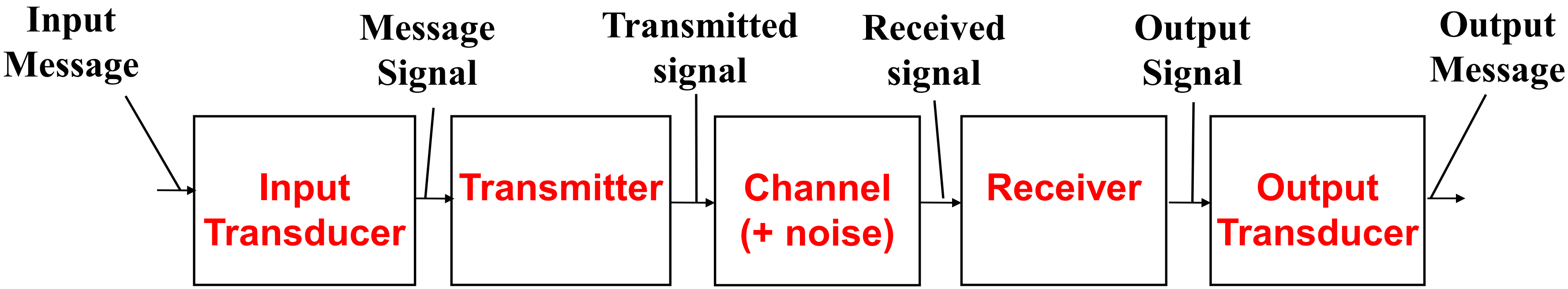
Communications Systems

- From engineers' point of view, **Communications** involves the **transmission of information or messages** from one point to another.

- A block diagram of a typical communications system is shown below



- **Input Transducer**
  - converts original message into an appropriate electrical form - microphone, video camera, temperature or pressure sensor, etc
- **Transmitter**
  - couples electric message to the channel –antenna, laser
- **Channel**
  - medium carring message between the two points- twisted pair, coax, wireless or optical fiber.
- **Receiver**
  - extracts original electric signal among many signals in the channel – antenna, photodetector
- **Output transducer**
  - recovers message from the electric signal - speaker



- No matter whether the communications system is for mobile telephones, pagers, TV or computers, these 5 components will always be present.

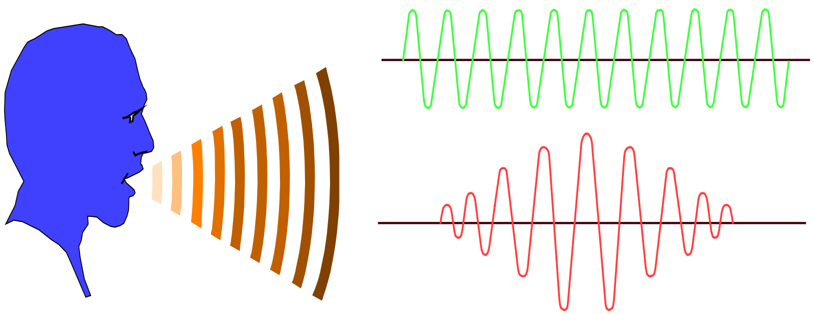
- Yet each specific communications system is unique in its implementation and design. Its design depends on many factors and constraints:
  - bit rate, transmission distance, transmission medium, cost, number of user, quality of service

Transmission Systems

Difficult to talk the noise Receive.

- **Analog Communications**
  - Information is from an analog source
  - Signal waveform changes according to information content
  - Fidelity is usually defined in terms of SNR. Signal-to noise ratio

방지를 control



- **Digital Communications**
  - Information is from a digital source or a digitized analog signal
  - Signal is made up of discrete symbols selected from a finite set (e.g., binary data)
  - Fidelity or Accuracy is specified in terms of bit error rate (probability of making a bit error).

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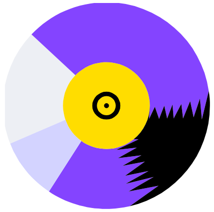
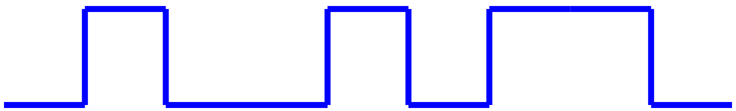




Transmission Protocols

- **Simplex**
  - Communication flow can only occur in **one direction** (**e.g., typical courses at HKUST**)
- **Half Duplex**
  - Communication flow can occur in **both directions, but not at the same time**
- **Full Duplex**
  - Communication link can support **simultaneous two-way communications**.

