EE140 Introduction to Communication Systems

Lecture 1

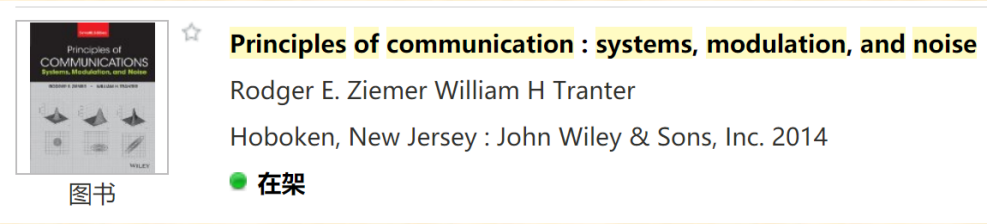
Instructor: Prof. Lian Lixiang
ShanghaiTech University, Fall 2025

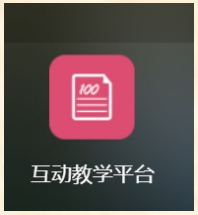
Course Information (I)

- Instructor:
  - Prof. Lixiang Lian (lianlx@shanghaitech.edu.cn)
- TA:
  - Chuanqi Bai (baichq2024@shanghaitech.edu.cn)
  - Jiahao Qu (qujh2022@shanghaitech.edu.cn)
- Office hours
  - Wednesday 15:00~17:00
  - 199 Haike Rd., SIST Bldg. 2, **Room 2-302C**
- Rules in classroom
  - Questions, discussions and suggestions are always welcome

Course Information (II)

- Course title:
  - **Introduction to Communication Systems**
- Course pre-requisites:
  - Signal and systems; Probability; Linear algebra;
- Reference textbook
  1. Ziemer, R., & Tranter, W. (2014). Principles of communication: Systems, modulation, and noise (**Seventh** ed.).





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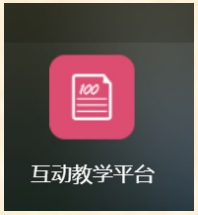
2. Gallager G. Robbert, ”Principles of Digital Communication"



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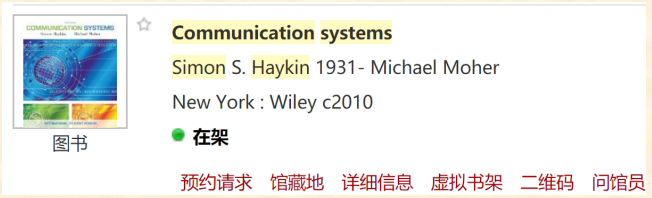
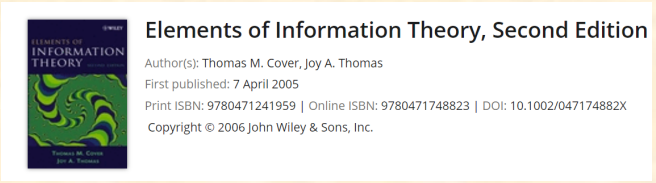
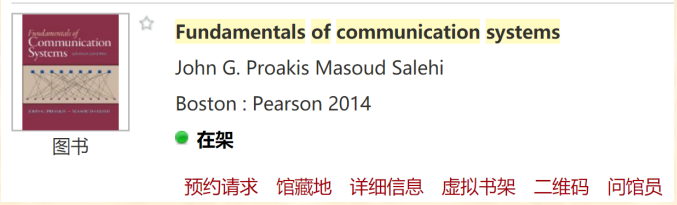
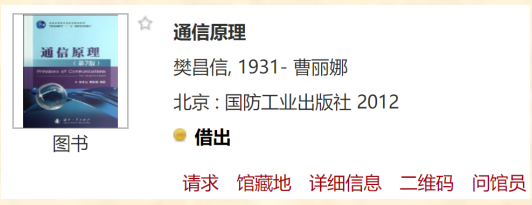
  1. S. Haykin, Communication Systems, 5th edition, Wiley, 2010





  2. Thomas M. Cover, Joy A. Thomas, "Elements of Information Theory"
  3. J. Proakis, M. Salehi, Fundamentals of Communication Systems, 2nd Edition, Prentice Hall, 2013
  4. D. Tse, Fundamentals of Wireless Communication, 1st Edition, Cambridge University Press, 2005.
  5. J. Proakis, M. Salehi, Digital Communications, 5th Edition, McGraw-Hill, 2007
  6. 樊昌信，曹丽娜，《通信原理》，国防工业出版社，2012





Course Information (III)

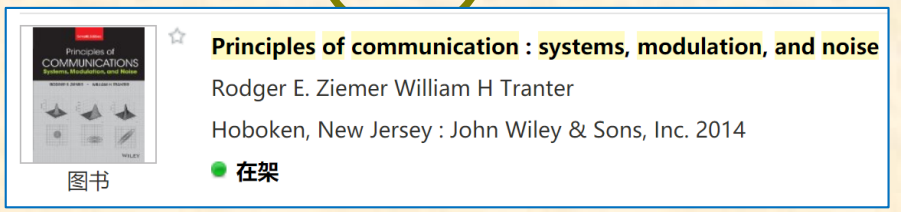
- Grading
  - Homework (~12 sets): 30%
  - Midterm(8th week): 30% (one A4 cheat sheet)
  - Final: 40% (one A4 cheat sheet)
- Homework:
  - Release on **Friday** on Blackboard
  - Due on **Friday** (**hard deadline**)
  - Posting and submission: Gradescope (Entry code: **NGDKED**) https://www.gradescope.com
- Honor code:
  - Plagiarism, zero tolerance

Course Information (III)

- Grading
  - Homework (~12 sets): 30%
  - Midterm(8th week): 30% (one A4 cheat sheet)
  - Final: 40% (one A4 cheat sheet)
- Homework:
  - Release on **Friday** on Blackboard
  - Due on **Friday** (**hard deadline**)
  - Posting and submission: Gradescope (Entry code: **NGDKED**) https://www.gradescope.com
- Tutorial
  - Every Week (time and venue: to be determined)

