Department of Electrical Engineering
University of Arkansas

ELEG4623/ELEG5663 Communication Theory
Ch. 0 Introduction

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OUTLINE

- Historical Background
- Elements of a Communication System
- Digital Communication v.s. Analog Communication
- Underpinning Theories of Communication Systems

HISTORICAL BACKGROUND

- **Historical Background**
  - 1838: Cooke and Wheatstone build the telegraph
  - 1844: Morse demonstrates the telegraph line between Baltimore, MD and Washington, DC
  - 1858: the first transatlantic cable is laid (fails after 26 years)
  - 1864: Maxwell predicts electromagnetic radiation
  - 1876: Bell develops and patents the telephone
  - 1887: Hertz verifies Maxwell's theory
  - 1894: Lodge demonstrates wireless communication over a distance of 150 yards.
  - 1901: Marconi transmits and receives the first transatlantic wireless signals.
  - 1920: KDKA, Pittsburgh, PA, begins the first scheduled radio broadcasts
  - 1926: Baird and Jenkins demonstrate television
  - 1933: Armstrong invents frequency modulation (FM)
  - 1935: Watson-Watt develops the first practical radar

HISTORICAL BACKGROUND

- **Historical Background (Cont'd)**
  - 1948: Shannon publishes his work on information theory.
  - 1953: NTSC color television is introduced in the U.S.
  - 1961: Stereo FM broadcasts begin in the U.S.
  - 1962: Satellite communication begins with Telstar I (between U.S. and Europe)
  - 1963-66: Error-correction codes and adaptive equalization for high-speed digital communications are developed.
  - 1971: ARPANET (prototype of Internet) was put in service
  - 1972: Motorola demonstrates the cellular telephone.
  - 1980: Bell System fiber-optic communication is developed.
  - 1981: FCC adopts rules creating commercial cellular telephone service
  - 1985: ARPANET renamed Internet
  - 1988-1989: installation of trans-Pacific and trans-Atlantic optical cables for light-wave communications.
  - 1990: World Wide Web was introduced
  - 1990 – Present: digital communication systems widely deployed

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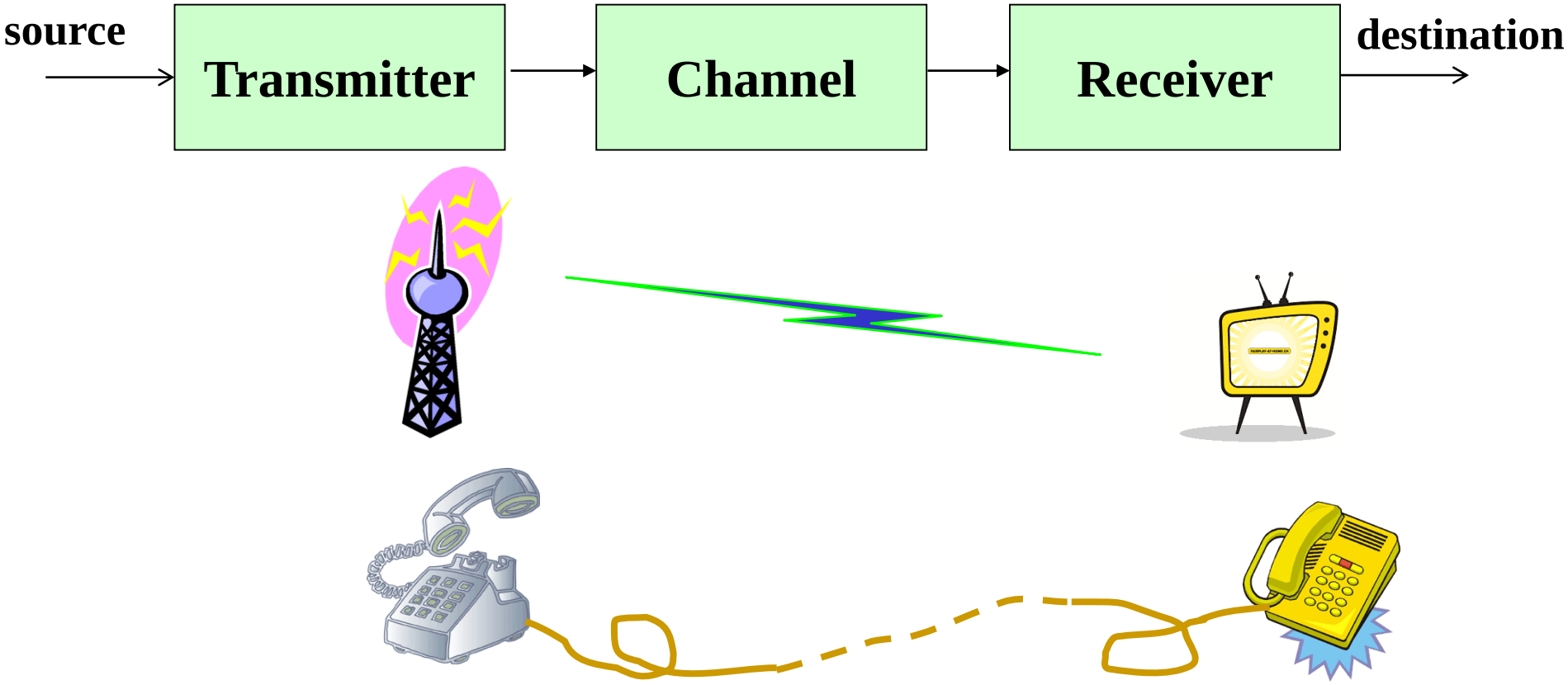
ELEMENTS

