

# Introduction to Digital Communication Systems

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# Outline

- Components of a communication system
- Digital vs. analog communications
- SNR, bandwidth and channel capacity
- Purpose of this course – Building a digital communications system

# Components of a Communication System (1)

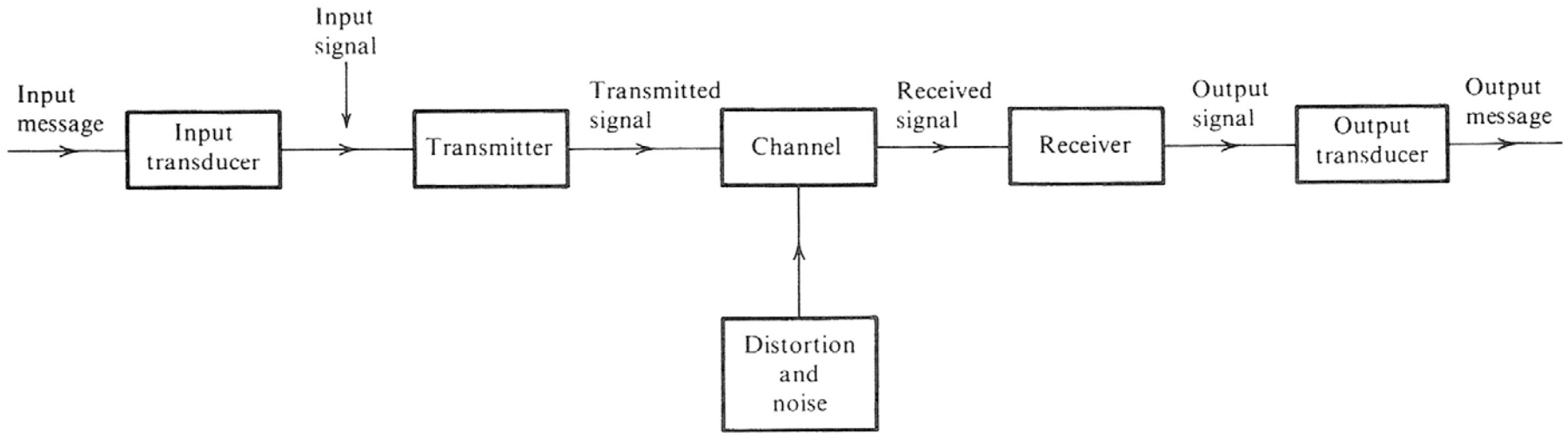


Figure 1: Communication Systems

## Components of a Communication System (2)

- The **source** originates a message, which could be a human voice, a television picture or data. The source is converted by an **input transducer** into an electrical waveform referred to as the **baseband signal** or **message signal**.

# Components of a Communication System (3)

- The **transmitter** modifies the baseband signal for efficient transmission. The transmitter generally consists of one or more of the following subsystems: a pre-emphasizer, a sampler, a quantizer, a coder and a modulator.
- The **channel** is a medium through which the transmitter output is sent, which could be a wire, a coaxial cable, an optical fiber, or a radio link, etc. Based on the channel type, modern communication systems are divided into two categories: **wirelined communication systems** and **wireless communication systems**.

# Components of a Communication System (4)

- The **receiver** reprocessed the signal received from the channel by undoing the signal modifications made at the transmitter and the channel. The task of the receiver is to extract the message from the **distorted and noisy signal** at the channel output. The receiver may consist of a demodulator, a decoder, a filter, and a de-emphasizer. The receiver output is fed to the **output transducer**, which converts the electrical signal to its original form.

