Lecture 1: Historical Notes and Overview

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Course Information

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Handouts:

- Slides
- Problem sheets

Grading:

- Labs (30%)
- Mid-term exam (10%)
- Final 2-hour exam (60%)

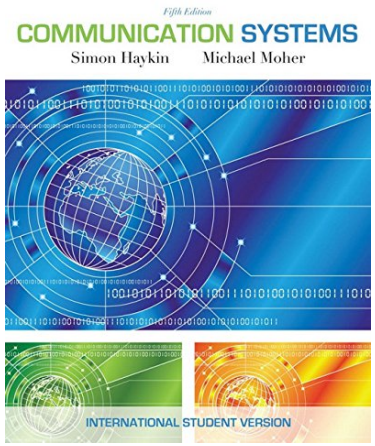
Contents

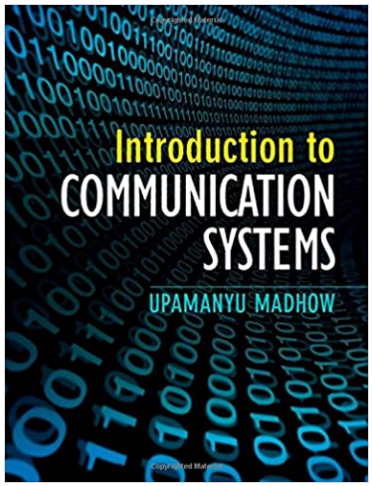
ELEC50002: Communications

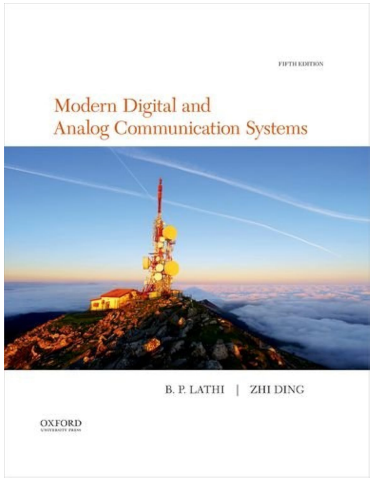
- Communication systems performance in the presence of noise
- Statistical aspects and impact of noise
- Analog vs. digital communications
- Basics of information theory
- Main mathematical tools: Fourier transform, probability, and stochastic processes

References

- [Haykin] S. Haykin and M. Moher, *Communication Systems*, 5th ed., Wiley, 2009.
- [Madhow] U. Madhow, *Introduction to Communication Systems*, Cambridge University Press, 2015.
- [Lathi] B. Lathi and Z. Ding, *Modern Digital and Analog Communication Systems*, 5th ed., Oxford University Press, 2018.







