# Chapter 2: The Physical Layer

1 What is the basic goal of the physical layer?

2 How to define the physical layer protocols?

3 What is the theoretical basis for the physical layer?

*4 What are the commonly used transmission media?

*5 What are the common physical layer interface standards?

# Keypoints and Difficulties

## Keypoints:

- Nyquist's Law and Shannon-Hartley theorem
- Symbol code types: NRZ, Manchester encoding, Differential Manchester encoding

## Difficulties:

- Channel transmission rate calculation

# 1 The Goals

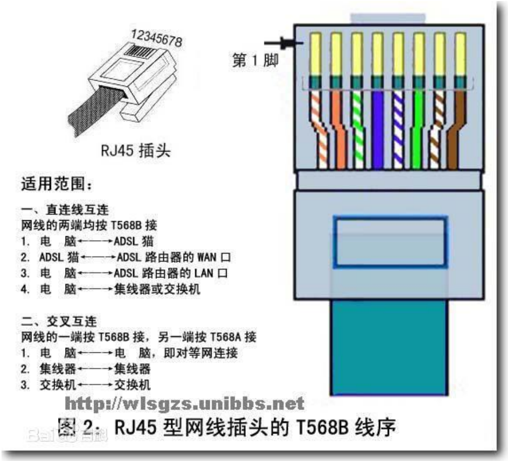
- To ensure the correctness of the transmitted signals "0" and "1" and the consistency of transmission and reception;
- Bit – transmission mode, speed, duration, and signal distortion;
- Interface design: the number of pins, specifications, functions, etc.;
- Signal transmission procedures: how to arrange the transmission process and the order of events;

# Four Important Characteristics

- Mechanical Characteristics
  - Specifies the size of the connector used in the physical connection, the number and arrangement of pins.
- Electrical Characteristics
  - Specifies the transmission mode, voltage level, coding, impedance matching, transmission rate and distance limit when transmitting the binary bit.

# Four Important Characteristics

- Functional Characteristics
  - Define the function of each physical line, indicating the means of a special voltage appears on a line
  - Line functions are divided into four categories: Data, Control, Timing, Power Supply
- Procedural Characteristics
  - Define the working rules and timing relationships for each physical line
  - Signal transmission: simplex, half duplex, full duplex


12345678
第 1 脚
RJ45 插头

适用范围：

一、直连线互连

网线的两端均按 T568B 接

1. 电　脑←——→ADSL 猫
2. ADSL 猫←——→ADSL 路由器的 WAN 口
3. 电　脑←——→ADSL 路由器的 LAN 口
4. 电　脑←——→集线器或交换机

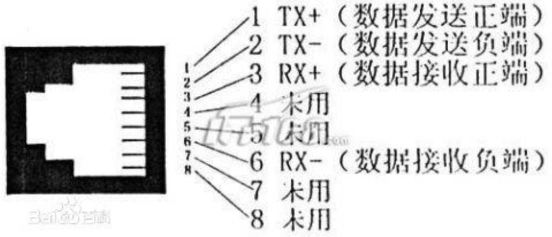
二、交叉互连

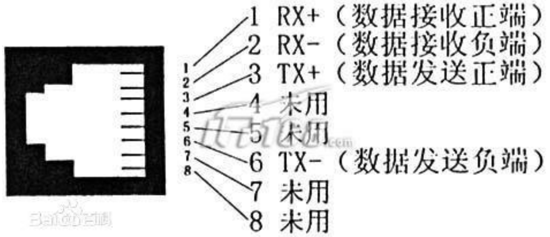
网线的一端按 T568B 接，另一端按 T568A 接

1. 电　脑←——→电　脑，即对等网连接
2. 集线器←——→集线器
3. 交换机←——→交换机

http://wlsgzs.unibbs.net

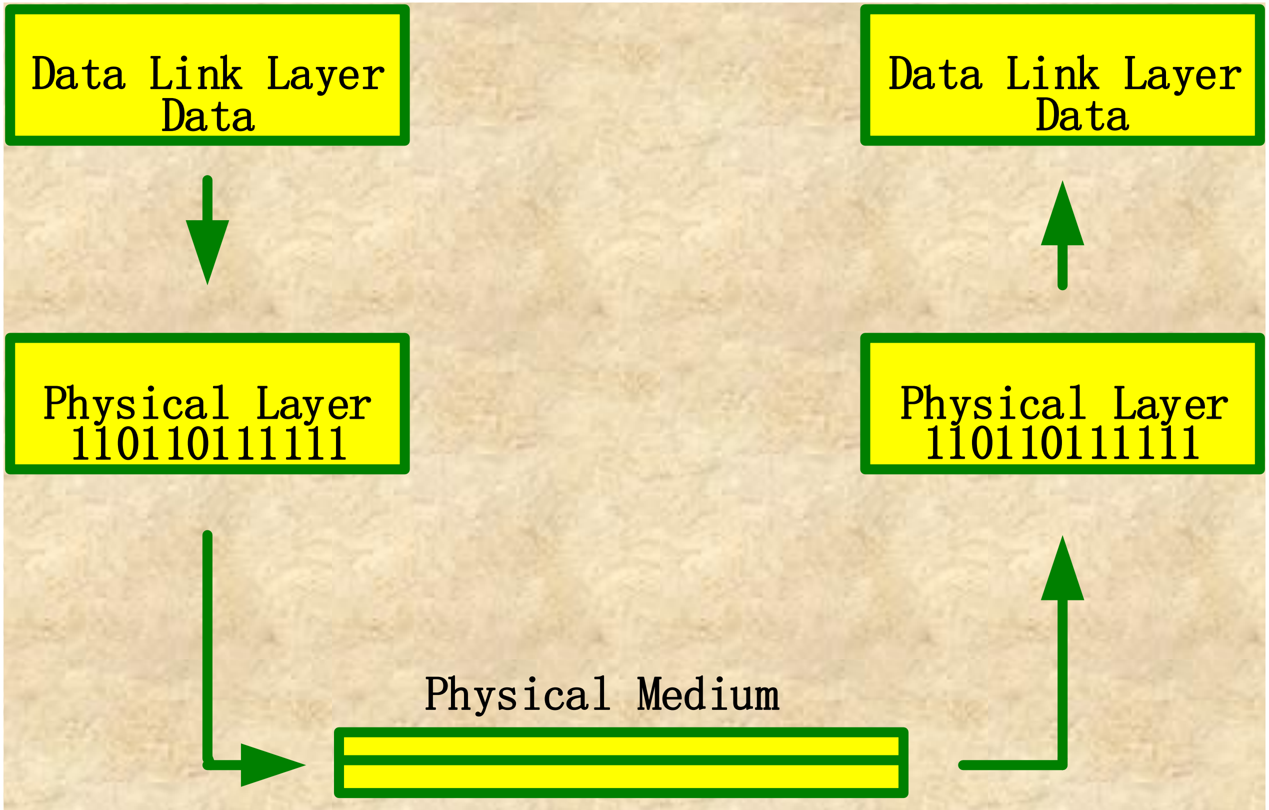
图 2：RJ45 型网线插头的 T568B 线序


1 TX+（数据发送正端）
2 TX-（数据发送负端）
3 RX+（数据接收正端）
4 未用
5 未用
6 RX-（数据接收负端）
7 未用
8 未用
1
2
3
4
5
6
7
8


1 RX+（数据接收正端）
2 RX-（数据接收负端）
3 TX+（数据发送正端）
4 未用
5 未用
6 TX-（数据发送负端）
7 未用
8 未用
1
2
3
4
5
6
7
8

# 2 Contents of Physical Layer Protocol

- Responsible for reliably transmitting bit data from one end of the physical medium to the other