Course Information (IV)

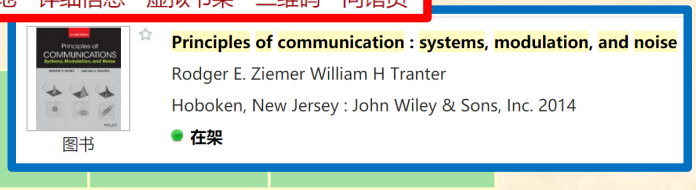
- Syllabus (first half)



	Content	Hours	Week
	Introduction to communication systems (Chapter1)	1	1
techniques	Review Fourier transform & linear systems (Chapter2)	3	1
techniques	Probability Theory and Random process (Chapter 6 &7)	4	2
Analog Communication	Analog modulation: linear modulation (Chapter 3)	6	3&4
Analog Communication	Analog modulation: angle modulation (Chapter 4)	6	5&6
Analog Communication	Noise in Modulation System (Chapter 8)	6	7&8
	Midterm	2	8

Course Information (IV)

- Syllabus (second half)



Content		
Introduction to digital communication sys (Chapter 1)	1	9
Information Theory and Source Coding (Chapter 2, Chapter 12)	5	9&10
Sampling and Quantization (Chapter 3)	6	10&11
Vector space and signal space (Chapter 5, Chapter 11)	6	12&13
Modulation and Demodulation (Chapter 6, Chapter 10)	6	13&14
Detection and Channel Coding (Chapter 8, Chapter 9,11,12)	6	15&16
Wireless Communication (Chapter 9)	2	16

Course Objective

- We focus on the fundamental system aspects of modern digital communication systems
  - **What?**
  - **How?**
  - **Analyze:**
    - **provide analytical tools for determining the performance of particular systems**
    - **put fundamental limits on the performance of any system**
- After this course, the students are expected to
  - ***Understand*** the principles and technique of modulation, coding and transmission.
  - ***Analyze*** the merits and demerits of current communication systems and eventually ***design*** improved new systems

Before we start

Mathematically heavy, conceptually rich

- Some Practical Tips
  1. Attend every lecture and stay engaged
  2. Take homework seriously
- Some suggestions
  - Strengthen your foundations
  - Focus on the core concepts: physical meanings and the relationships
  - Derive key results yourself: assumptions and conditions
  - Work through examples
  - Draw block diagrams
  - Review regularly
  - Try to connect every math expression to "what it means physically" .
  - build the intuition step by step

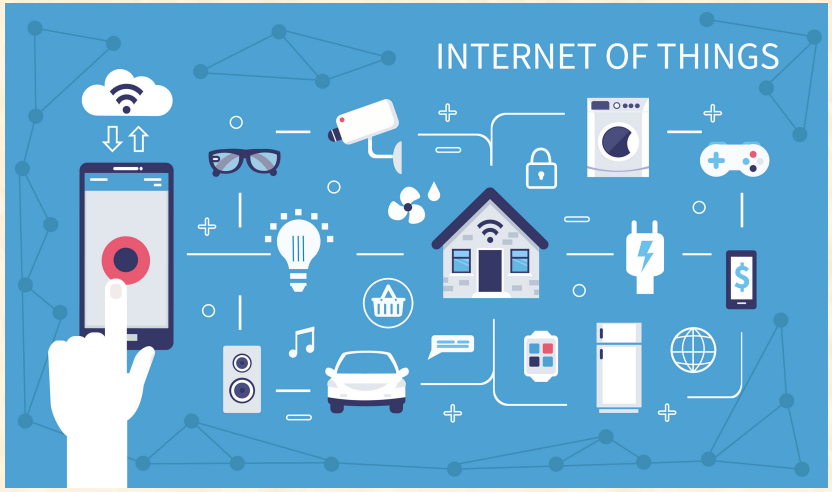
Contents

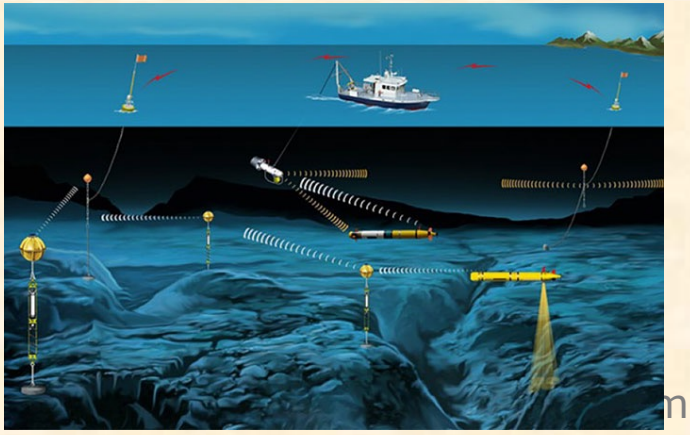
- Course information
- Introduction to communication systems
  - What is communication?
  - Examples in Modern Society
  - Basic architecture
  - Fundamental questions

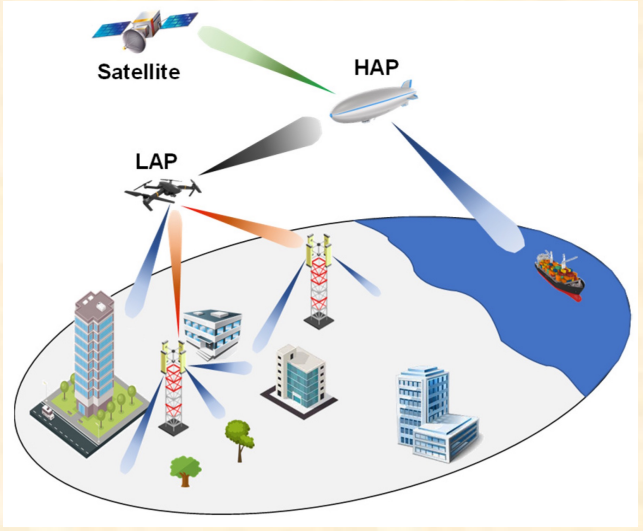
What is Communication?