# Goal of this course

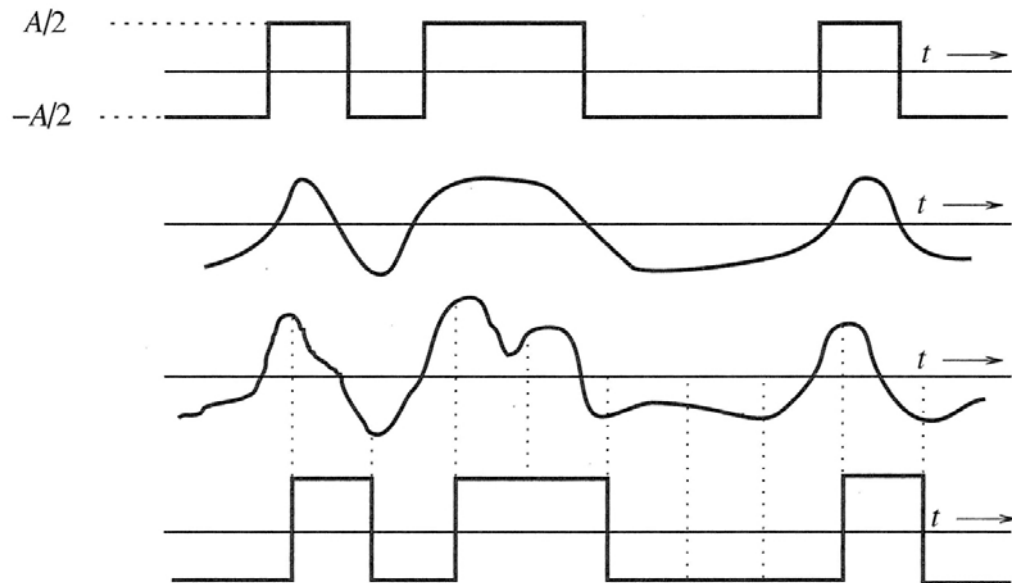
- When the signal is transmitted through the channel, it is not only distorted by the channel, but also contaminated/interfered by **noise**. Transmitters and receivers are carefully designed to overcome the distortion and noise, *the main purpose of this course is to introduce the principles on how to design efficient communication systems.*

# Digital vs. Analog Communications (1)

- Analog and Digital Signals
  - Messages are digital or analog.
    - **Digital messages** are constructed with a finite number of symbols. For example, a text file is a digital message constructed from 50 symbols, consists of 26 letters, 10 numbers, a space and several punctuation marks. Similarly, a Morse-coded telegraph is a binary message, implying only two symbols – mark and space.
    - **Analog messages** are characterized by data whose values vary over a continuous range. For example, a speech waveform has amplitudes that vary over a continuous range. A picture is also an analog message.



# Noise immunity of digital signals



**Figure 1.3** (a) Transmitted signal. (b) Received distorted signal (without noise). (c) Received distorted signal (with noise). (d) Regenerated signal (delayed).

# Digital vs. Analog Communications (2)

- **Noise immunity of digital signals** – digital data can be recovered without any error as long as the distortion and noise are within limits. On the other hand, for an analog message, even a slight distortion or interference in the waveform will cause an error in the received signal.
- **Regenerative repeaters**—Based on this “**noise immunity**”, when transporting a bit stream over a long distance, **regenerative repeaters** or **repeater stations** are placed along the path of a digital system at distances short enough to ensure that noise and distortion remain within a limit. **The viability of regenerative repeaters is the main reason for the superiority of digital systems over analog ones.**

# Interface of Analog and Digital Systems

## -- A/D and D/A Conversion (1)

- **Sampling Theorem** A meeting ground exists for analog and digital signals: conversion of analog signals to digital signals. The backbone that supports the interface is **Shannon's Sampling Theorem**, which states that **if the highest frequency in the signal spectrum is  $B$ (in hertz), then the signal can be recovered from its samples, taken at a rate not less than  $2B$  samples per second.**

# Interface of Analog and Digital Systems

## -- A/D and D/A Conversion (2)

- **Quantization** each sample is approximated, or round off to the nearest quantized level, the information is thus digitalized. The quantized signal is an approximation of the original one. We can improve the accuracy of the quantized signal to any desired degree by increasing the number of levels  $L$ .