Data Link Layer
Data

Physical Layer
110110111111

Physical Medium

Data Link Layer
Data

Physical Layer
110110111111

# 3 Basic theory of data communication

(1) Basic concepts

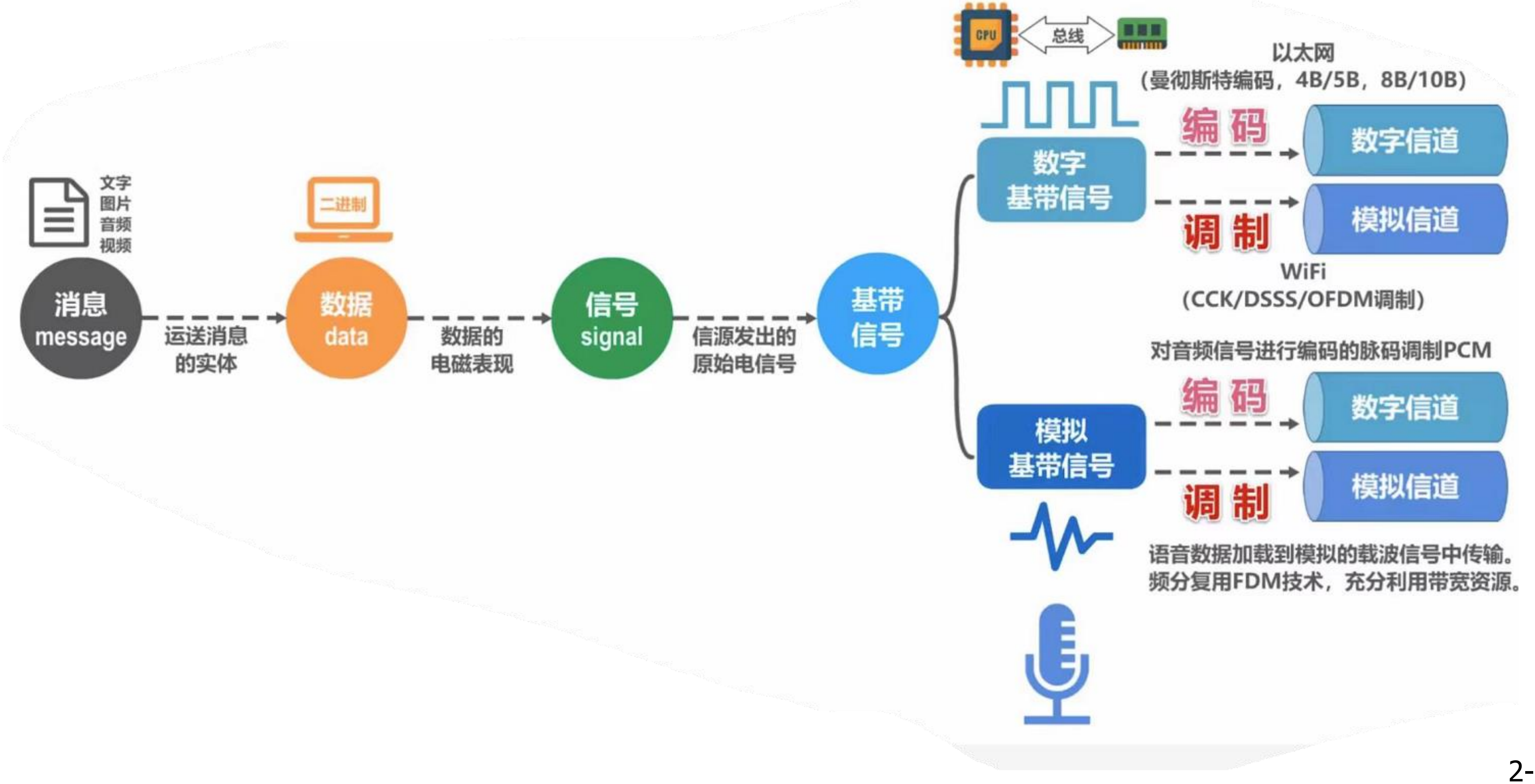
(2) For a specific physical communication channel, what is the maximum transmission rate? Infinite?

(3) How to transmit Bits in specific physical communication channels? Transmission speed, transmission duration, signal distortion?

(4) In order to save communication equipment and costs, how to transmit the information of multiple computers in one physical channel?

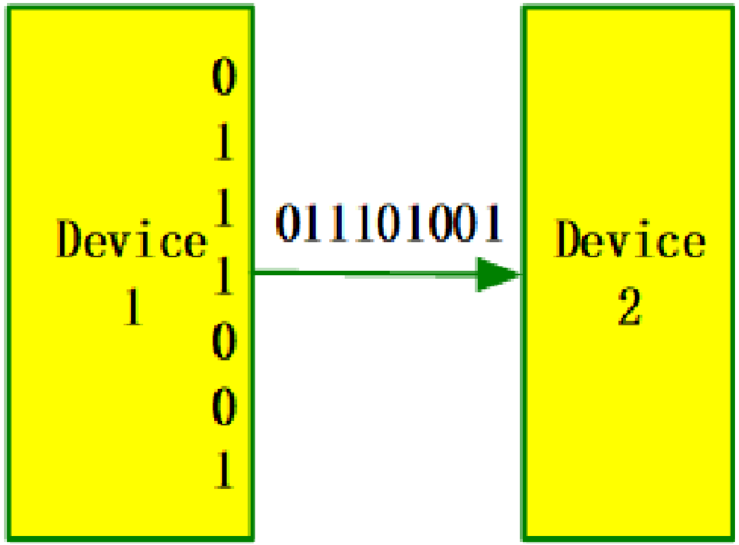
# (1) Basic concepts

- **Data**: Physical symbols describing objective facts
- **Signal**: Form of data transmission process
- **Channel**: media that sends information in a certain direction


CPU
总线
以太网
(曼彻斯特编码，4B/5B，8B/10B)
文字
图片
音频
视频
二进制
消息
message
运送消息
的实体
数据
data
数据的
电磁表现
信号
signal
信源发出的
原始电信号
基带
信号
数字
基带信号
编 码
数字信道
调 制
模拟信道
WiFi
(CCK/DSSS/OFDM调制)
对音频信号进行编码的脉码调制PCM
模拟
基带信号
编 码
数字信道
调 制
模拟信道
语音数据加载到模拟的载波信号中传输。
频分复用FDM技术，充分利用带宽资源。

# (1) Basic concepts

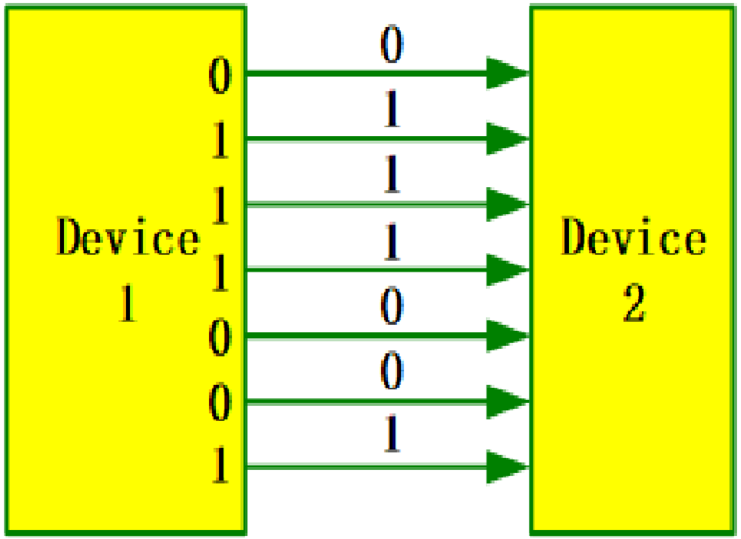
**Serial transmission**



Device 1
0
1
1
1
0
0
1
011101001
Device 2

- Suitable for long distance communication

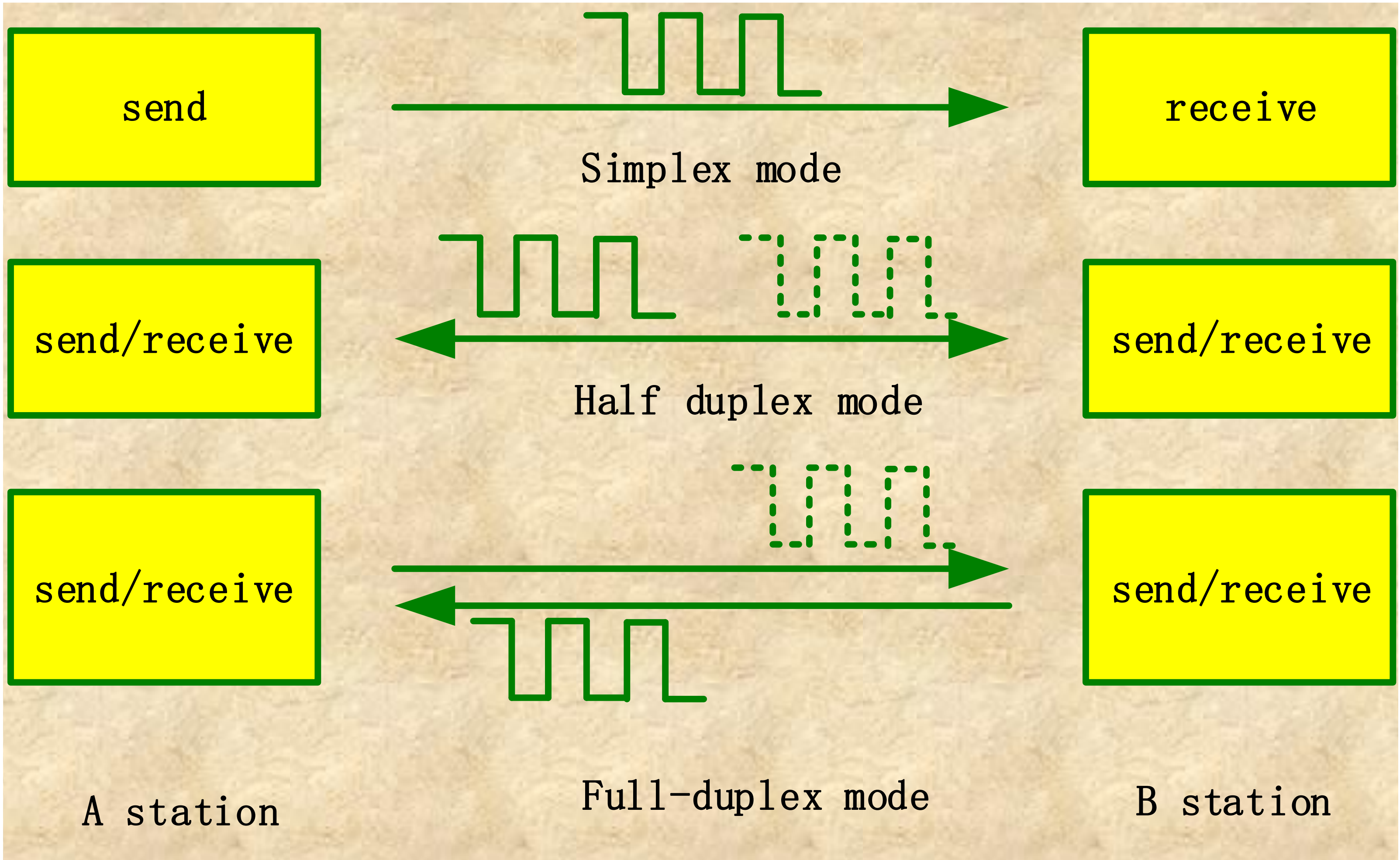
**Parallel transmission**



Device 1
0
1
1
1
0
0
1
0
1
1
1
0
0
1
Device 2

- Suitable for short distance communication

# (1) Basic concepts


send
receive
Simplex mode
send/receive
send/receive
Half duplex mode
send/receive
send/receive
Full-duplex mode
A station
B station

# 3 Basic theory of data communication

(1) Basic concepts

(2) For a specific physical communication channel, what is the maximum transmission rate? Infinite?