- **Communication system:**
  - A system designed to transfer information



Use electrical signal to transmit information from one location to another location.

ELEMENTS

- **Transmitter (input transducer)**
  - Convert the message from the source to an electrical signal suited to the characteristics of the transmission channel.
  - It involves operations such as modulation, coding, etc.
- **Channel**
  - The electrical medium that bridges the distance from source to destination.
  - Wired channel: twisted pair, coaxial cable
  - Wireless channel: electromagnetic waves, visible light, laser beam.
  - Channel introduces undesirable effects to the signal
    - Attenuation: the signal power progressively decreases as the distance increases
    - Thermal noise: unwanted electrical disturbance due to the random movement of electrons.
    - Interference: unwanted electrical signals from other electrical/mechanical systems.
    - distortion: waveform perturbation caused by imperfect response of the system to the input signal.

ELEMENTS

- **Receiver (output transducer)**
  - Convert the received electrical signal to its original format (e.g. audio, video).
  - It involves operations such as demodulation, decoding, filtering, etc.

ELEMENTS

- **The operation of any communication system relies on two resources**
  - Transmitted power: the average power of the transmitted signal
  - Channel bandwidth: the frequency range of the channel that allows the signal to pass through.

  - Both resources are limited.
  - The objective of communication system design is to achieve better communication qualities with less resources
    - E.g. less transmitted power ➔ longer battery life
    - E.g. less bandwidth ➔ more users in a certain frequency range.