Simplex
Broadcast radio or TV

Half Duplex
Walkie-Talkies, CB radio

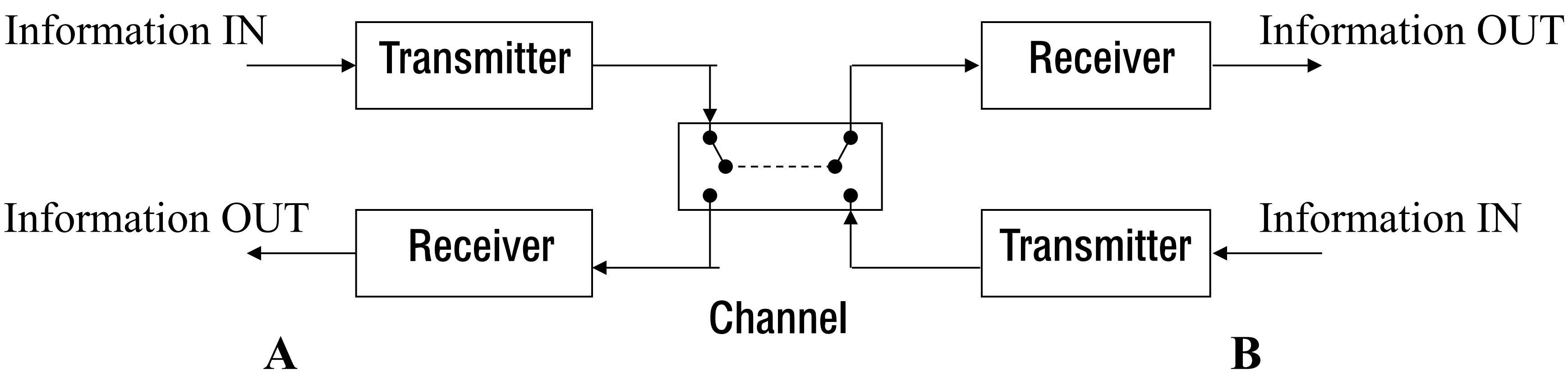
Point-to-Point Communication

Simplex Communication

- one way communication, in one direction only

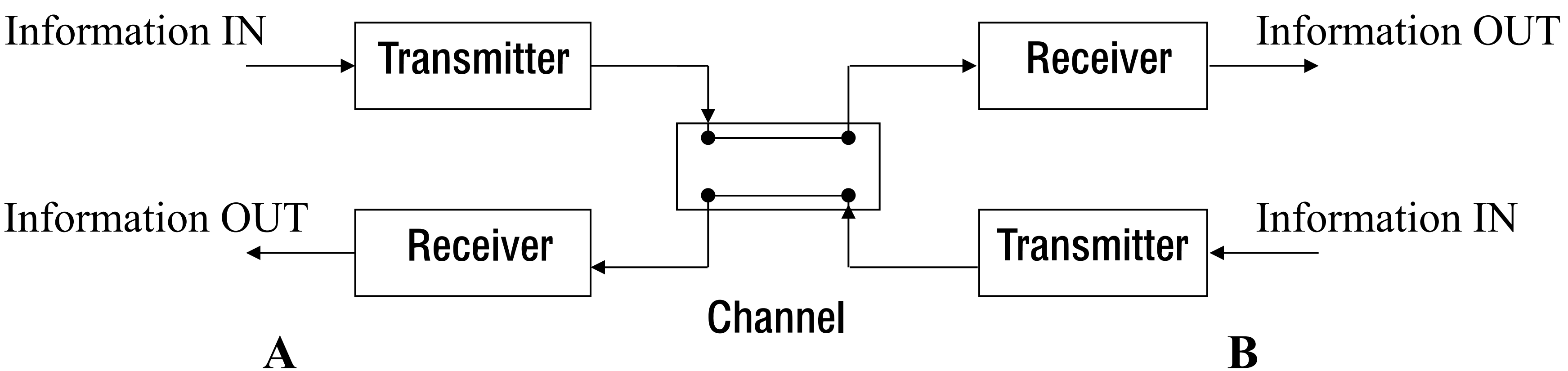
Half Duplex Communication

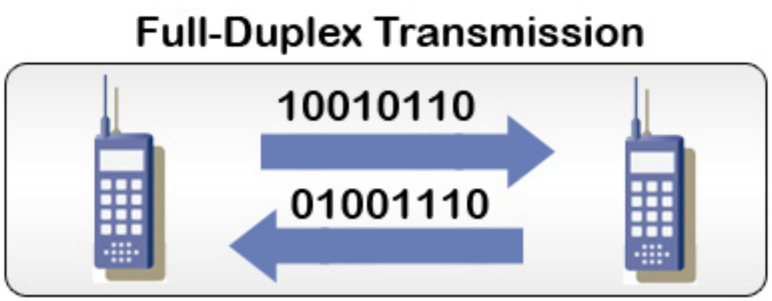
- two way communication, but at different time