(3) How to transmit Bits in specific physical communication channels? Transmission speed, transmission duration, signal distortion?

(4) In order to save communication equipment and costs, how to transmit the information of multiple computers in one physical channel?

# (2) Channel Characteristics

- Symbol: A digital pulse, which represents the basic waveform of a discrete value
  - ASCII code of letter 'A': 1000001, can be represented by 7 pulses/symbols
- The amount of information carried by a symbol is determined by the number of discrete values taken by the symbol
  - Two discrete values ("0" or "1"): 1 bit
  - Four discrete values for a symbol: 2 bits
  - If N discrete values for a symbol of n (bits), then

$$n = \log_2 N$$

# (2) Channel Characteristics

- Baud rate (modulation rate or symbol rate) :
  - The number of times the signal changes every second
    - 1 baud sends one symbol per second
- Bit rate :
  - The number of bits transmitted per second
- Relationship between them:
  - If each symbol has n bits: bit rate (b/s) = baud rate * n
  - If each symbol has 3 bits, then the bit rate is three times the baud rate
  - If each symbol has 1 bit, the bit rate and baud rate are the same

# (2) Channel Characteristics

- Channel capacity (bandwidth in networks)
  - The maximum number of bits that can be transmitted over a channel per unit time, expressed in bps

- Frequency bandwidth (in communication)
  - Frequency range of the signal allowed by the channel (= maximum frequency - minimum frequency), in Hz
  - E.g., people can hear sound waves of 20Hz ~ 20kHz, i.e., frequency bandwidth of hearing system is19980Hz

# (2) Channel Characteristics

- Nyquist's Law :

  1) For an ideal low-pass channel with the frequency bandwidth of W (Hz), its maximum symbol transmission rate = 2W Baud

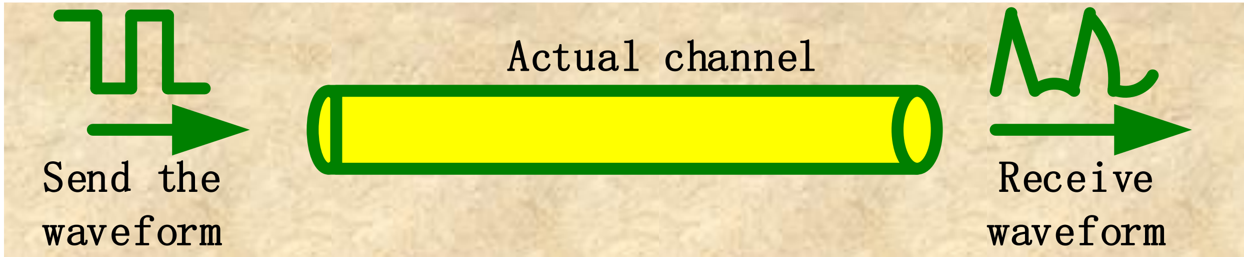
  2) For an ideal band-pass channel with the frequency bandwidth of W (Hz), its maximum symbol transmission rate = W Baud

- Question
  - The frequency band of a standard telephone channel is 300 ~ 3400Hz, i.e., the frequency bandwidth is 3100Hz. What is the maximum symbol transmission rate through the ideal low-pass channel?

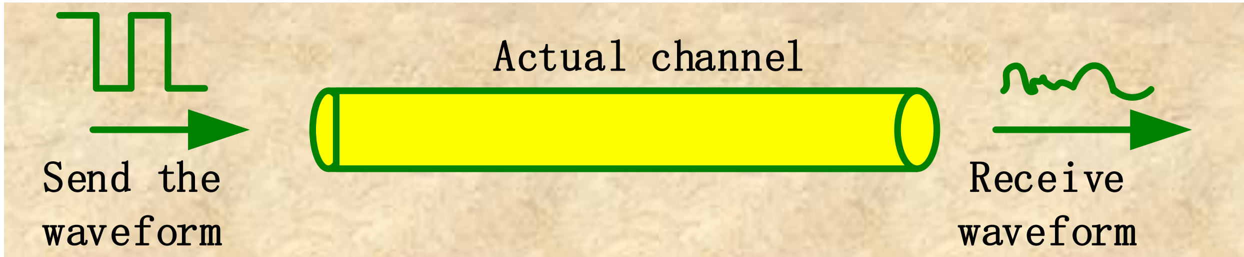
# (2) Channel Characteristics

- Actual channels are not ideal – Distortion exists
  - Higher symbol transmission rate
  - Farther signal transmission distance

  } Larger distortion
- Small and recognizable distortion


Actual channel
Send the waveform
Receive waveform

- Large and unrecognizable distortion


Actual channel
Send the waveform
Receive waveform

# (2) Channel Characteristics

- Shannon's Formula: limit information transmission rate C of channel can be expressed as:

$$C = W\log_2(1+S/N)$$

  - W - Frequency bandwidth in Hz
  - S - Average signal power through the channel
  - N - Gaussian noise power through the channel
  - S/N – related to signal-to-noise ratio
    - Typically in db (decibels): $10\log_{10}S/N$
- Actual rate much lower than C due to signal loss
- Possible to achieve error-free transmission as long as transmission rate < C

# (2) Channel Characteristics

- Example:
  - For the standard telephone channel with frequency bandwidth of 3.1 kHz, if the signal-to-noise ratio S/N = 2500, then can the information transmission rate be 50kb/s?
- Solution:
  - Put W = 3.1kHz, S / N = 2500 into Shannon's Formula
  - The limit information transmission rate is 35kb/s, so it is impossible to reach 50kb/s
- In order to achieve 50kb/s, you can
  - improve the signal-to-noise ratio in the channel
  - or increase the frequency bandwidth

# 3 Basic theory of data communication

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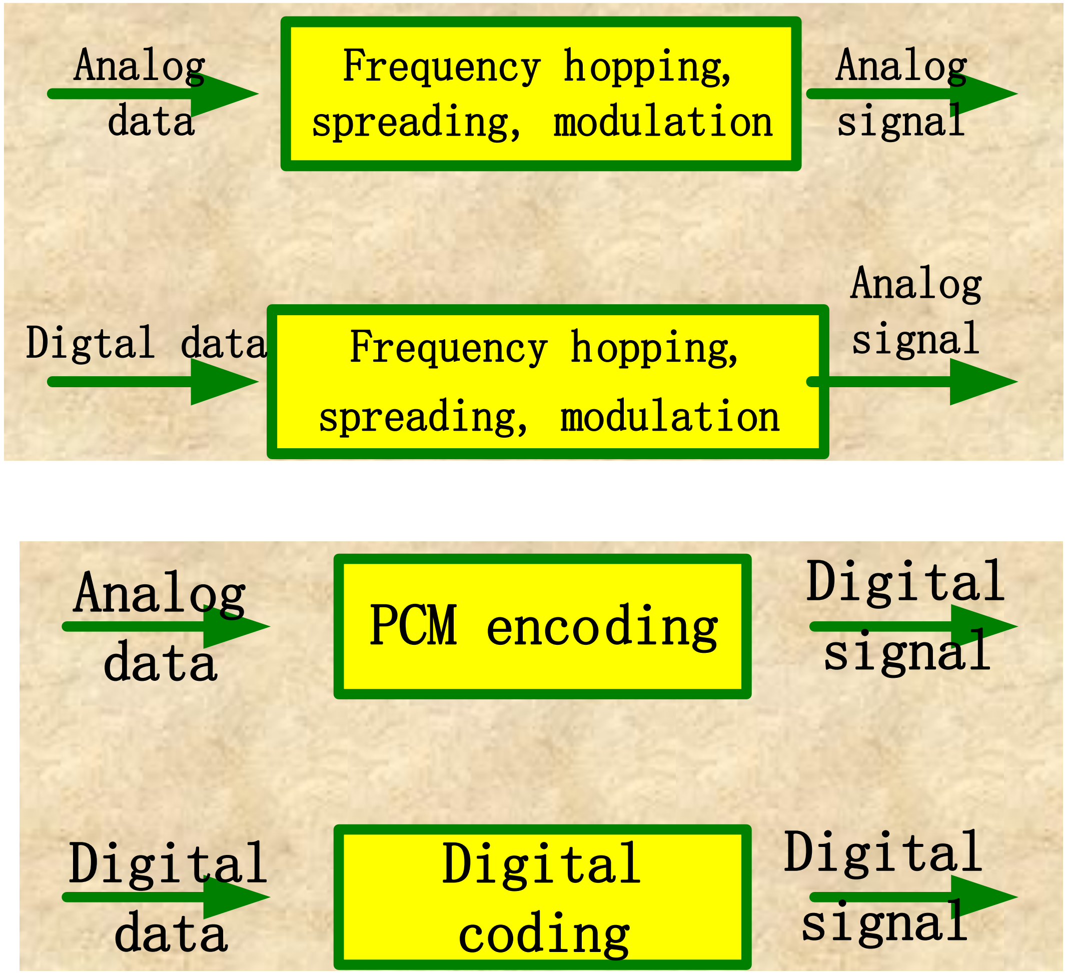
# Techniques in analog/digital transmission