- Communication – From Wikipedia
  - from Latin commūnicāre, meaning "to share"
  - the act of conveying intended meanings from one entity or group to another through the use of mutually understood signs and semiotic rules

Examples of Modern Communication Systems







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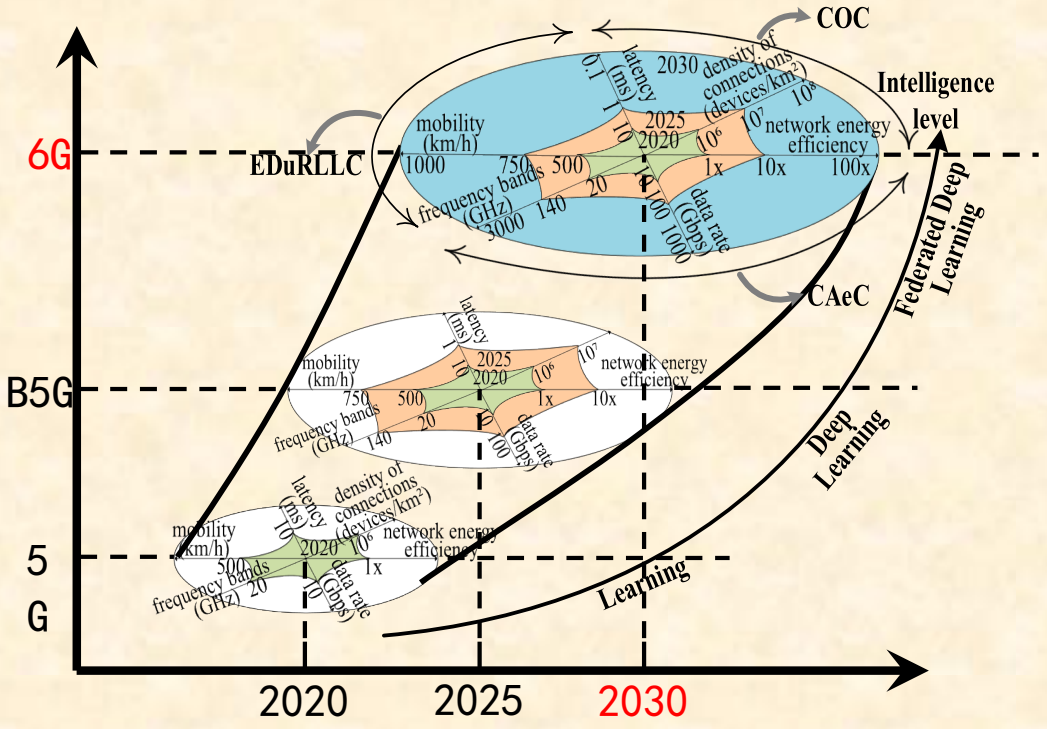
Communications in Modern Tech.

- 6G

Communications in Modern Tech.

- 6G



KPIs comparison between 5G and 6G:

- Latency: 10ms → 0.1ms
- Network energy efficiency: 100x
- Data rate: 10Gbps → 1Tbps
- Frequency bandwidth: 20GHz → 3THz
- Mobility: 500km/h → 1000km/h
- Connections: 10^6 devices/km² → 10^8 devices/km²

K. B. Letaief, W. Chen, **Y. Shi**, J. Zhang, and Y. Zhang, "The roadmap to 6G - AI empowered wireless networks," *IEEE Commun. Mag.*, vol. 57, no. 8, pp. 84-90, Aug. 2019. **(IF:11.05)**

Communications in Modern Tech.

- 6G

Ref: 6G总体愿景与潜在关键技术 - 中国信通院

图2 沉浸式云XR：虚拟空间的广阔天地

图3 全息通信：身临其境的极致体验

图4 感官互联：多维感官的交融响应

图5 智慧交互：情感思维的互通互动

Communications in Modern Tech.

- 6G

Ref: 6G总体愿景与潜在关键技术 - 中国信通院

图 6 通信感知：融合通信的功能拓展

图 7 普惠智能：无处不在的智慧内核

图 8 数字孪生：物理世界的数字镜像

图 9 全域覆盖：无缝立体的超级连接

Communications in Modern Tech.

- 6G: Technologies
  - Physical Layer Techniques, e.g., Modulation, Coding, Waveform, Multiple Access (NOMA)
  - Massive MIMO (ultra-massive antenna arrays)
  - Intelligent Reflective Surface
  - Cell-free and distributed MIMO systems
  - Integrated Communication and Sensing
  - Terahertz Communication
  - Visible light and molecular communication
  - AI-native wireless networks
  - Quantum communication and security
  - Semantic communication
  - Digital twin and holographic communications
  - Integrated Space-Air-Ground Network