Point-to-Point Communication

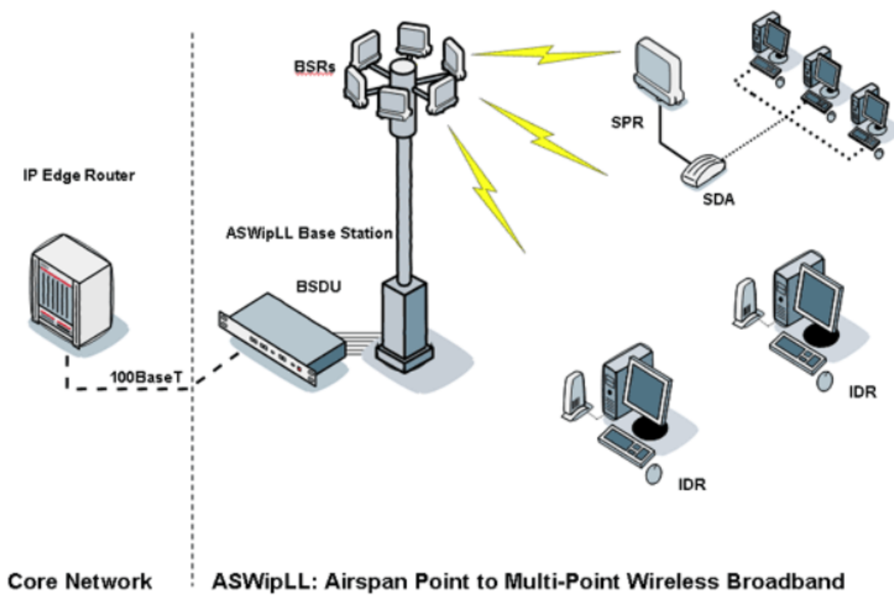
Full Duplex Communication
- simultaneous two-way communication





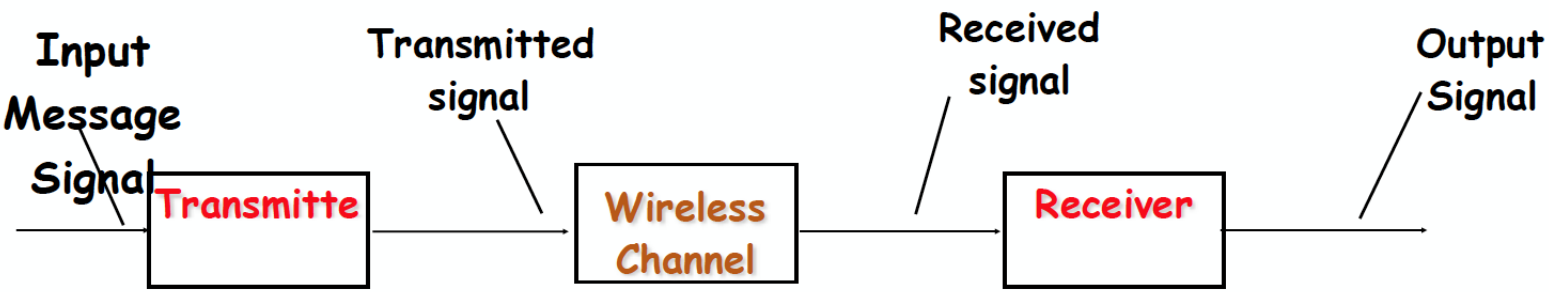
Why Wireless?