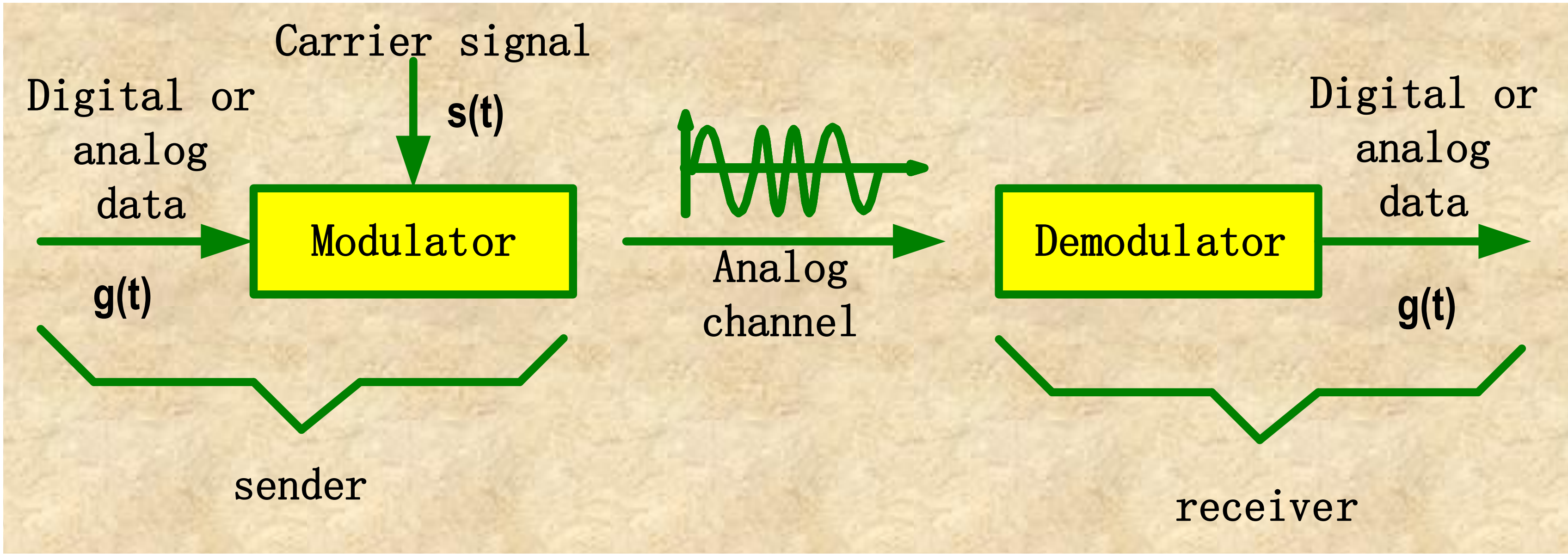
Analog data → Frequency hopping, spreading, modulation → Analog signal

Digtal data → Frequency hopping, spreading, modulation → Analog signal

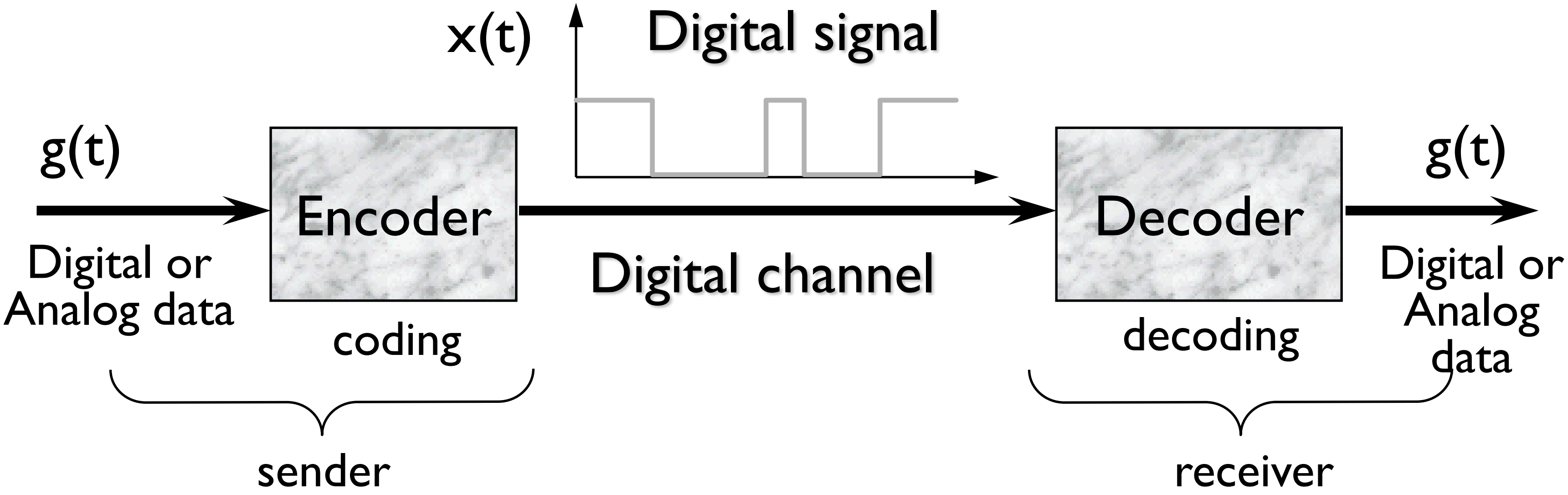
Analog data → PCM encoding → Digital signal

Digital data → Digital coding → Digital signal

# Modulation / demodulation system model

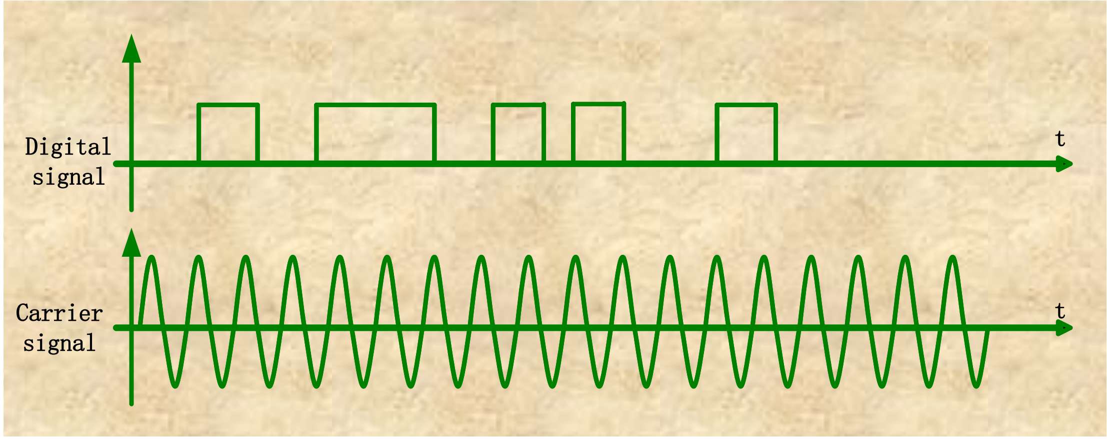

Carrier signal
s(t)
Digital or analog data
g(t)
Modulator
Analog channel
Demodulator
Digital or analog data
g(t)
sender
receiver

# Coding / decoding system model

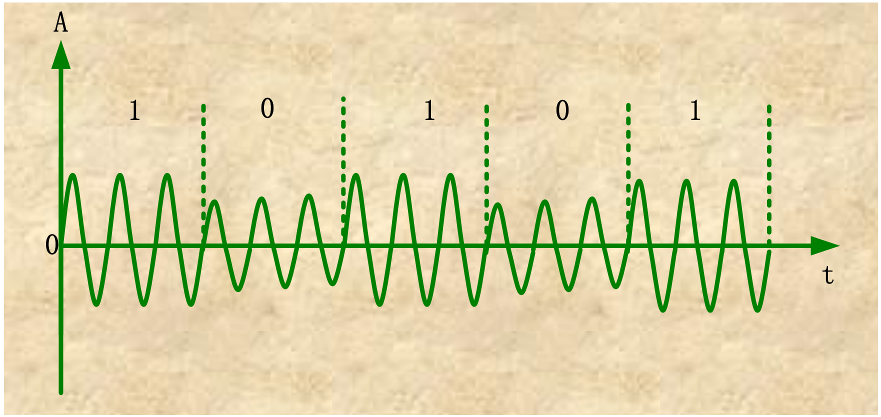

x(t)
Digital signal
g(t)
Encoder
Decoder
g(t)
Digital or Analog data
coding
Digital channel
decoding
Digital or Analog data
sender
receiver