# Interface of Analog and Digital Systems

## -- A/D and D/A Conversion (3)

- **Pulse-code-modulation (PCM)** -- the scheme of transmitting data by digitizing and then using pulse codes to transmit the digitized data.
- Example: Multi-amplitude PCM vs. binary PCM

# Interface of Analog and Digital Systems

## -- A/D and D/A Conversion (4)

- During each sampling interval, we transmit one quantized sample, which takes on one of the  $L$  values. This requires  $L$  distinct waveforms, which maybe constructed in two ways: Form  $L$  distinct waveforms directly or use a combination of only two basic pulsed. The later is the so called binary case, where signaling is carried out by means of only two basic pulses or symbols.

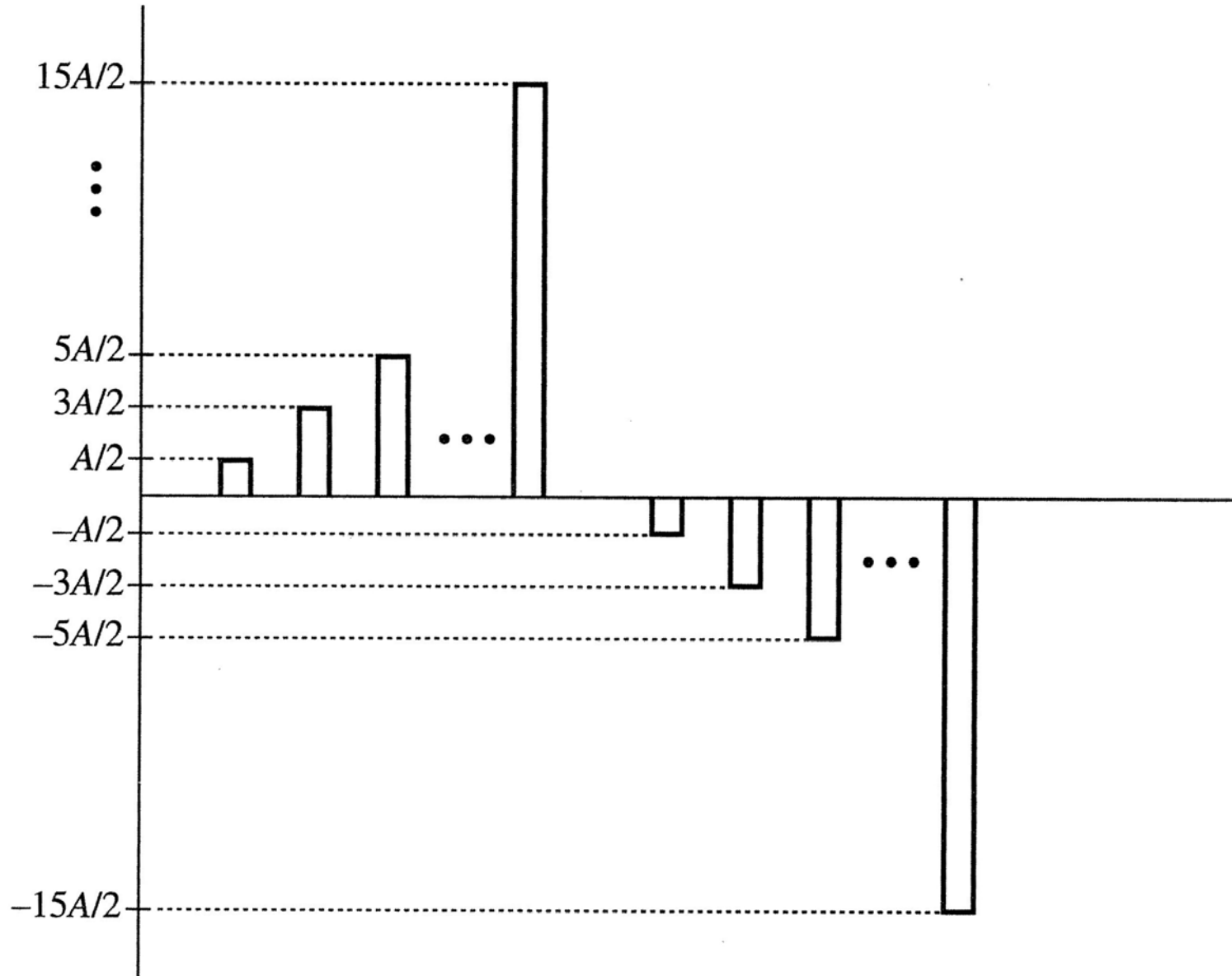


Figure 3: Multi-amplitude PCM

















Digit	Binary equivalent	Pulse code waveform
0	0000	
1	0001	
2	0010	
3	0011	
4	0100	
5	0101	
6	0110	
7	0111	
8	1000	
9	1001	
10	1010	
11	1011	
12	1100	
13	1101	
14	1110	
15	1111	