Pros: Ubiquitous Communications, Convenient, Mobile Communications, Cost Effective
[The dream of Tesla to go for Wireless]

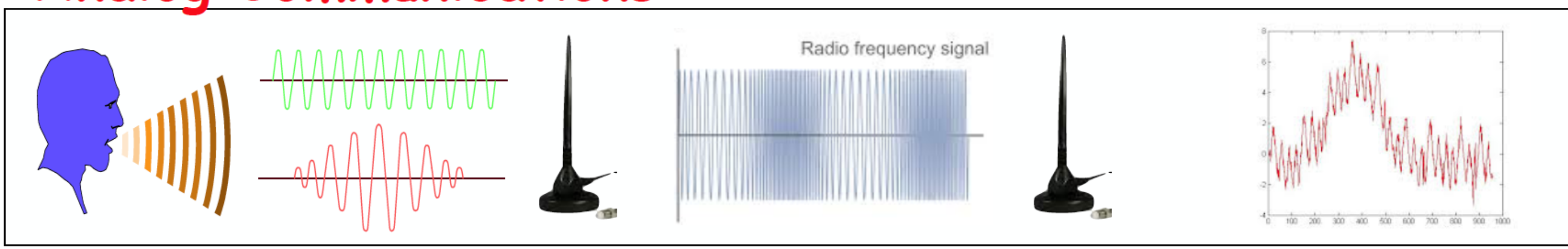


Challenges: Hostile Wireless Channels, Limited Spectrum, Limited Coverage, Limited Range

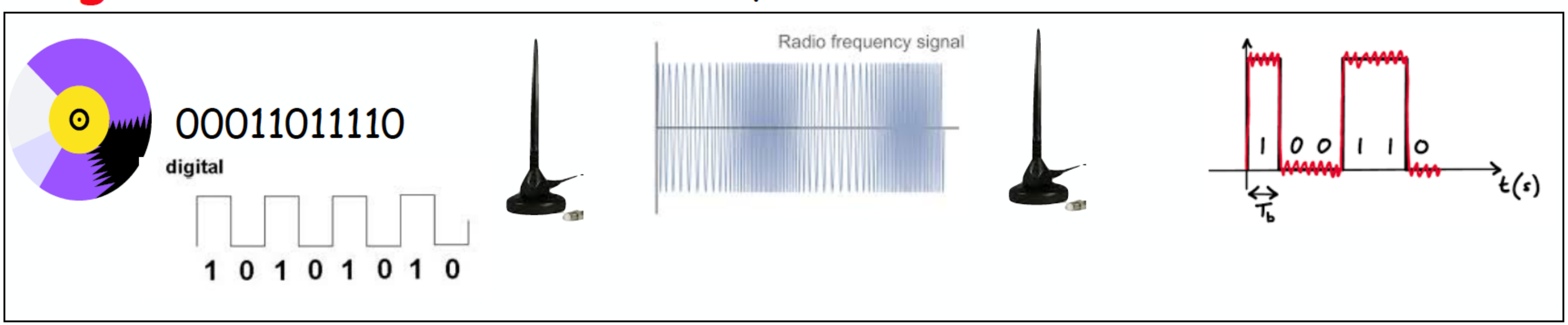
Wireless Communication System



Analog Communications Noisy Wireless Channels

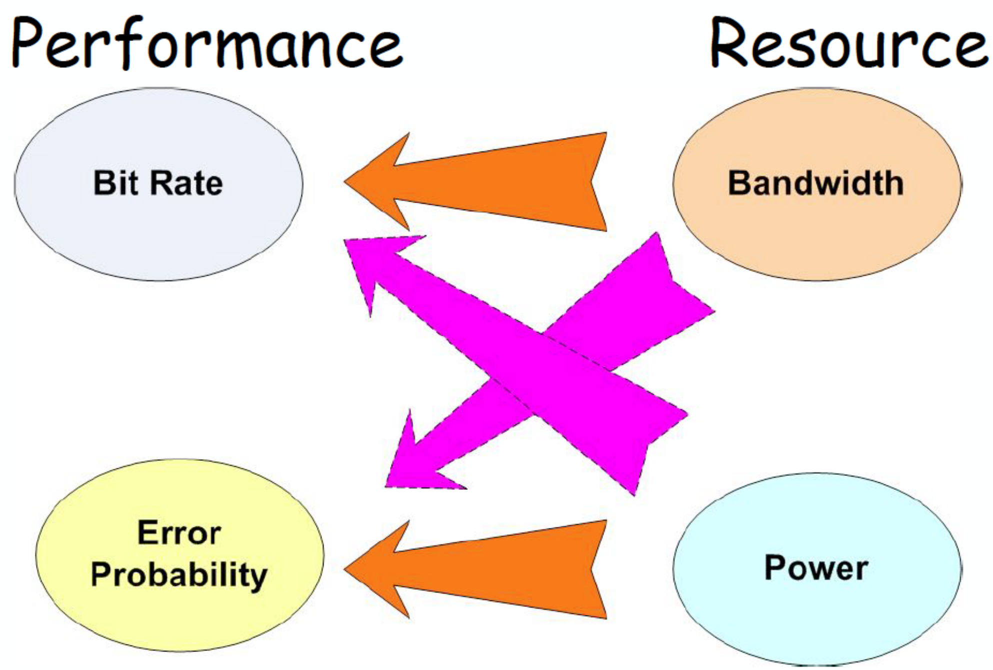


Digital Communications Noisy Wireless Channels



What makes Communications Systems Interesting ?