# Modulation
(digital data to analog signals)

- Digital and carrier signals

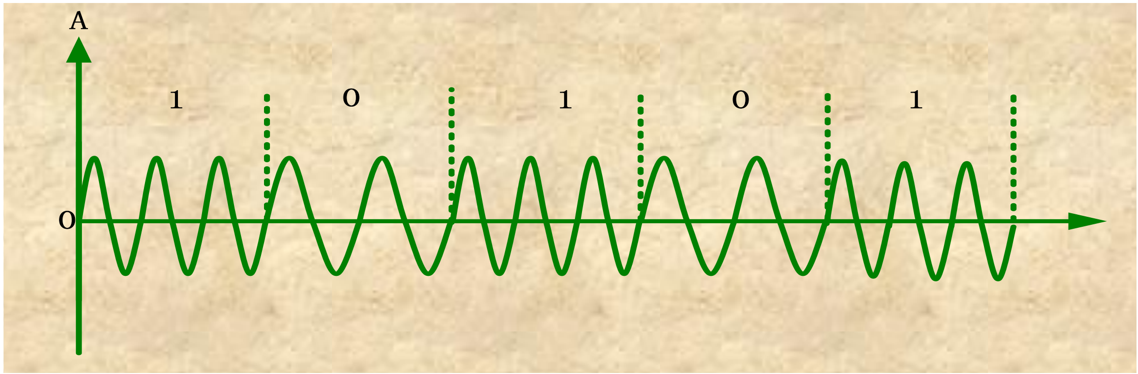

Digital
signal
t
Carrier
signal
t

- Amplitude Modulation (AM)

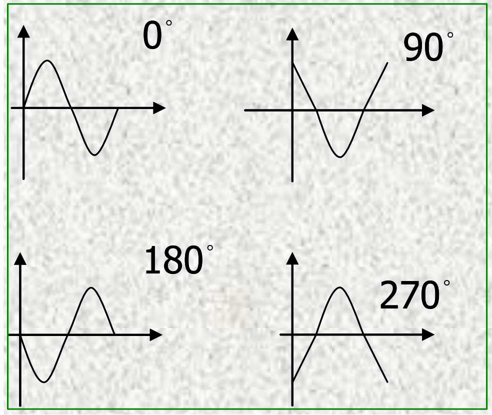


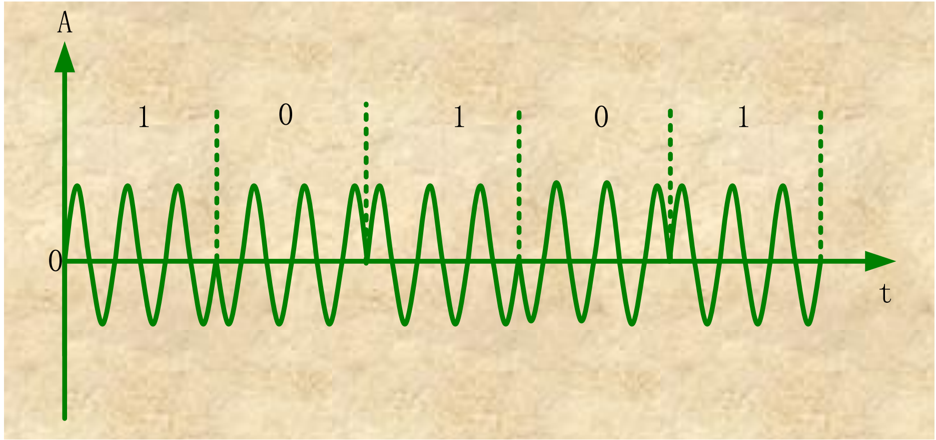
# Modulation
## (digital data to analog signals)

- Frequency Modulation (FM)



- Phase Modulation (PM)

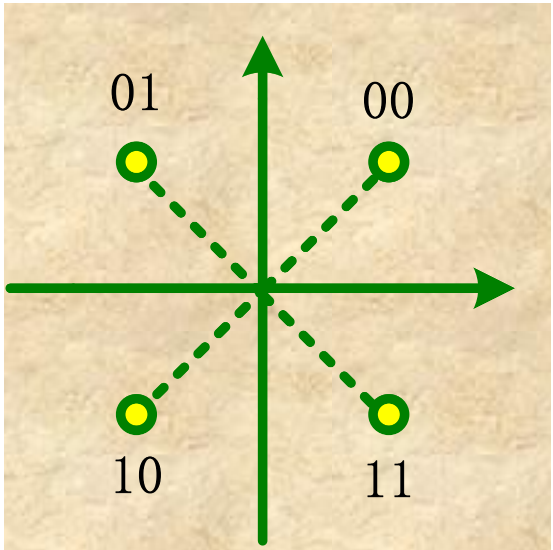




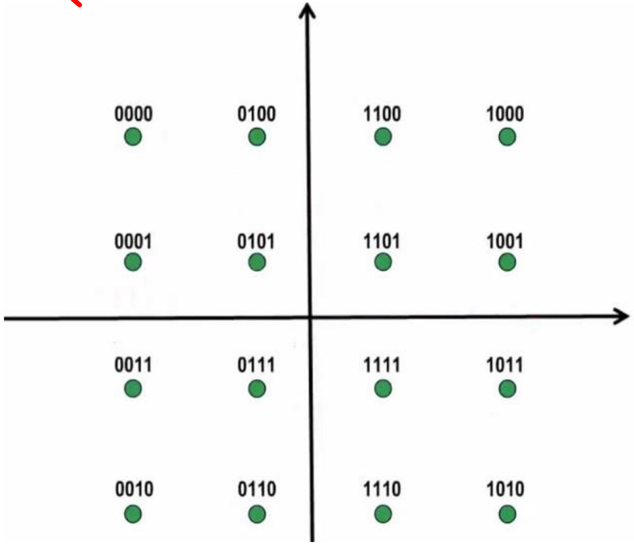
# Modulation
(digital data to analog signals)

- Quadrature Amplitude Modulation (QAM)
  - PM and AM techniques
  - If there are x changes in phase and y changes in amplitude, then there are x * y combined changes

4-QAM constellation table

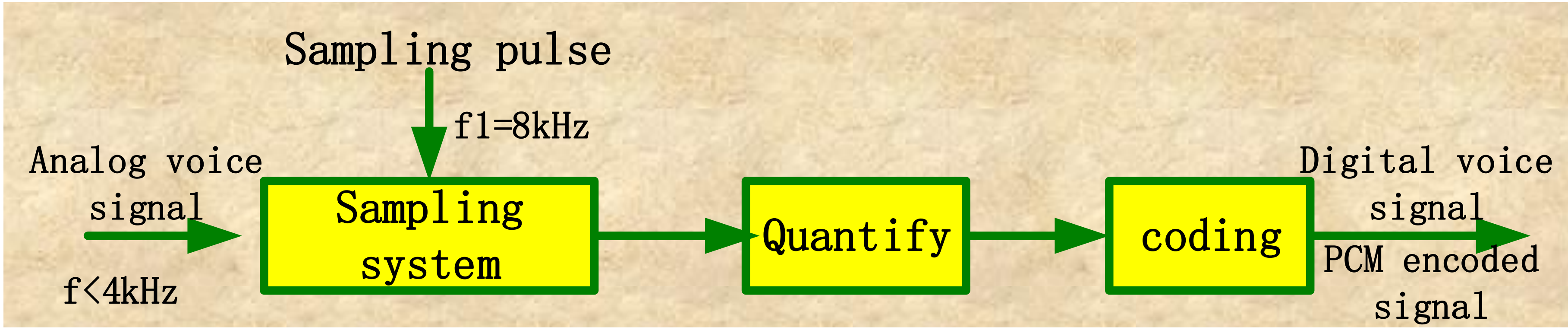


16-QAM constellation table


0000
0100
1100
1000
0001
0101
1101
1001
0011
0111
1111
1011
0010
0110
1110
1010

# Pulse Code Modulation (PCM) (analog data to digital signals)

- Sampling Theorem
  - As long as the sampling frequency is not less than twice the maximum frequency of the signal, the original signal can be recovered from the sampling pulse without distortion
- PCM system model