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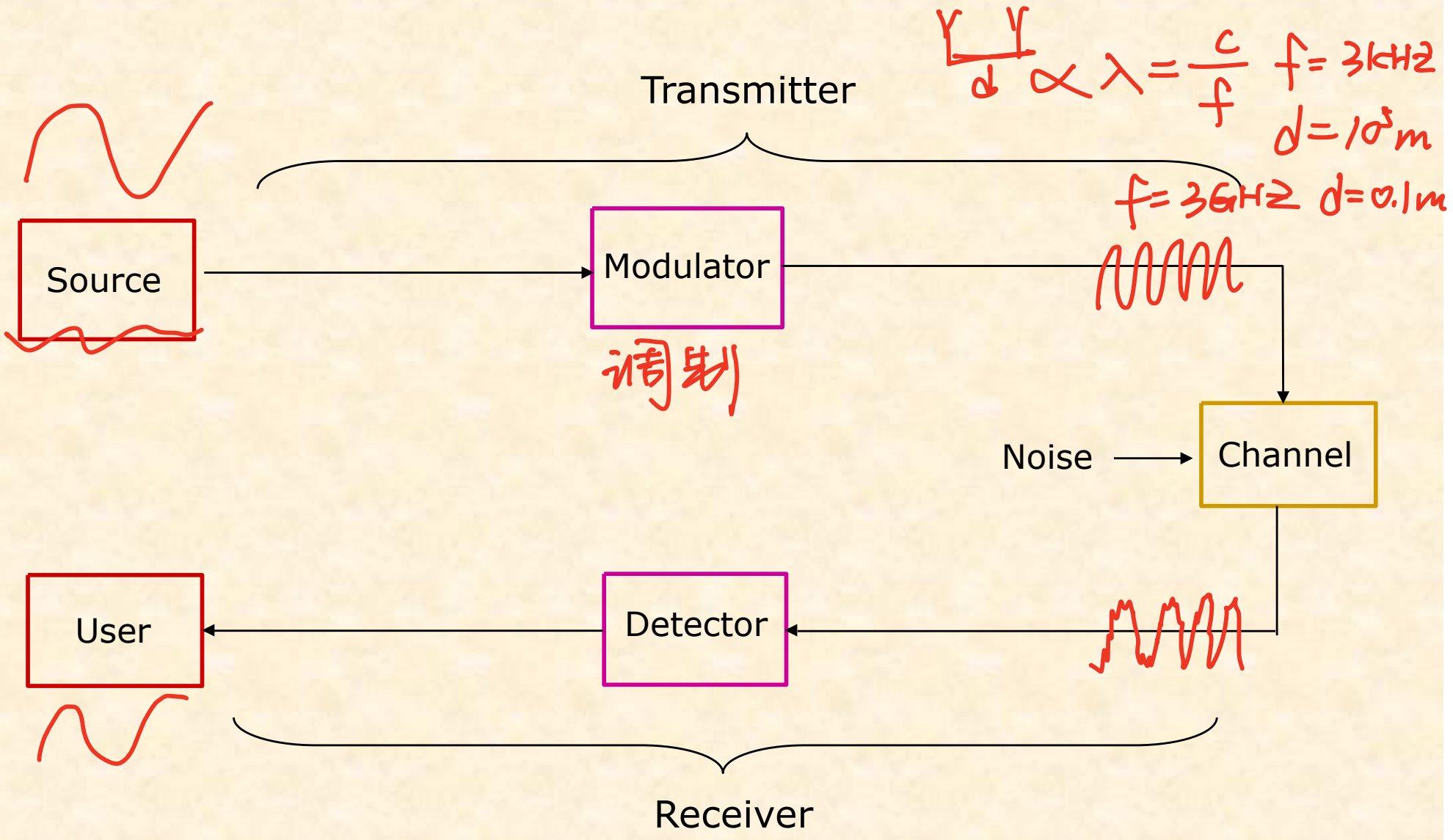
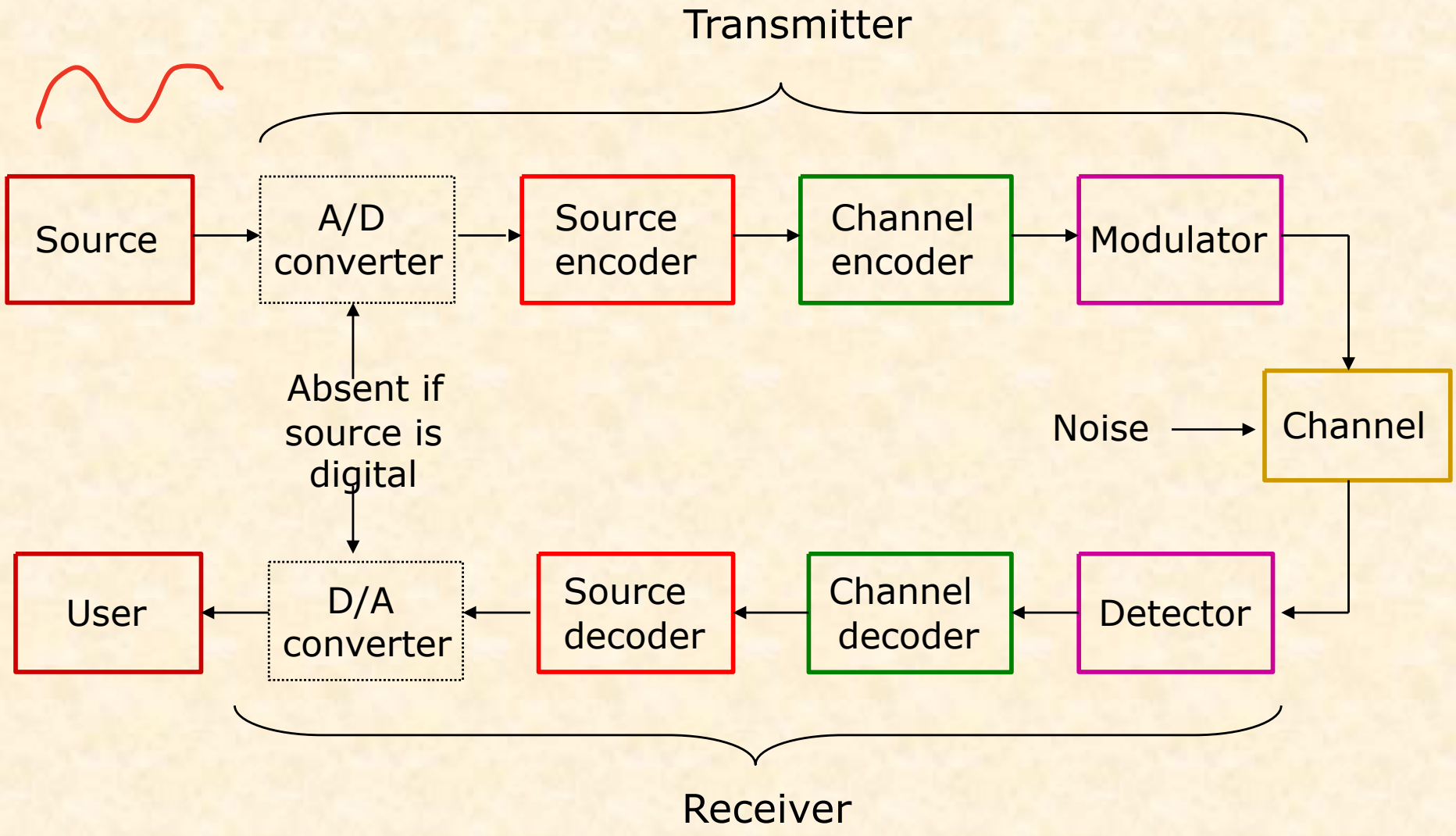
Architecture of an Analog Communication System