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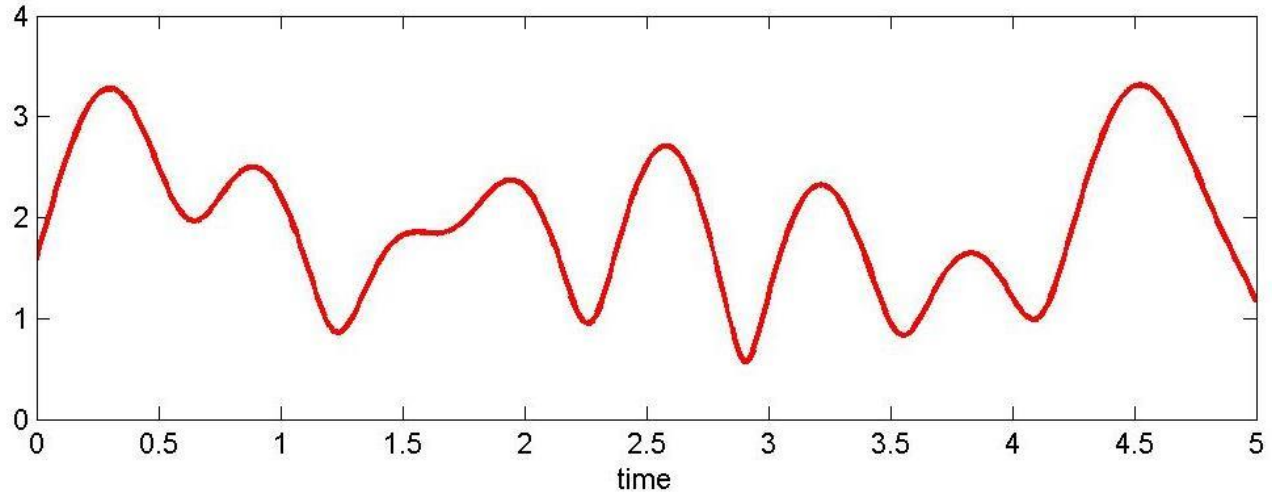
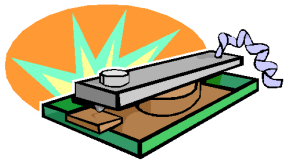
ANALOG V.S. DIGITAL

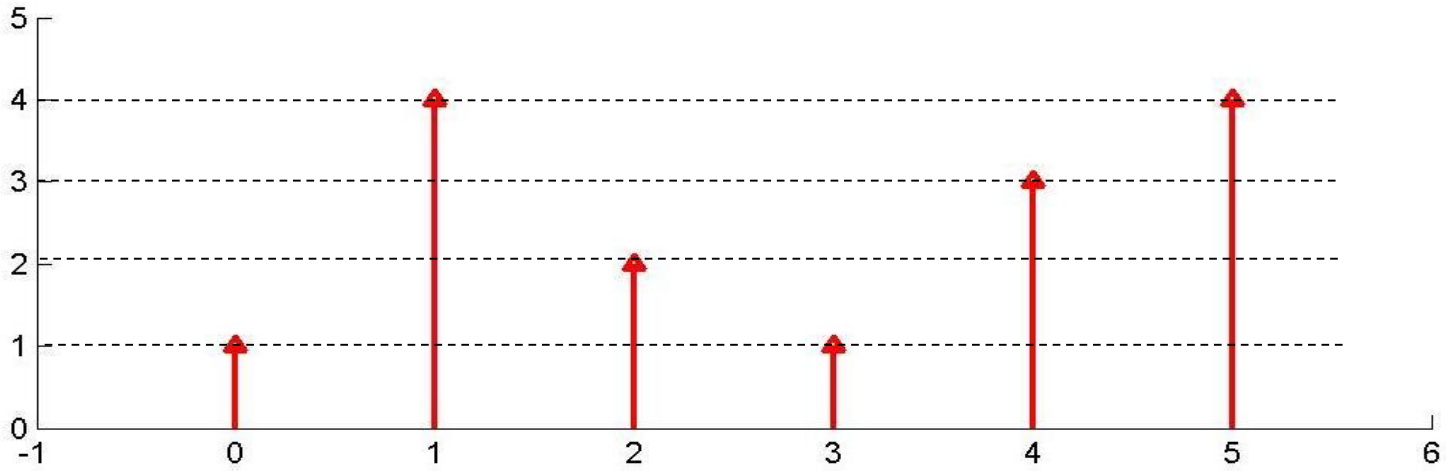
- **Analog Message**
  - A message that is defined on a continuum, i.e., the signal can take infinitely many values.
  - Waveform fidelity is important.
  - Example: human speech.

- **Analog Signal**
  - The electrical signal used to represent analog message



ANALOG V.S. DIGITAL

- **Digital Message**
  - A Message that has finitely many possible values.
  - Example: traffic lights  Telegraph 
- **Digital Signal**
  - The electrical signal used to represent digital message.