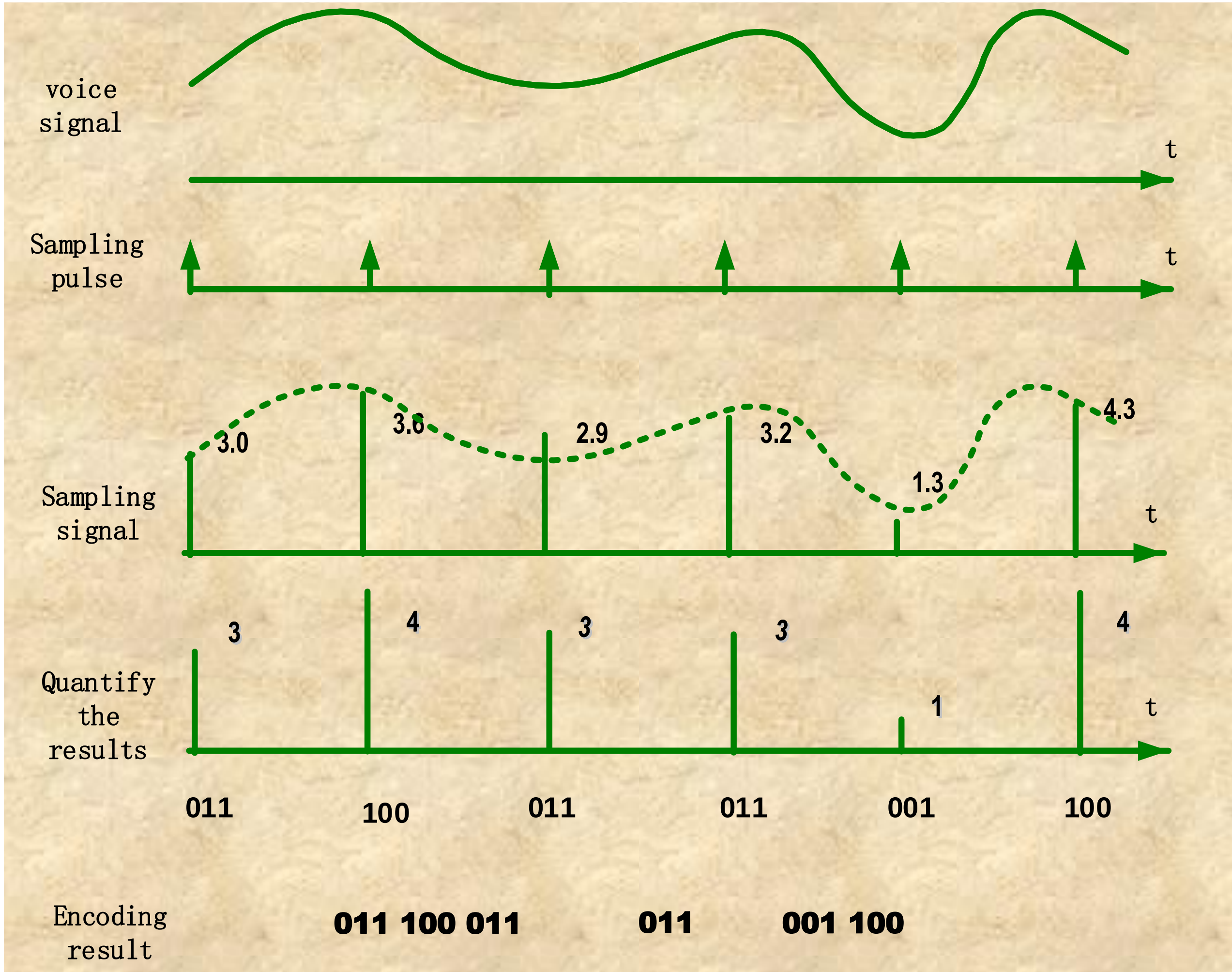

Sampling pulse
f1=8kHz
Analog voice signal
f<4kHz
Sampling system
Quantify
coding
Digital voice signal
PCM encoded signal

# Pulse Code Modulation (PCM) (analog data to digital signals)

- Voice signal digitization
  - Voice frequency bandwidth f <4kHz
  - Sampling clock frequency: 8kHz (> 2 times the maximum voice frequency)
  - Sample quantization series: 256 (8bit / per sample)
  - Data rate: 8000 times / s * 8bit = 64kb / s
  - The rate of each PCM signal = 64kb / s

# Pulse Code Modulation (PCM)
# (analog data to digital signals)

PCM coding process example

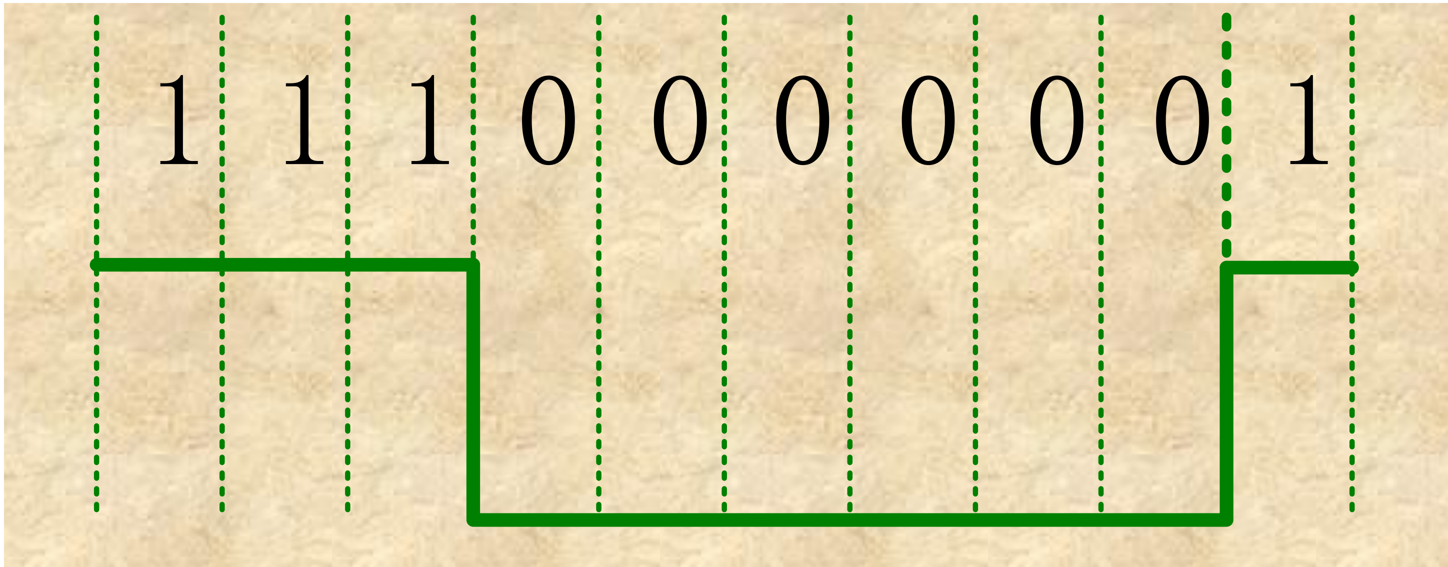

voice signal
t
Sampling pulse
t
3.0
3.6
2.9
3.2
1.3
4.3
Sampling signal
t
3
4
3
3
1
4
Quantify the results
t
011
100
011
011
001
100
Encoding result
011 100 011
011
001 100

# Digital signal coding
(digital data to digital signals)

- Non-Return-to-Zero (NRZ)
- Manchester encoding
- Differential Manchester encoding
- Block encoding (4B / 5B, 8B / 10B)

# Digital signal coding
(digital data to digital signals)

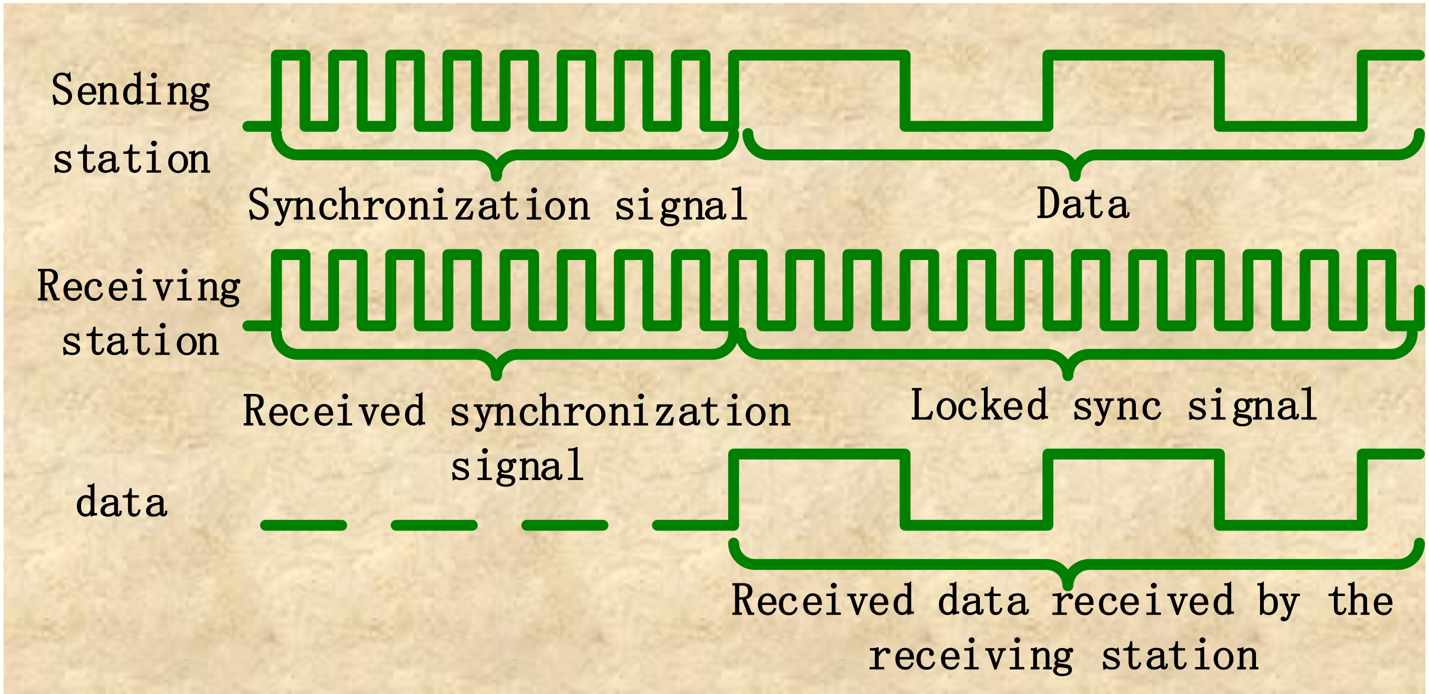
- Non-Return-To-Zero Level (NRZ-L) Coding