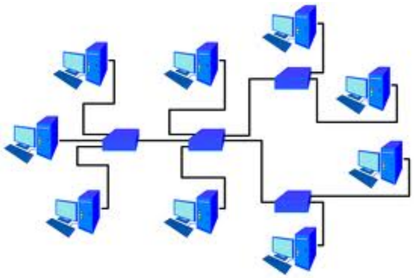
- There is no "universally optimal design" that fits for all situations.
- MUST know about the specific channel / situation before we could think about what design to use.
  - Example: **wireless systems requires a different design from an optical fibre.**
- **Complex Tradeoff between "Performance" and "Resource"**



Communications Networks

Communications Networks

- By directly connecting two devices with some transmission medium, we form the simplest point-to-point communications system.
- In most circumstances, point-to-point communications system is impractical, both technologically and economically, because:
  - It would be extremely costly to string a dedicated link between two devices, especially when the distance between them is long.
  - In a multiple-user environment, it would be cumbersome to provide dedicated connection between each pair of users.
  - Dedicated link is not an efficient use of resource (bandwidth).



- Communications networks can be formed among devices to utilize bandwidth more efficiently and to reduce complexity.

Why signal processing is needed in communications systems?

Information source and input transducer → Source Coding → Channel Coding → Modulator

↓

Channel

↓

Demodulator (Matched Filter) → Channel Decoding → Source Decoding → Information sink and output transducer

Communication: Transmission of information

- **What carries information?**
- **How can we transmit them effectively?**
  - **With least resources**
  - **With least errors**
  - **To a far distance**

Signals

Complicated function

- Signals play an important role in our daily life.
- Definition: A signal is a function of independent variables such as time, distance, position, temperature, and pressure. *(Understanding: Signal is some physical quantity or measurement that varies with time or space…)*
- Examples:
  - Speech and music signals:
  - Electrocardiography (ECG) Signal:

  - Video signals: A sequence of images, called frames.



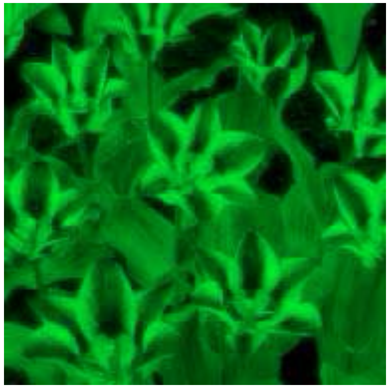
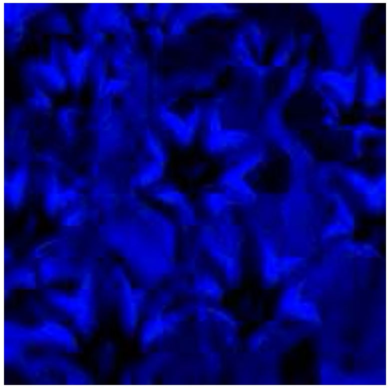

Signals and Signal Processing

- A signal carries information.
- Objective of signal processing: Design signals to effectively carry information or extract the useful information from the signal.
- This course is concerned with the discrete-time representation of signals and the discrete-time processing for communications purpose.

Classification of Signals

- **Type of signals:**
  - x(t) x[n] ✓
  - **Continuous or discrete**
  - Both!
  - **Real-valued or complex-valued**
  - x: 1D x: matrix for 2D
  - **One-dimension vs. Multi-dimension**
    - **1-D: a function of a single variable (Speech signal)**
    - **M-D: a function of more than one independent variables**