ANALOG V.S. DIGITAL

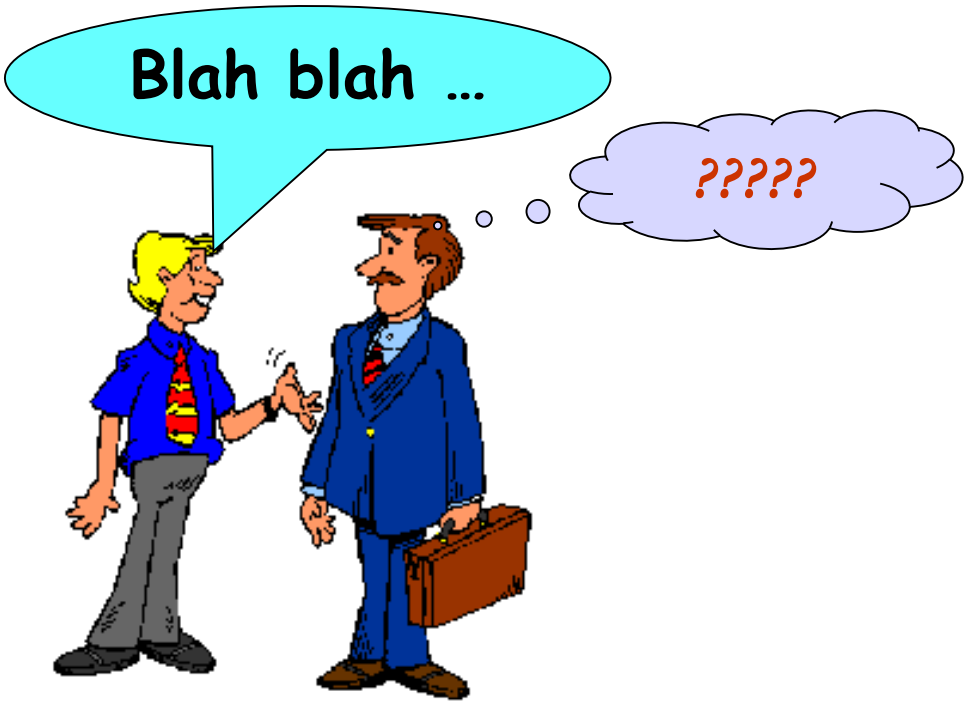
- **Usually, digital signals are used for digital message**
  - E.g., computer bit on Ethernet wire
- **Also, analog signals are used for analog message**
  - E.g., voice over telephone wire
- **However, one can use analog signal to carry digital message**
  - E.g., computer bits over telephone wire via a Modem
- **Also, analog message can be converted to digital message, then digitalized message can be carried by digital signal.**
  - Through sampling and quantization
  - E.g., audio in a MP3 player
- **Also, digital message can be converted to analog message, then the converted message can be carried by analog signal.**
  - Through interpolation
  - E.g., photo from digital camera displayed on a regular TV

ANALOG V.S. DIGITAL

- **Analog Communication System**
  - Transfers information from an analog message source to a destination (sink)
    - Analog message is transmitted in channel
    - Recover analog message at receiver
  - Objective: keep the fidelity of the analog waveform.
  - Example: AM/FM radio
- **Digital Communication System**
  - Transfers information from a digital message source to a destination (sink)
    - Digital message is transmitted in channel.
    - Recover digital message at receiver
  - Objective: Recover the digital message at the receiver.
    - Waveform fidelity is no longer important.
  - Example: Computer Network.