1
1
1
0
0
0
0
0
0
1

# Digital signal coding (digital data to digital signals)

- Disadvantages of NRZ-L
  - Difficult to tell the end of one and the beginning of another
  - The sender and the receiver must have clock synchronization
  - If the signal "0" or "1" appears continuously, the signal DC component will accumulate
  - Prone to propagation errors

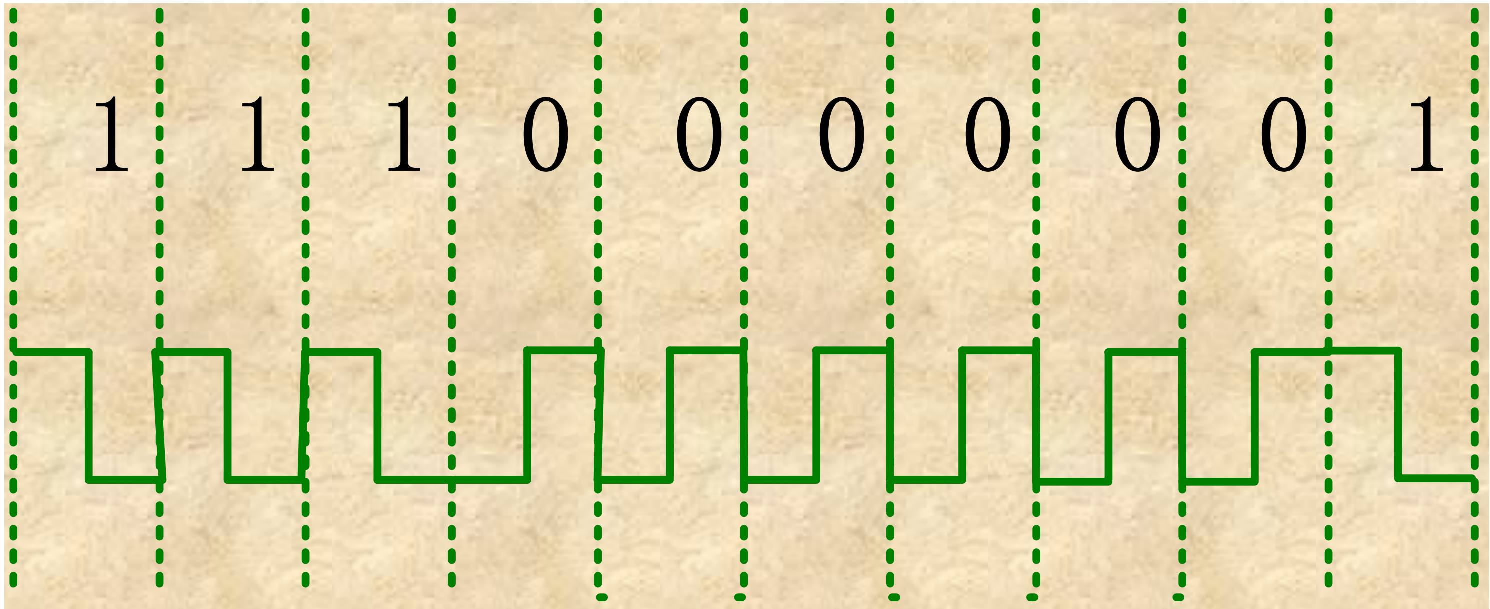
- Bit synchronization
  - The purpose is to synchronize each bit of information received by the receiver with the sender
- External synchronization


Sending station
Synchronization signal
Data
Receiving station
Received synchronization signal
Locked sync signal
data
Received data received by the receiving station

- Self-synchronization

# Digital signal coding
(digital data to digital signals)

- Manchester Coding
  - Each symbol is divided into two equal intervals
    - "1": the previous interval is high and the next low
    - "0": the previous interval is low and the next high
  - Feature: A level hop in the middle time of each symbol



# Digital signal coding
# (digital data to digital signals)

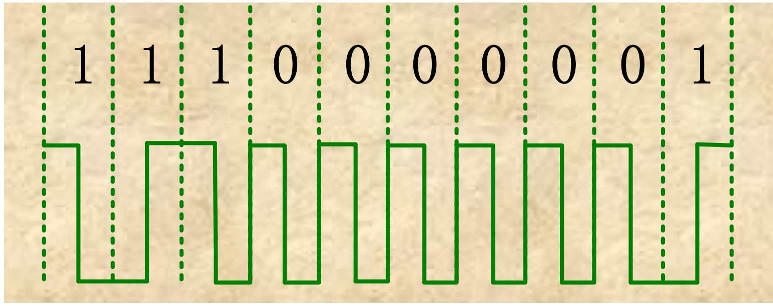
- Advantages
  - Overcoming the disadvantages of the NRZ Coding
  - Each jump in the middle of a symbol can be used as data, and also as a clock for self-synchronization
- Disadvantages
  - Doubling the frequency bandwidth requirement of the transmission channel
  - High-frequency noise also increases – susceptible to noise interference
  - Ambiguous

# Digital signal coding
# (digital data to digital signals)

- Differential Manchester Coding
  - "1": the level of the first half of the symbol is the same as the level of the second half of the previous symbol
  - "0": the level of the first half of the symbol is opposite to the level of the second half of the previous symbol
- Regardless of whether the previous bit is 1 or 0

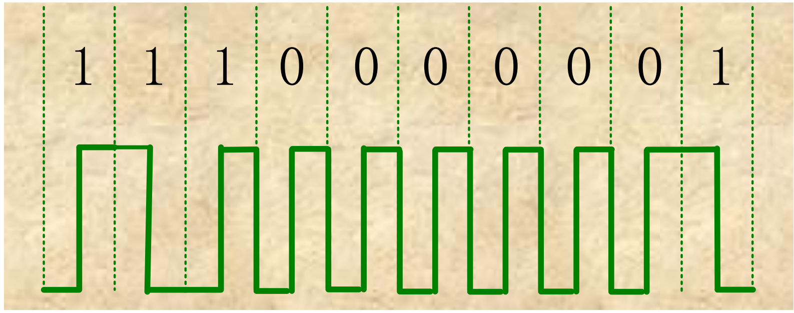
**Waveform 1**

Assuming the previous bit rises from low to high



**Waveform 2**

Assuming the previous bit drops from high to low



# Digital signal coding (digital data to digital signals)

- Advantages
  - Regardless of whether the symbol is "1" or "0", there must be a level hop in the middle of each symbol => better anti–interference performance
  - Separation between bit clock and data => easy data extraction
  - Transition uniquely determined by the second half of the previous symbol => ambiguity eliminated
- Disadvantages
  - Doubling the frequency bandwidth requirement of the transmission channel
  - High-frequency noise also increases – susceptible to noise interference

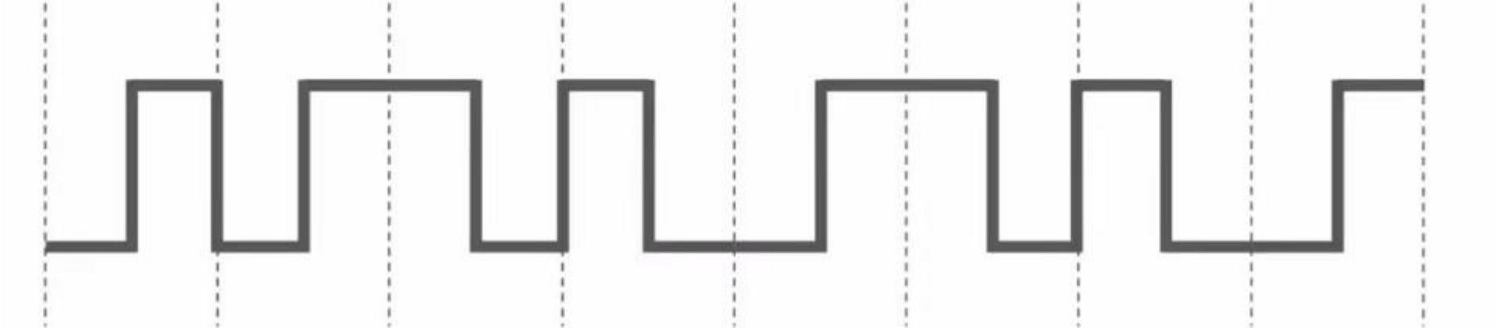
# Digital signal coding (digital data to digital signals)