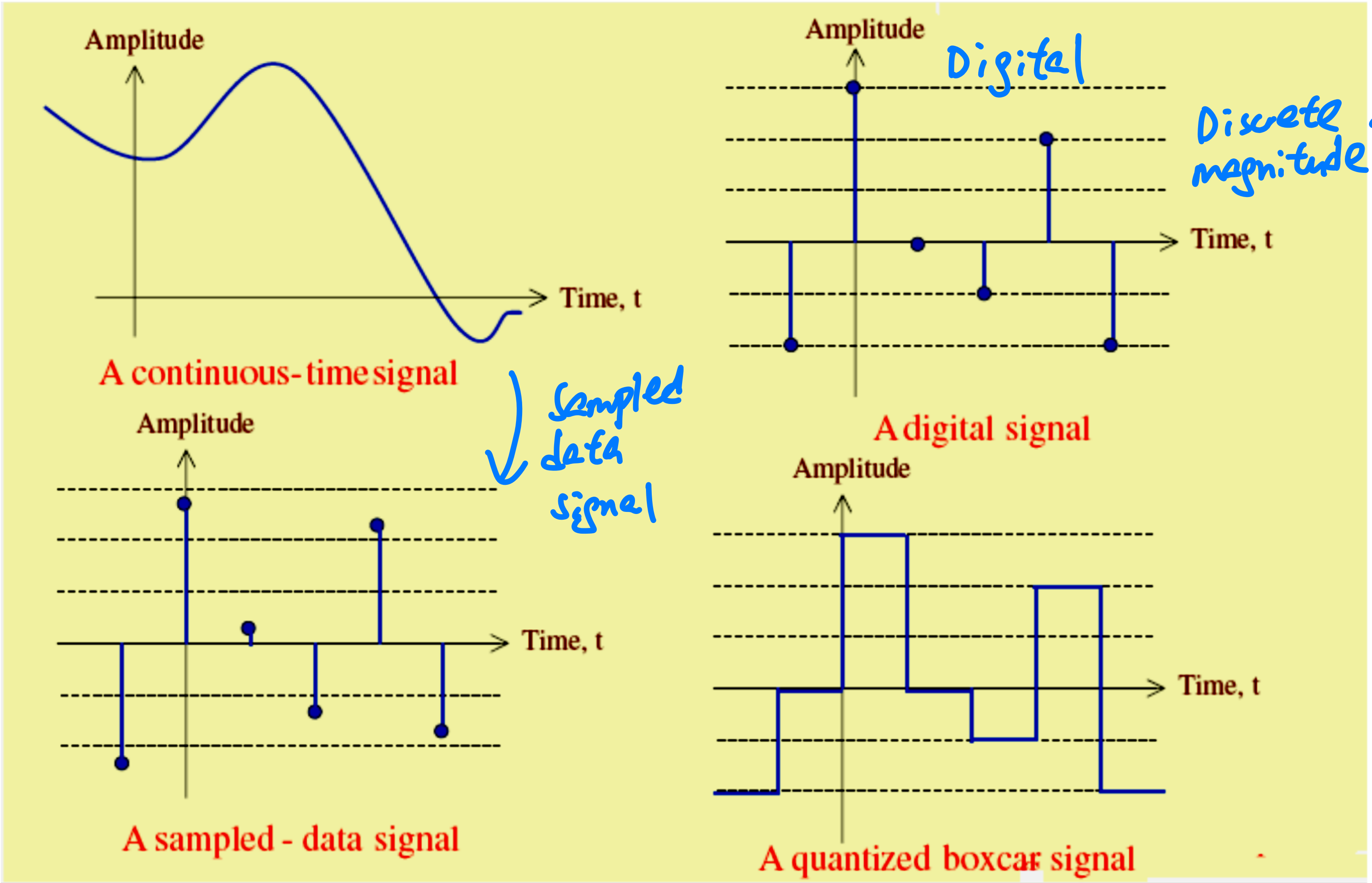
2D: Image
3D: Video
4D: Dynamic 3D video!

Classification of Signals

- **For 1-D signal, the independent variable is usually labeled as time**
  - **Continuous-time**
    - **Analog signal: Continuous value**
    - **Quantized boxcar signal: Discrete-valued**
  - **Discrete-time**
    - **Sampled data: Continuous valued**
    - **Digital signal: Discrete valued (quantized sampled-data)**