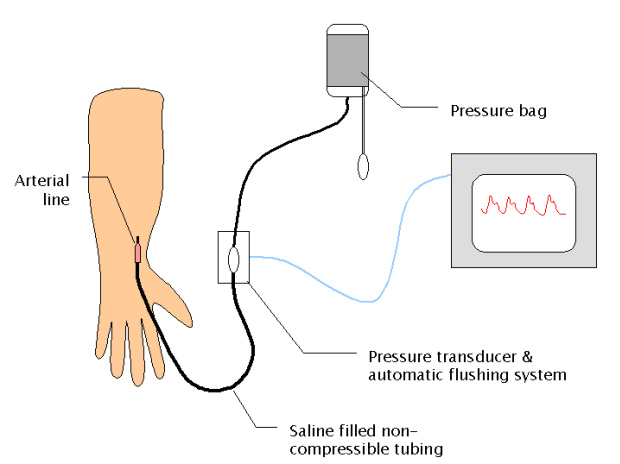


Architecture of a Digital Communication System



Source Information

- *Message:* generated by source
- *Information:* the unpredictable part in a message
- *Signal:* a function that conveys information about the behavior or attributes of some phenomenon



Transducer: convert sensing signal to electric signal

Analog signal vs. digital signal

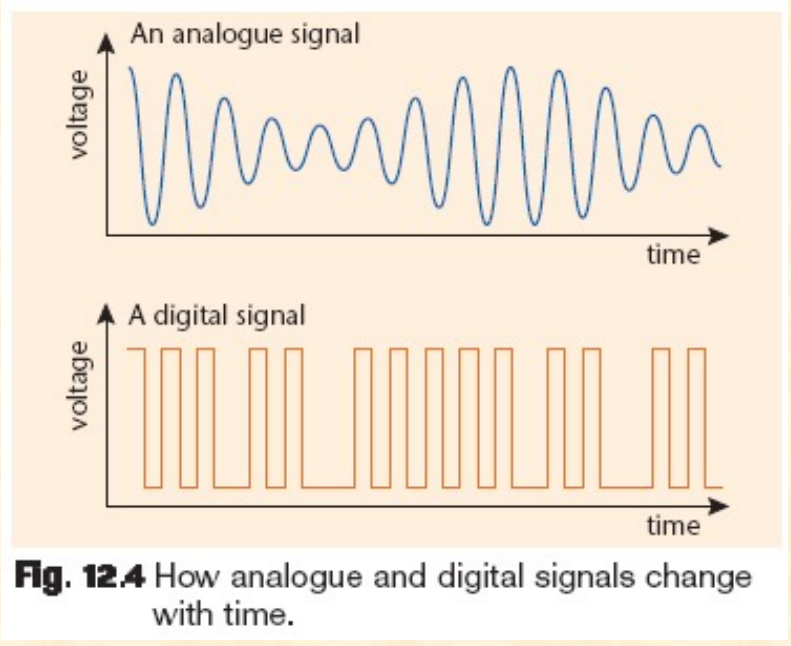


Fig. 12.4 How analogue and digital signals change with time.

Voice temperature.

signs, text, number

Source Coding

- Source coding (data compression): to reduce space for the data stream.
  - Sampling (discretize)
  - Quantization (discretize in amplitude)
  - Source coding (bits or symbols)

- Source coding example
  - Speech coding
    - human voice, 20 Hz~20 kHz, quantization ➔ raw data rate >1 Mbps
    - Standard PCM coding, 3.4kbps

Encryption (Not Shown in the Diagram)

- Encryption: to encrypt information for security purpose.

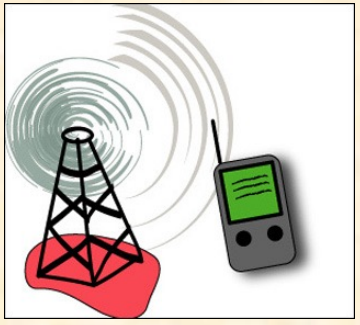
- Cryptography example: Caesar cipher
  - ABCDEFGHIJKLMNOPQRSTUVWXYZ
  - Key = 3
  - DEFGHIJKLMNOPQRSTUVWXYZABC

- Example
  - Plaintext: OLINCOLLEGE
  - Ciphertext: ROLQFROOHJH
  - Decryption: Shift backwards by KEY = 3

Channel Coding

- Channel coding (error control): to encode a signal so that error occurred can be detected and possibly corrected.
  - Protection is achieved by adding redundancy!

- Channel coding example:
  - Repetition code: (3, 1) repetition code
    - Message bits: $m = 101001$
    - Coded bits: $c = 111000111000000111$
    - Decoder: majority logic