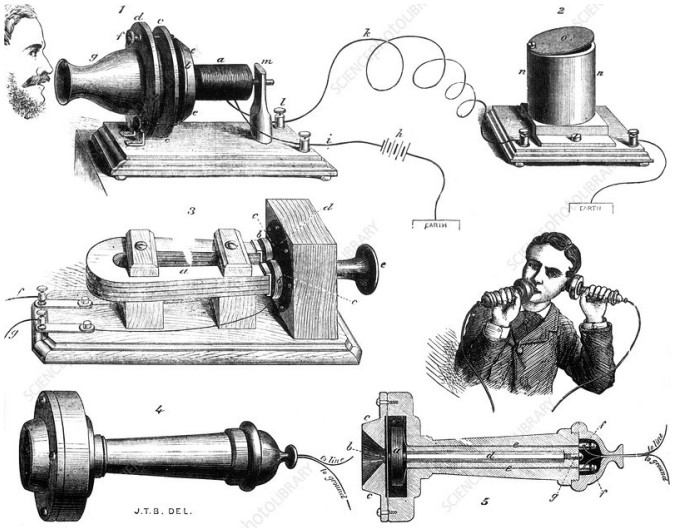
Milestones in Communications: I

19th-century demonstration of the semaphore

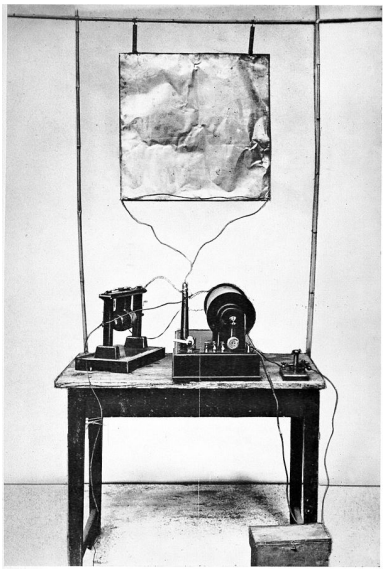
Souvenir card for the Dover-Calais cable, 1854

- 1792, Chappe invented optical telegraph "semaphore" in France (mechanical method)
- 1837, First commercial telegraph service, Paddington station and West Drayton by William Cooke and Charles Wheatstone (telegraph/digital, wire)
- 1851, England connected to Europe by a cable between Dover, UK and Calais, France (submarine cable)
- 1864, Maxwell formulated the electromagnetic (EM) theory (predicted the existence of EM waves)

Milestones in Communications: II



Bell's first telephone



Marconi's first radio transmitter

- 1875, Bell invented the telephone (transmit analog signal/speech, wired)
- 1887, Hertz demonstrated physical evidence of EM waves (made radio communication possible)
- 1890's-1900's, Marconi & Popov, long-distance radio telegraph (first wireless communication, telegraph)
- 1906, First radio broadcast (first live opera broadcast from New York Metropolitan Opera House - 1910)

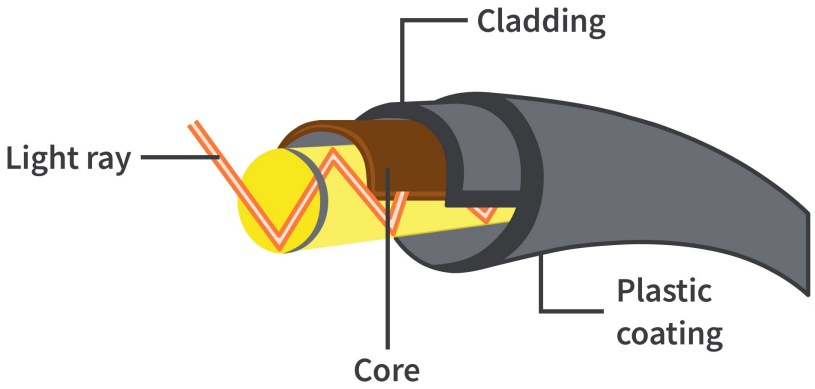
Milestones in Communications: III

Edwin Howard Armstrong (1890-1954) was an American electrical engineer who invented frequency modulation (FM) radio and the superheterodyne receiver system.

John Logie Baird (1888-1946) was a Scottish electrical engineer who invented live television (TV) and color television systems.

- 1918, Armstrong invented superheterodyne radio receiver (and FM in 1933)
- 1920, First commercial radio station (500 stations by 1923)
- 1925, Baird demonstrated transmission of moving images (TV) in London
- 1928, First TV station by General Electric (GE) factory in Schenectady, New York
- 1928, Nyquist discovered sampling theorem at Bell Labs (will introduce in Lect. 10)
- 1948, Shannon established information theory at Bell Labs