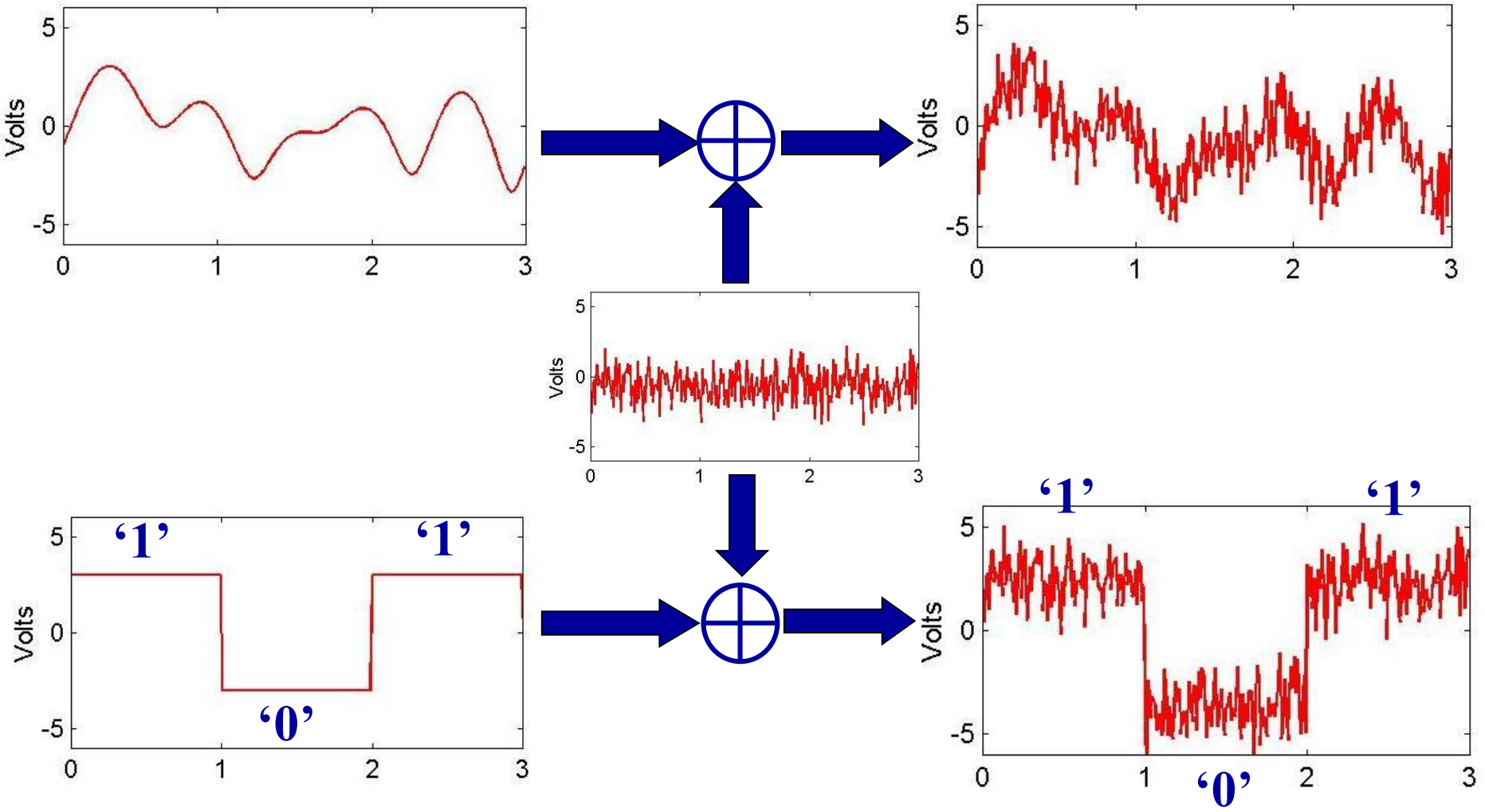
ANALOG V.S. DIGITAL

- When two people are talking with each other face by face, is this an analog communication system or digital communication System? What if they talk over cell phone?



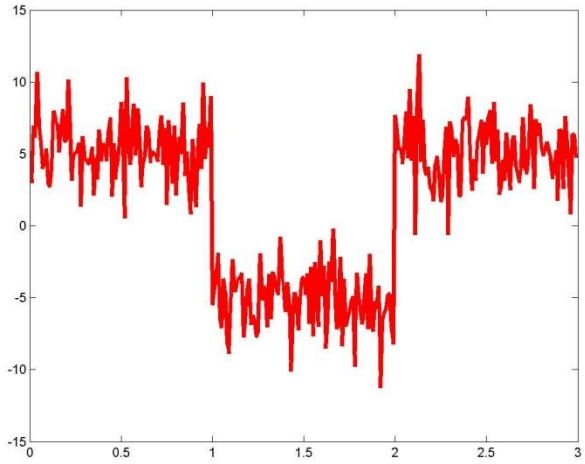
What matters is what kind of message is transmitted in channel.