Continuous vs. Discrete



Signal Processing Operations

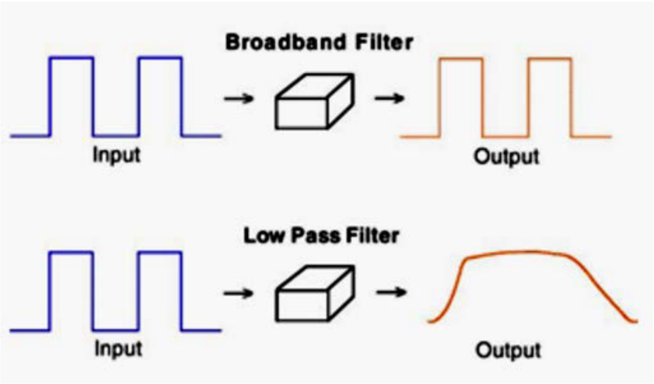
- Most signal processing operations in the case of analog signals are carried out in the time-domain.
- In the case of discrete-time signals, both time-domain or frequency-domain operations are usually employed.
- Signal processing operations

  ? handle
  → use few lectures

  - Elementary operations: Scaling, delay, addition, Integration, and differentiation.
  - Complex operations: Combining two or more elementary operations.

Complex Operations: Filtering

- **Filtering:** is one of the most widely used complex signal processing operations.
- **Filter:** The system implementing this operation.
- A filter passes certain frequency components without any distortion and blocks other frequency components
  - **Low-pass**
  - **High-pass**
  - **Band-pass**
  - **Band-stop**
  - **Other types: Notch, Multiband, Comb**



Complex Operations

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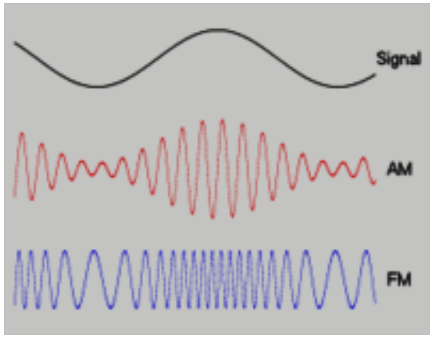
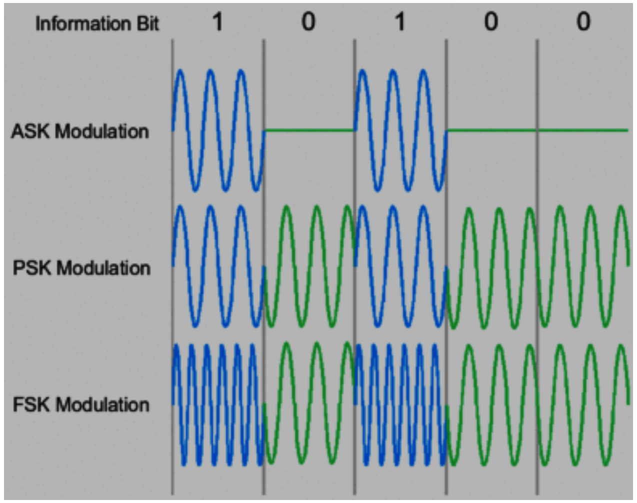
- Generation of complex signals: **Analytical signals**
- **Analog Modulation and Demodulation**
  - Amplitude Modulation (AM)
  - Frequency Modulation (FM)
  - Phase Modulation (PM)
  - Pulse Amplitude Modulation (PAM)



- **Digital Modulation**



Signal Processing: Examples

- Digital Sound Synthesis
  - Spectral Synthesis: Produces sounds from frequency domain models
  - Nonlinear Synthesis: Widely used in synthesizers and PC sound cards
  - Physical Modeling: Models the sound production method
    - Guitar with nylon strings:
    - Marimba:
    - Tenor saxophone:

Communications Purpose?

- Signal processing techniques for communications purposes

  Improve communication speed! → compress the signal

  - **Signal coding & Compression**: Concerned with efficient digital representation to provide maximum quality to the listener or viewer. (**Source Coding**)

    Send 多余 codes

  - **Signal Protection**: Protection of signals from fading, noise, and interference. (**Channel coding**)

    focus on this (Random) → difficult

  - **Signal Enhancement**: To emphasize specific signals features to provide maximum quality to the listener or viewer. (**Noise/interference removal**)

Signal Coding & Compression

Information source and input transducer → Source Coding → Channel Coding → Modulator → Channel → Demodulator (Matched Filter) → Channel Decoding → Source Decoding → Information sink and output transducer

Original 66206 bytes

Compressed 9295 bytes

How can we transmit them effectively?