Figure 4: Binary PCM



## Interface of Analog and Digital Systems

### -- A/D and D/A Conversion (5)

- Take  $L=16$  as an example. One way to construct  $L$  distinct waveforms is to use a rectangular pulse of amplitude  $A/2$  and its multiples, for instance,  $\pm A/2, \pm 3A/2, \pm 5A/2, \dots, \pm 15A/2$ .
- As shown in Fig. 3. The second alternative is to use combination of only two basic pulses,  $A/2, -A/2$ . A sequence of four such pulses gives 16 distinct patterns, as can be seen in Fig. 4.

# Interface of Analog and Digital Systems

## -- A/D and D/A Conversion (6)

- By increasing  $L$ , we can reduce the quantization error to any desirable amount. At the same time, because of the use regenerative repeaters, we can transmit signals over a much longer distance than would have been possible for the analog signal. With modern data compression and transmission technology, **PCM transmission of analog signals can be accomplished with less bandwidth than the analog transmission of the same signal.** This is critical in wireless communication, since bandwidth/radio spectrum is in short supply.

## Interface of Analog and Digital Systems

### -- A/D and D/A Conversion (7)

- From all this discussion, we arrive at a rather interesting conclusion: **every possible communication can be carried on with a minimum of two symbols, i.e., by using a proper binary sequence.** In the last 20 years, digital communication gradually replace its analog competitors, and the revolution is now nearly complete.

# SNR, Bandwidth and Channel capacity (1)

- The fundamental parameters that control the rate and quality of information transmission are the channel bandwidth **B** and the signal power **S**.
- The **bandwidth** of a channel is the range of frequencies that it can transmit with reasonable fidelity. For example, if a channel can transmit with fidelity a signal whose frequency components occupy a range from 0(dc) up to a maximum of 5000 *Hz*, the channel bandwidth **B** is 5k*Hz*.

## SNR, Bandwidth and Channel capacity (2)

- **The rate of information transmission is directly proportional to B.** Consider the possibility of increasing the speed of information transmission by time compression of the signal. If a signal is compressed in time by a factor of 2, it can be transmitted in half the time, and the speed of transmission is doubled. However, compression by a factor of 2 causes the signal to “wiggled” twice as fast, implying that the frequencies of its components are doubled. To transmit this compressed signal without distortion, the channel bandwidth must also be doubled.

## SNR, Bandwidth and Channel capacity (3)

- The **signal power  $S$**  plays a dual role in information transmission.
  - First,  $S$  is related to the quality of transmission. Increasing the signal power reduces the effect of channel noise, and information is received more accurately, or with less uncertainty. A larger signal-to-noise(ratio) also allows transmission over a longer distance. In any event, a certain minimum SNR is necessary for communication.

## SNR, Bandwidth and Channel capacity (4)

- The second role of signal power is that **S is exchangeable with the bandwidth B; that is, to maintain a given rate and accuracy of information transmission, one can trade S for B and vice versa.** Rigorous proof will be provided in this course later on and here we only give a “plausible” argument.

## SNR, Bandwidth and Channel capacity (5)

- Consider the PCM scheme discussed earlier. Let  $E_b$  stand for the energy of the basic pulse in the binary case. For the multiamplitude case, the average pulse energy is

$$\begin{aligned} E_{s1} &= \frac{2}{16} [E_b + 9E_b + 25E_b + \dots + (16-1)^2 E_b] \\ &= \frac{16^2 - 1}{3} E_b \end{aligned}$$

- For the binary case, the average pulse energy is simply  $4E_b$ , the power is reduced by a factor of  $255/12=21.25$ , but the required bandwidth is 4 times as great as that of the 16-ary case.