Milestones in Communications: IV



Parts of optical fiber: core, cladding, and plastic coating

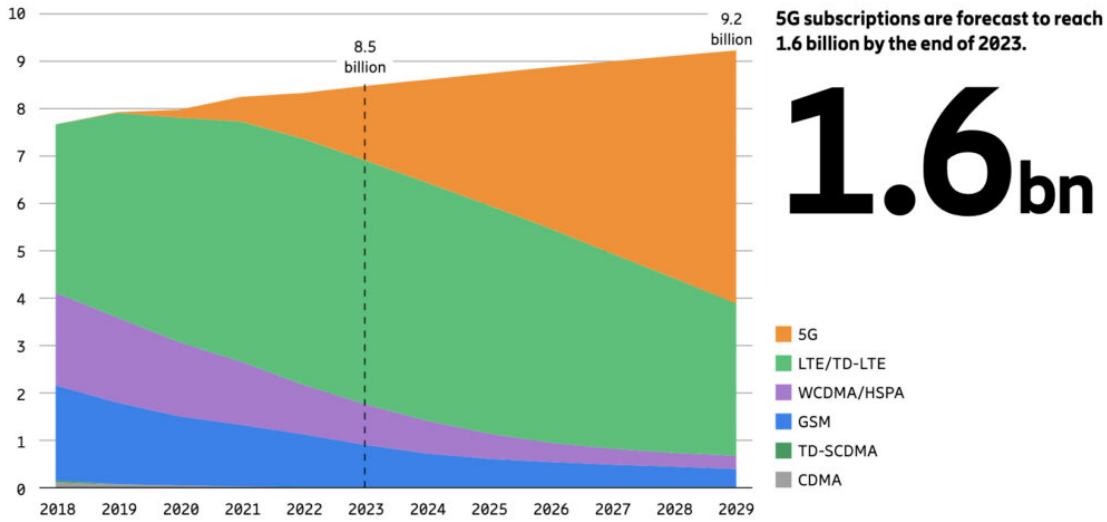
Martin Cooper reenacting the first private handheld mobile-phone call, 2007

- 1966, Kuen Kao pioneered fiber-optical communications (Nobel Prize Winner)
- 1971, First public wireless network ALOHANET established at University of Hawaii
- 1973, First mobile phone by Martin Cooper, Motorola
- 1978, First cellular mobile phone system (1G) developed by AT&T Bell Labs

Growth of Mobile Communications

- 1G: analog communications
  - AMPS
- 2G: digital communications
  - GSM
  - IS-95
- 3G: CDMA networks
  - WCDMA
  - CDMA2000
  - TD-SCDMA
- 4G: multi-antenna, multi-carrier
  - WIMAX
  - LTE
  - OFDMA
- 5G: high speed, low latency, massive connectivity
  - eMBB
  - mMTC
  - URLLC
- 6G: intelligent, conscious, secure, sustainable

Figure 1: Mobile subscriptions by technology (billion)



[1] 1 GSA and Ericsson (November 2023).
[2] A 5G subscription is counted as such when associated with a device that supports New Radio (NR), as specified in 3GPP Release 15, and is connected to a 5G-enabled network.
[3] Mainly CDMA2000 EVDO, TD-SCDMA and Mobile WiMAX.

Transfer analog signal

- AM (525 – 1606.5 kHz)
- FM (87.5 – 108.0 MHz)
- Analog TV
  - Video 45 – 66.75/179.75 – 214.75 MHz
  - Audio 41.5 – 63.25/176.25 – 211.25 MHz
- 1G
  - AMPS (Advanced Mobile Phone System, 824 – 894 MHz) in America and Australia
  - TACS (Total Access Communication System, 890 – 950 MHz) in UK

Radio City Tower, Liverpool

Transfer digital signal

- Transfer of information in bits
- Digital TV, CDs, DVD
- Broadband, 2G – 5G, ...

The data side of a DVD

AI and Communications

- A new era in communications
- Communication networks relied on decades of engineering expertise. Can we instead rely on AI generated modules?
- How would intelligent AI agents communicate with each other?
- Is communication separate from intelligence?