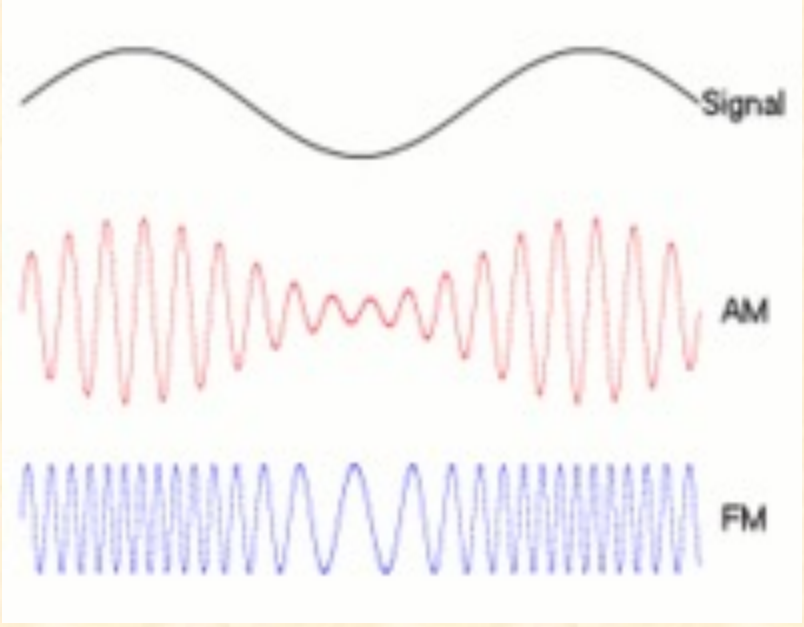


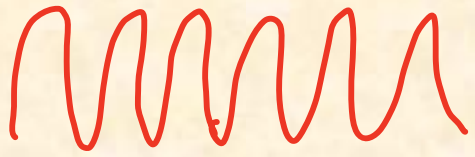
Wireless comm.

(Repetition, RS, CC, LDPC, Turbo…)

Modulation

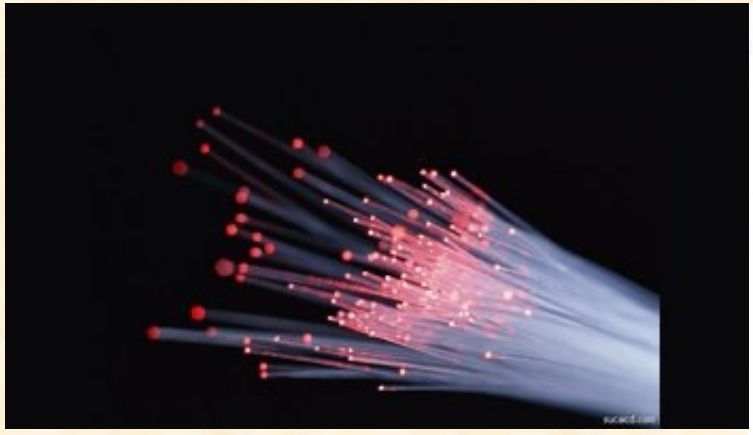
- Modulation is the process of conveying a message signal, for example a digital bit stream or an analog audio signal, inside another signal that can be physically transmitted.
- Example: baseband message signal ➔ passband RF signal

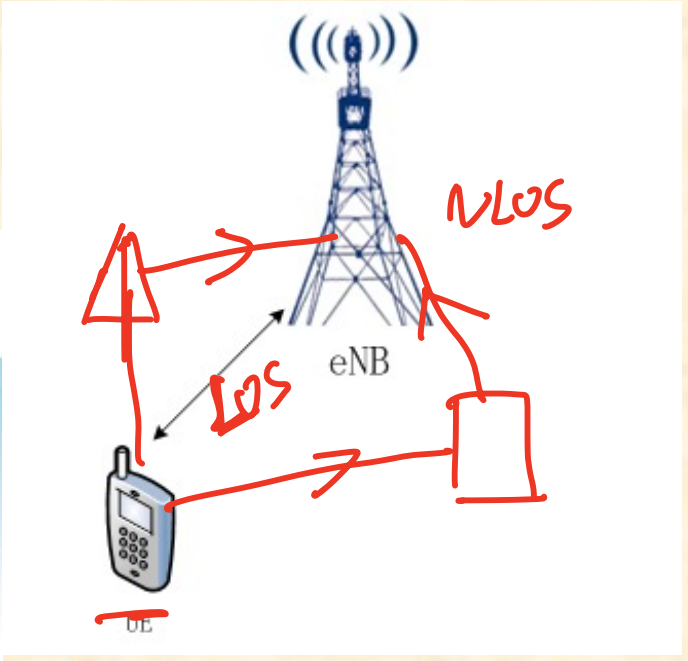




Channel

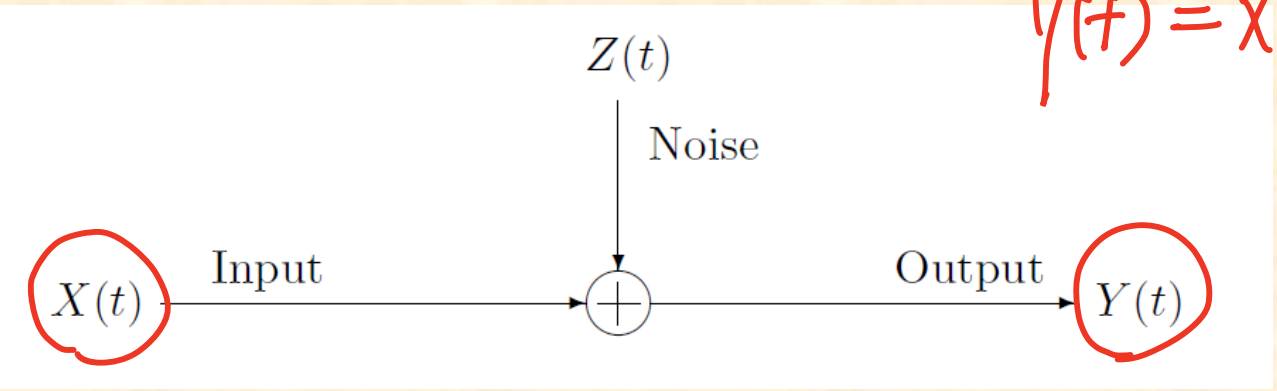
- Channel: a transmission medium used to convey information
- Common characteristics
  - Attenuation
  - Distortion
  - Noise
  - Wireless channels
    - Multipath, fading