- With least resources (time/frequency/energy)

Signal Enhancement

Information source and input transducer → Source Coding → Channel Coding → Modulator → Channel → Demodulator (Matched Filter) → Channel Decoding → Source Decoding → Information sink and output transducer

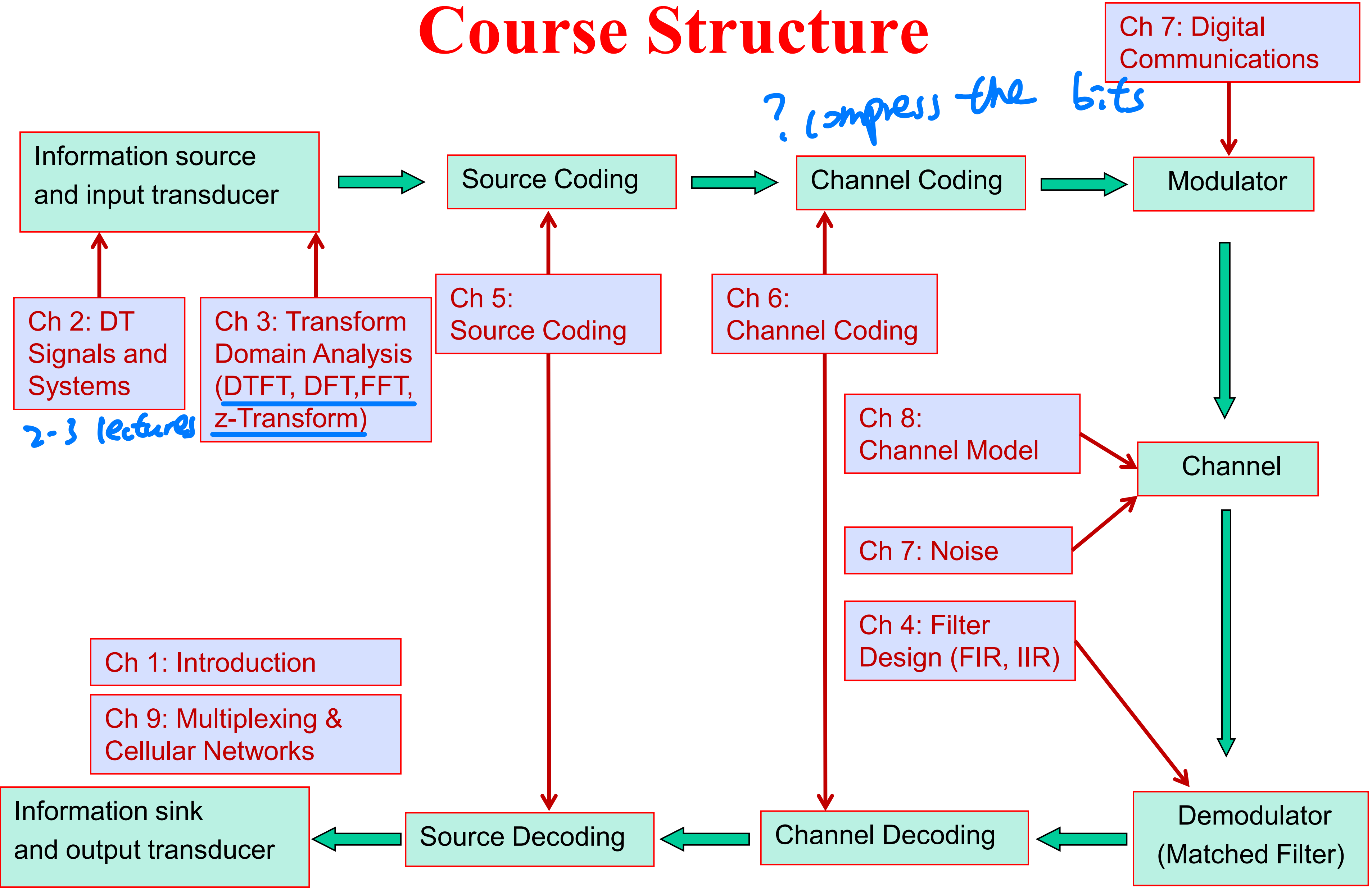
- **How can we transmit them effectively?**
  - **Signal enhancement**

(filter out high freq. noise)

Noise removed

Noisy

Course Structure



Topics to Be Covered

- ✓ Overview of Signal Processing and Communications Systems
- Discrete-Time Signals and Systems
- Transform-Domain Analysis: DFT/FFT, z-Transform,
- Filter Design
- Source/Channel Coding
- Digital Modulation
- Detection Theory, Signal Space, and Error Analysis
- Channel Models
- Noise Effects

DSP

Com