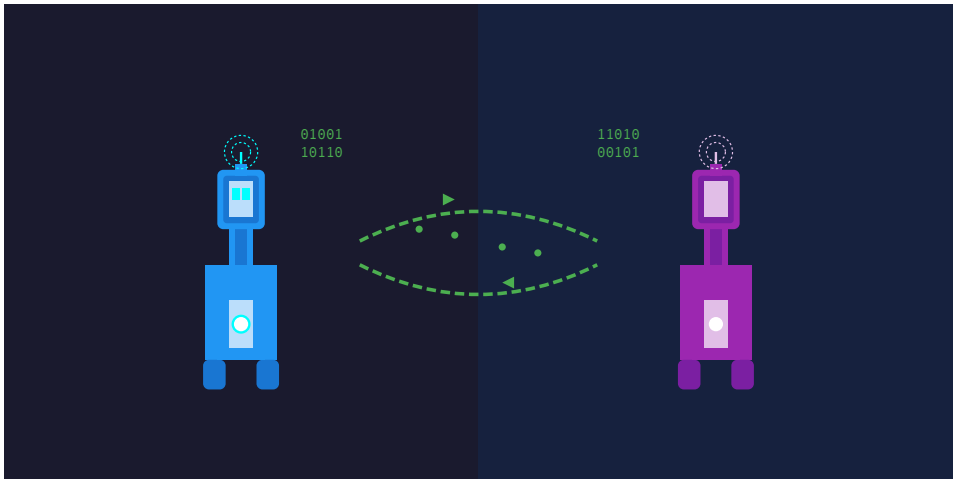
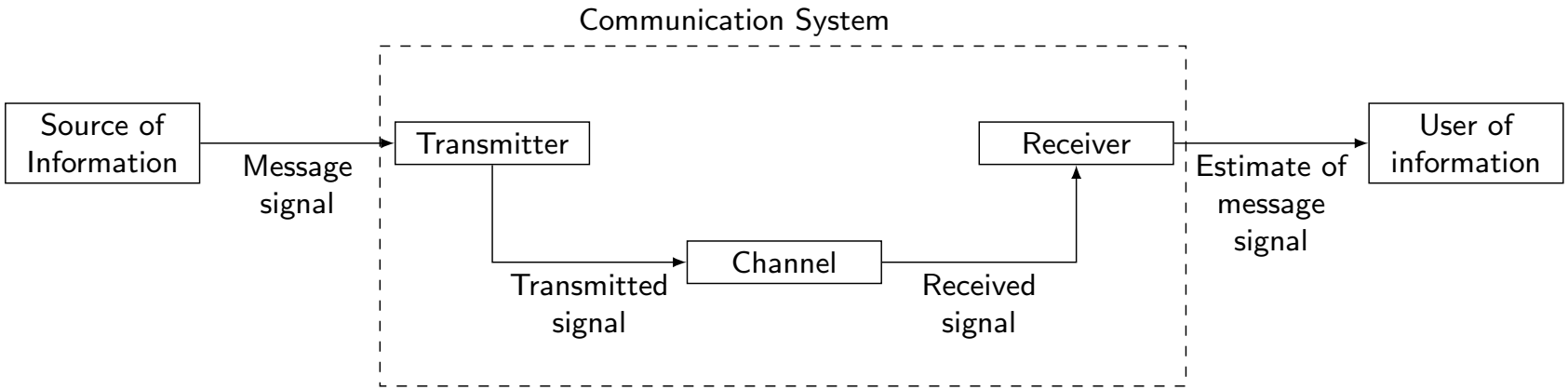


image generated by Claude 3.5 Sonnet

Communication Systems: Four Basic Elements

- Information source: voice, music, picture, video, ...
- Transmitter: converting information in the source into a form suitable for transmission over the channel
- Channel: the physical medium, introducing distortion, noise, and interference
- Receiver: reconstructing a recognizable form of the source signal



Block diagram of a communication system

Noise

- Unwanted signals in a communication system
- External noise: interference from nearby channels, human-made noise, natural noise...
- Internal noise: thermal noise, random motion of electrons
- Noise limiting the performance of communication systems
- Signal-to-noise ratio (SNR) is a widely used metric (will discuss in Lect. 7)

$$\text{SNR} = \frac{\text{average signal power}}{\text{average noise power}}$$

Transmitter

- converting the source signal into a form suitable for transmission over the channel
- including modulation and up-conversion