## SNR, Bandwidth and Channel capacity (6)

- In both cases, the minimum amplitude separation between transmitted pulses is  $A$ , we therefore have approximately the same error probability at the receiver. We have demonstrated here the exchangeability of **S** with **B**.
- In Conclusion, the two primary communication resources are the bandwidth and the transmitted power. In a given communication channel, one source maybe more valuable than the other. Hence, the communication systems should be designed accordingly.

## SNR, Bandwidth and Channel capacity (7)

- For additive white Gaussian noise (AWGN) channels, the limitation imposed on communication by the channel bandwidth and the SNR is highlighted by Shannon's equation,

$$c = \mathbf{B} \log_2(1 + SNR) \text{ bits} / s$$

Here  $C$  is the rate of information transmission per second, known as *channel capacity*.

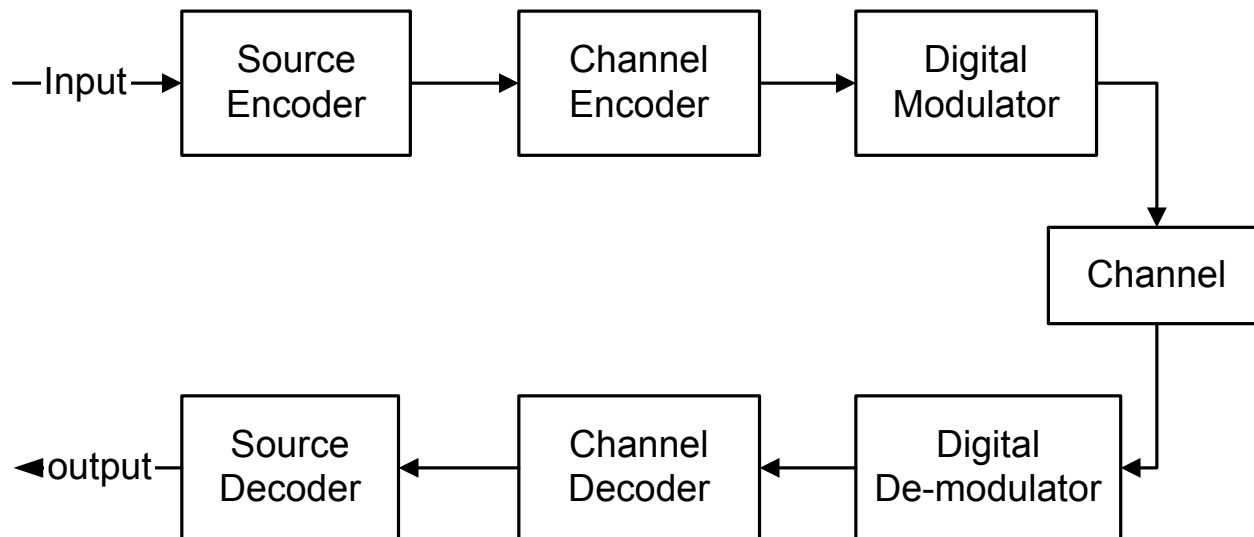


Figure 5: Digital communication system

# Building a Digital Communications System (1)

- **Source coding (data compression):** the process of efficiently converting the output of a source into a sequence of binary digit.
- **Channel coding** The introduction of redundancy in the information sequence for the purpose of combating the effects of noise and interference in the channel.

# Building a Digital Communications System (2)

- **Modulation** A process that converts the digital information sequences into waveforms that are compatible with the characteristics of the channel.
- **Channel estimation** Generally, channels may introduce distortion to the source signal, and the characteristics of the channel/distortion need to be estimated or identified at the receiver end, in order to reduce or eliminate the distortion and recover the original signal. This is called channel estimation or identification.

# Building a Digital Communications System (3)

- **Equalization** is the process to compensate for the channel distortion. Very often, equalizer is designed to minimize the ISI and the noise jointly.

# Homework and Assignments

- Read Chapter 1.
- Page 9, problem 1-1.