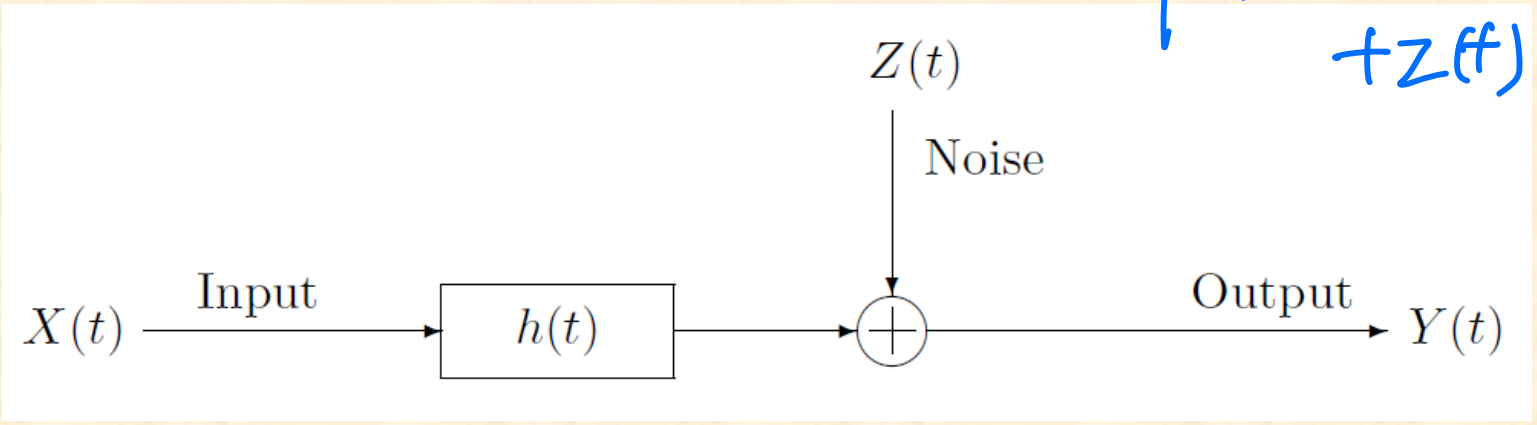
Channel Model

- AWGN channel



$Y(t) = X(t) + Z(t)$

- Linear channel

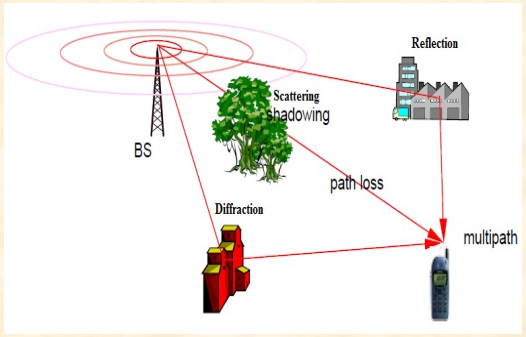


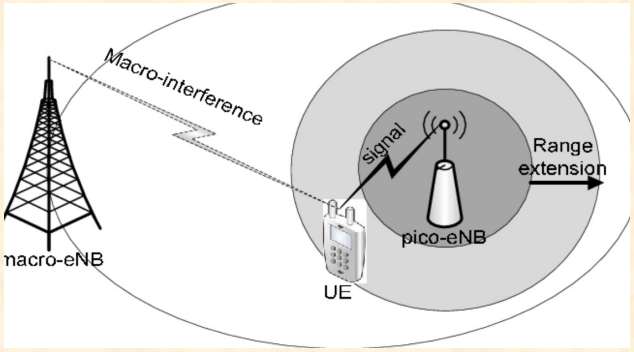
$Y(f) = X(f) * h(f) + Z(f)$

Noise

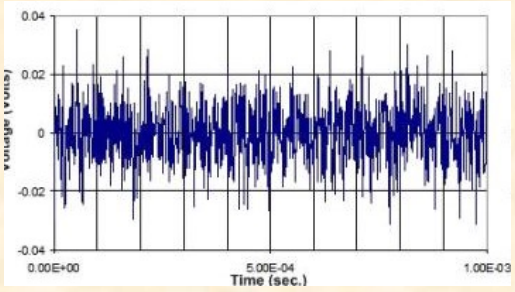
Internal noise: communication system

External noise: atmospheric, man-made

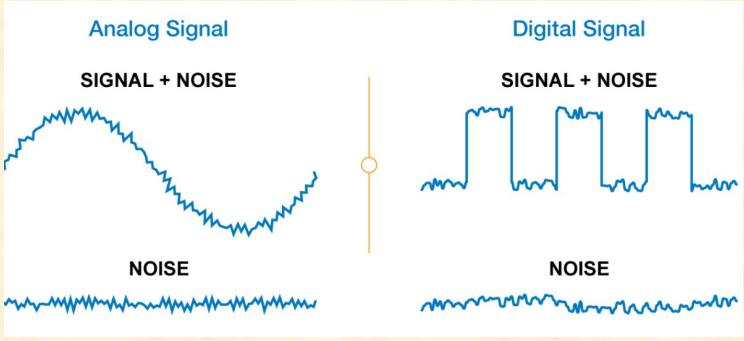




Random, unpredictable → Modeled probabilistically

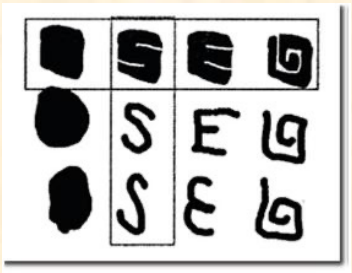


Distortion



Analog vs. Digital

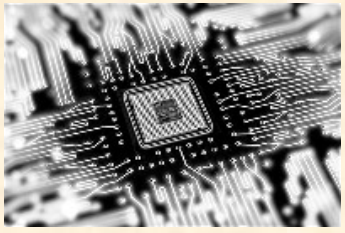
- Robustness to channel noise and external Interference