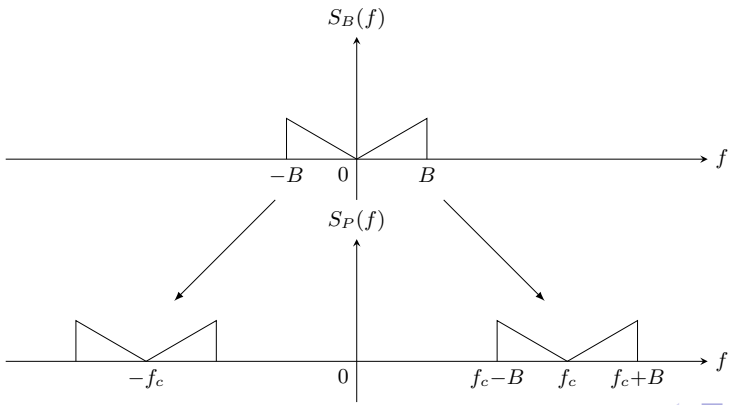
Modulation: changing some parameters of a carrier based on the source signal

- A carrier wave:

$$x(t) = A\cos(2\pi f_c t + \theta)$$

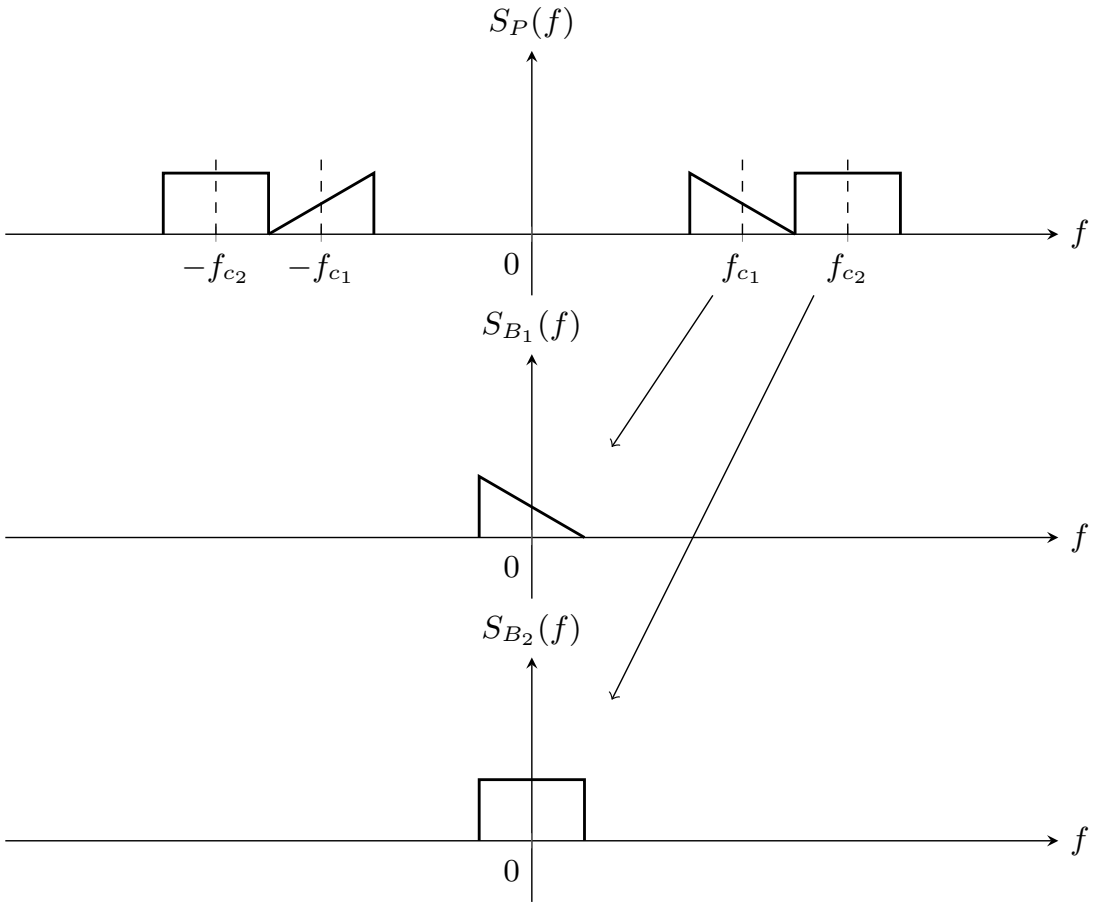
  - f_c: carrier frequency
  - A: amplitude
  - θ: phase
- Analog: AM, FM, PM (*M: modulation*)
- Digital: ASK, FSK, PSK (*SK: shift keying*)