ANALOG V.S. DIGITAL

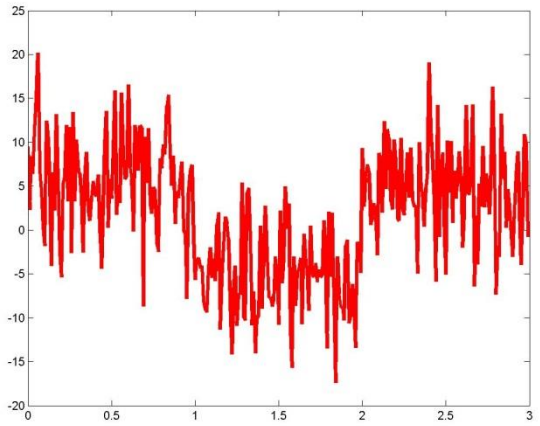


ANALOG V.S. DIGITAL: SNR

- **Signal to noise ratio (SNR): The ratio of the signal power to the noise power at the receiver.**
  - SNR = S/N, with S being the signal power, and N being the noise power observed by the receiver.
  - High SNR ➔ Signal is strong, and noise is weak ➔ Better communication quality.
  - Improve SNR ➔ Improve Tx power ➔ More power consumption



High SNR



Low SNR

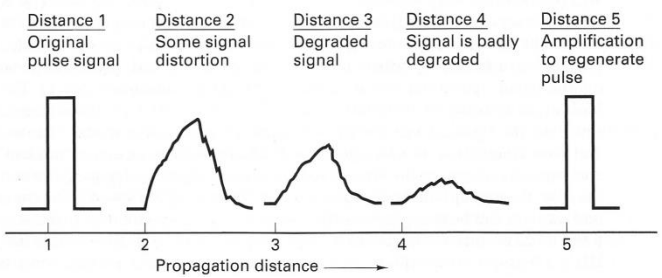
ANALOG V.S. DIGITAL: SNR

- **SNR is usually defined in the unit of dB (decibel)**
  - Linear value: SNR = S/N (no unit)
  - dB value: SNR(dB) = $10\log_{10}(S/N)$ dB
  - S/N = 2 ➔ SNR (dB) = $10\log_{10} 2$ = 3dB

- **Example:**
  - The proper operation of the 1st generation cell phone system (Analog) needs to maintain an SNR of approximately 18dB.
  - The proper operation of the 2nd generation cell phone system (Digital) needs to maintain an SNR of approximately 14dB.
  - Low SNR requirement ➔ Low Tx power ➔ Long battery life.
  - Even with less SNR requirement, the communication quality of the 2nd generation system is much better than that of the 1st generation system

ANALOG V.S. DIGITAL

- **Advantages of digital signals**
  - Less susceptible to distortion and interference than analog signals.