- Security of information during its transmission from source to destination

- Integration of diverse sources information into a common format

- Low cost DSP chips by very cheap VLSI designs

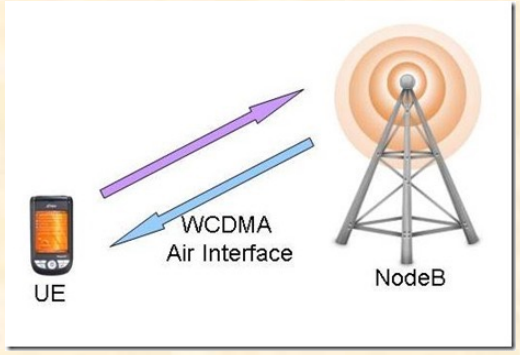


Duplex Transmission

- Simplex
  - one-way transmission only, e.g. broadcast systems

- Half-duplex
  - two-way transmission, but the common channel is alternately used for transmission in opposite direction, e.g. interphone systems installed on taxies

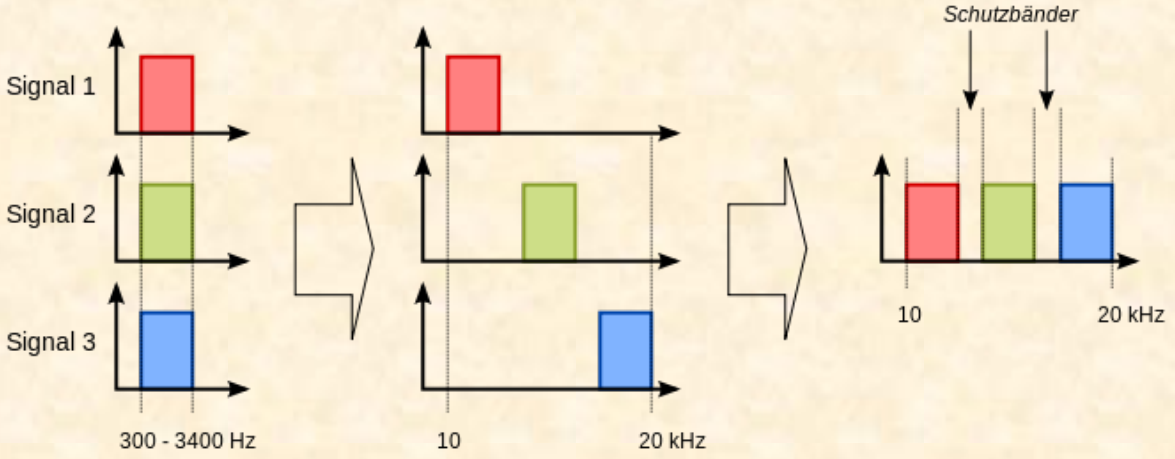
- Full-duplex
  - simultaneous two-way transmission, e.g. public telephone systems



Multiplexing

- Multiplexing
  - multiple analog or digital signals are combined into one signal over a shared medium. The aim is to share an expensive resource.

- Type
  - Frequency-division
  - Time-division
  - Code-division
  - Space-division
  - Polarization-division
    (e.g., in optical fiber)
  - Orbital angular momentum
    (OAM, 轨道角动量多址，光子纠缠，2013)



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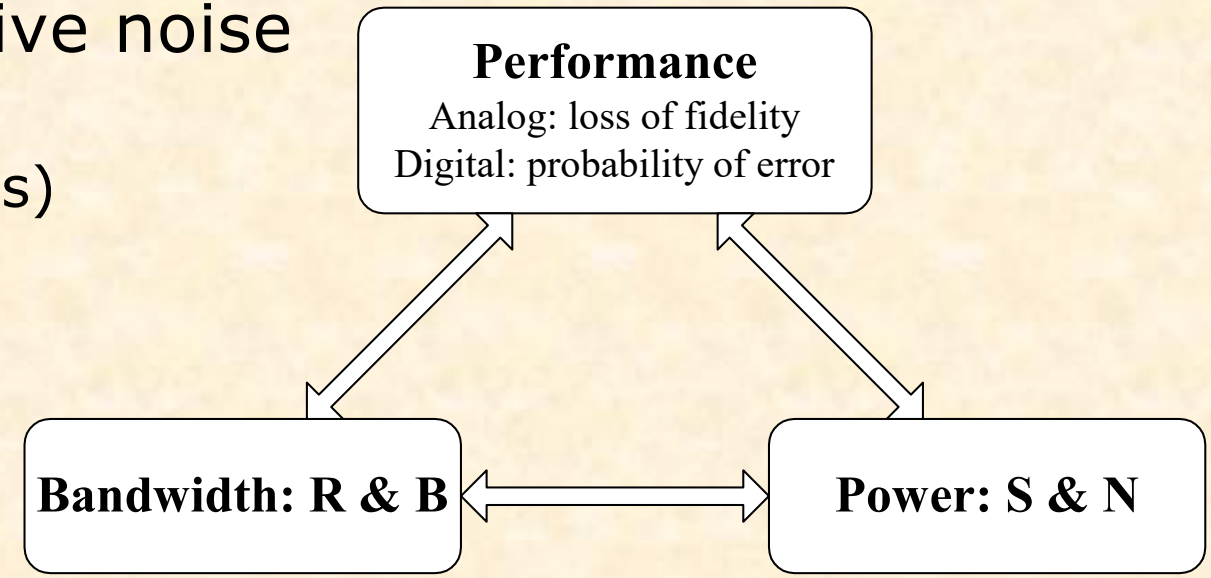
Performance Metrics of Communication Systems

- Reliability
  - SNR for analog systems
  - Bit error rate for digital systems
- Assumption: additive noise
  - R: information transmission rate (bps)
  - B: channel bandwidth (Hz)
  - S/N: signal-to-noise ratio (SNR)
  - C: channel capacity, the maximum value of R (bps)
  - Hartley-Shannon law: $C = B \log_2(1+S/N)$ bps



$R \leq C$

Performance Metrics of Communication Systems

- Efficiency
  - Bandwidth efficiency

$$\text{BE} = \frac{\text{rate}}{\text{BW}} \text{ bit/s/Hz}$$

  - Energy efficiency

$$\text{EE} = \frac{\text{rate}}{\text{Energy}} \text{ bits/s/Joule}$$

Thanks for your kind attention!

Questions?