Up-conversion: converting modulated signal to final radio frequency (RF)



Receiver

- reconstructing original message by down-conversion and demodulation
- no exact recovery due to noise and distortion
- degradation depending on the type of modulation and channel

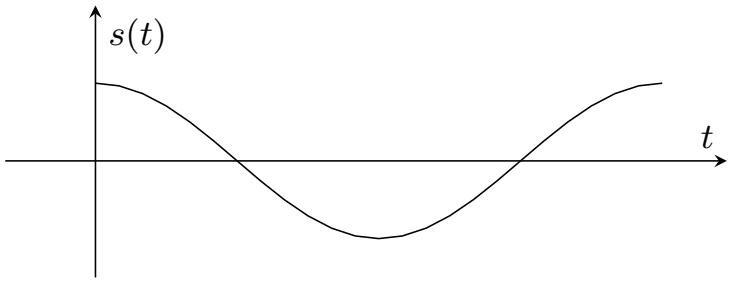


Digital, Discrete, Analog Signals

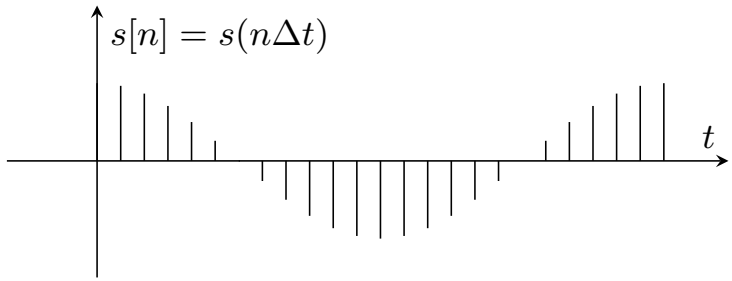
Analog signals: continuous in both time and amplitude (speech, image, video)

Discrete signals: discrete in time but continuous in amplitude (sampled version of continuous signal)

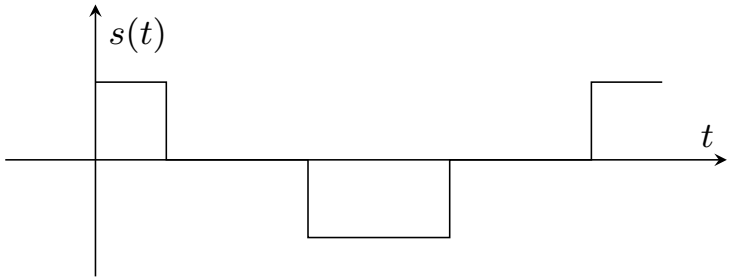
Digital signals: discrete in time and amplitude



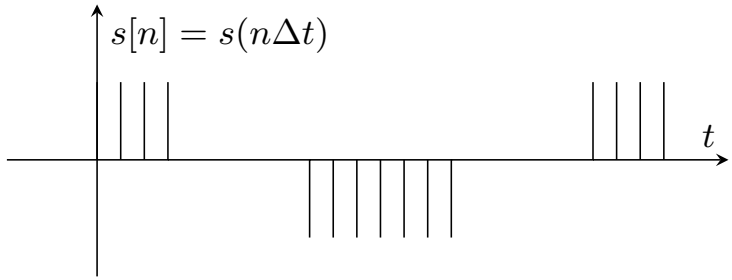
(a) Analog signal



(b) Discrete signal



(c) Digital signal



(d) Digital signal (seldom meet)

Digital vs Analog Communications

- Transmitted signals: current, voltages, EM waves $\rightarrow$ always analog
- Digital vs analog: depending on how parameters of these waveforms are formed
- Digital systems: source signal $\rightarrow$ source messages, digital signal (such as binary, etc.), analog signal for channel transmission
- Analog systems: conceptually simple, directly converting analog signal for channel transmission
- Digital communication: more efficient and reliable; more sophisticated types
- Digital design: universal and modular, any signal can be converted to digital format
- Performance metric of digital communications: Bit Error Rate (BER)

Notes