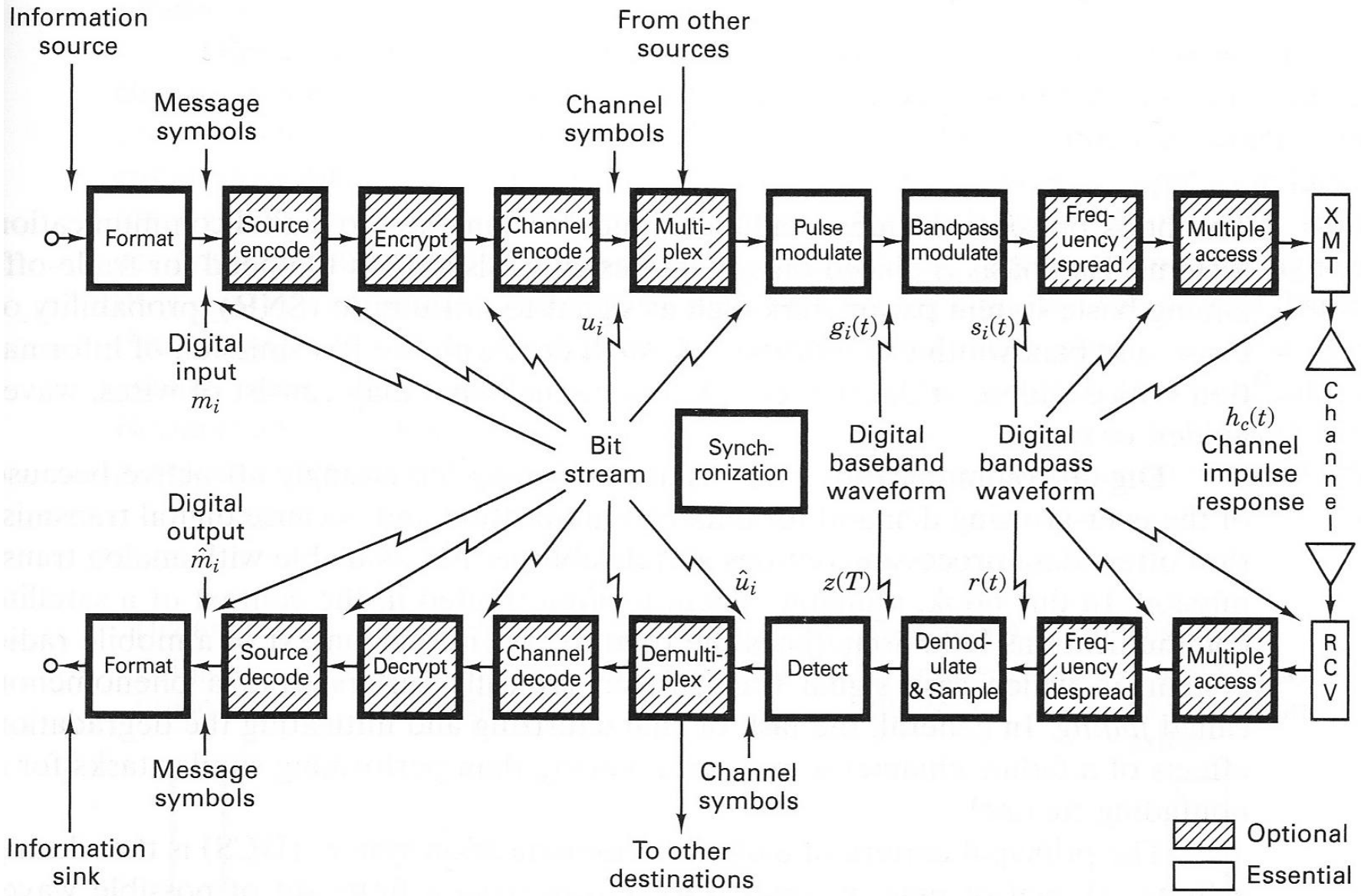


Regenerative repeaters

  - Digital circuits are more reliable and can be produced at a lower cost than analog circuits.
  - Digital system are more flexible than analog system
    - Microprocessor, VLSI (very large scale integrated circuits), DSP (Digital signal processor), TDM (time division multiplexing)
  - Different types of digital signals can be multiplexed together.
  - Can be protected via digital signal processing techniques.
  - Better security (encryption).

- **Digital $\neq$ Binary**
  - Binary signal is a type of digital signal
  - digital signal can take more than two discrete values
    - E.g. traffic lights (red, yellow, green), English alphabet (26 letters)

DIGITAL COMMUNICATION BLOCK DIAGRAM



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UNDERPINNING THEORIES

- **Essential theories for communication system**
  - Fourier analysis
    - Analyze the signal in the frequency domain
  - Modulation theory (linear system and signal processing)
    - Fundamental to the transmission of an information-bearing signal over a communication channel.
  - Detection theory (linear system and signal processing)
    - Recover the original message by analyzing the noise distorted signal at the receiver
  - Probability theory and random process
    - Message is random
    - Noise is random