- Exercise:

  Draw the waveform of "001101" with
  - NRZ-L
  - Manchester Coding
  - Differential Manchester Coding

# Exercise-3

1.If the following figure shows the signal waveform received by the 10Base-T network interface card, the bit string received by the network interface card is



A. 00110110 B. 10101101 C. 01010010 D. 11000101

# Digital signal coding
(digital data to digital signals)

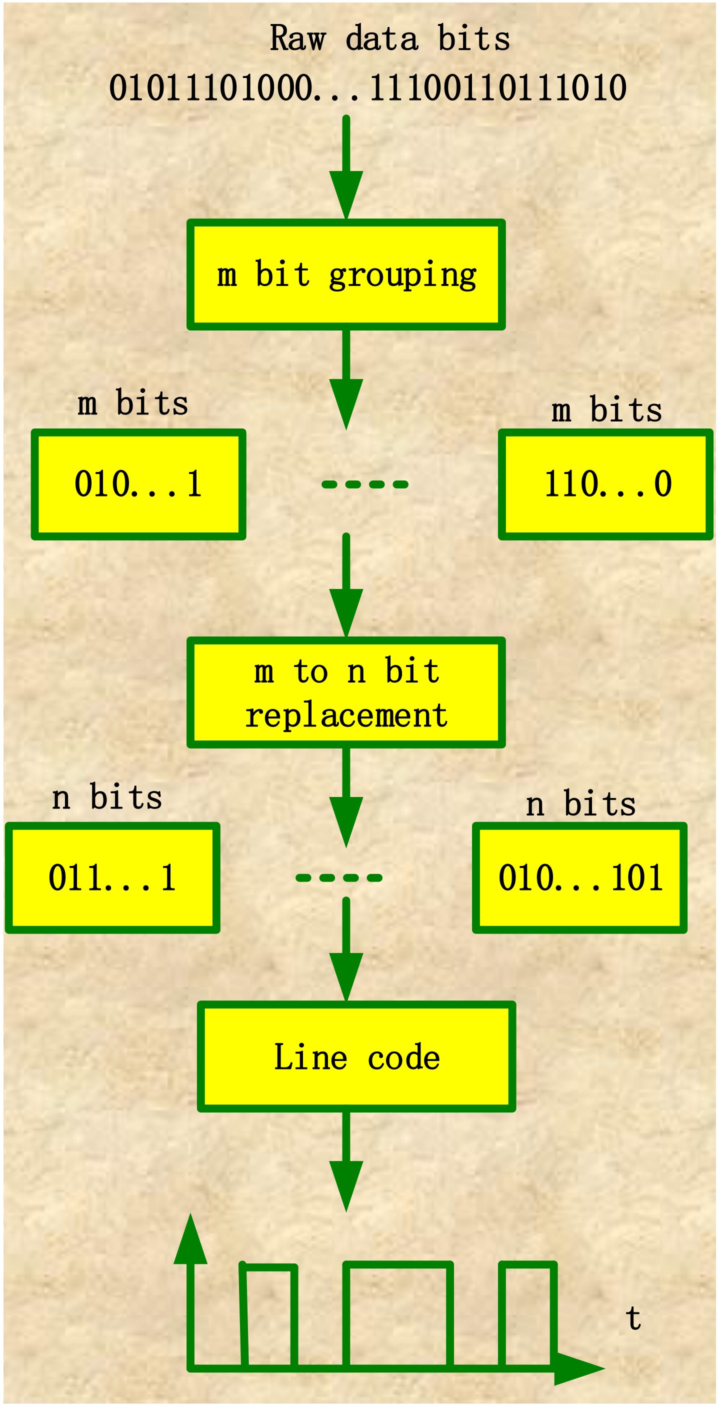
- Block Coding
  - Advantages
    - Can improve the coding efficiency, reduce the modulation rate, and reduce the transmission line requirements
    - Some redundant bits can be added for error detection or synchronization
  - Applications
    - 4B / 5B (FDDI, 100M Fast Ethernet)
    - 8B / 10B (Gigabit Ethernet)

# Digital signal coding
## (digital data to digital si

Steps (mB / nB, m < n) :

- Grouping
- Substitution
    - The extra bit sequence can be used for
        - error detection
        - synchronization
        - or other controls

      or not used
- Line coding


Raw data bits
01011101000...11100110111010
m bit grouping
m bits
010...1
----
m bits
110...0
m to n bit replacement
n bits
011...1
----
n bits
010...101
Line code

# 3 Basic theory of data communication

(1) Basic concepts

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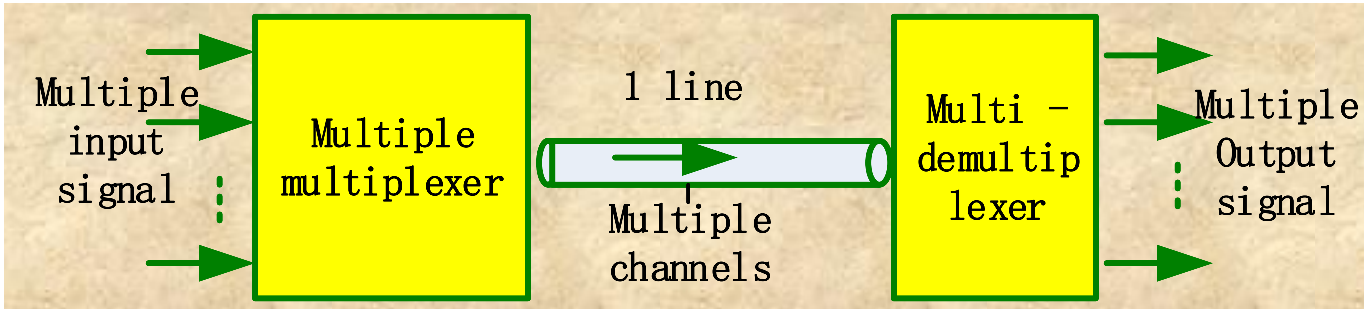
# Multiplexing (Multi-pass)

- To send multiple sources of information in one physical channel at the same time

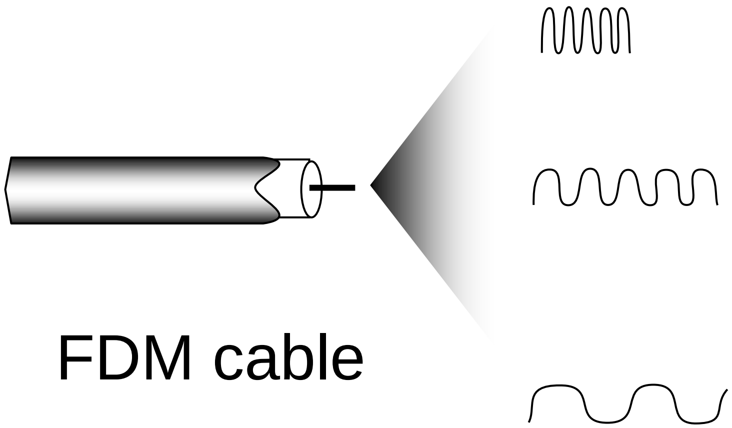

Multiple input signal
Multiple multiplexer
1 line
Multiple channels
Multi – demultiplexer
Multiple Output signal

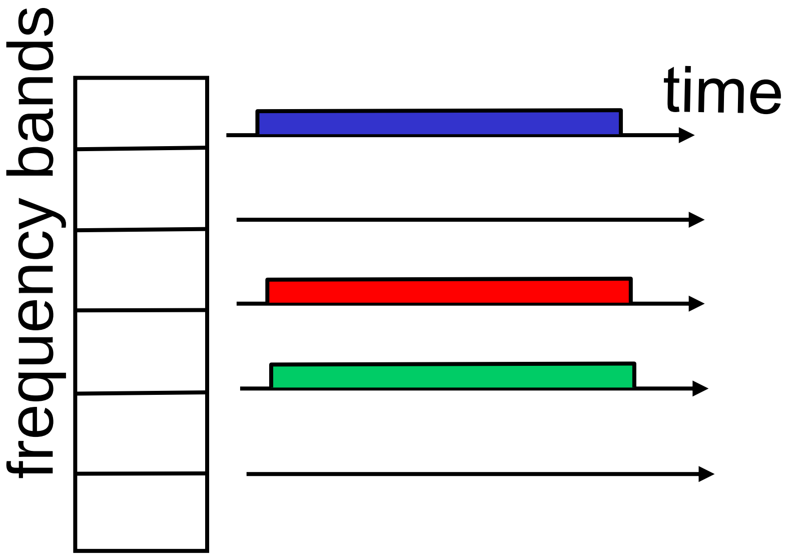
- Commonly used techniques
  - Frequency division multiplexing (FDM)
  - Time division multiplexing (TDM)
  - Wavelength division multiplexing (WDM)
  - Code division multiplexing (CDM)

# *Multiplexing : FDMA

## FDMA: frequency division multiple access

- channel spectrum divided into frequency bands
- each station assigned fixed frequency band
- unused transmission time in frequency bands go idle
- example: 6-station LAN, 1,3,4 have pkt, frequency bands 2,5,6 idle

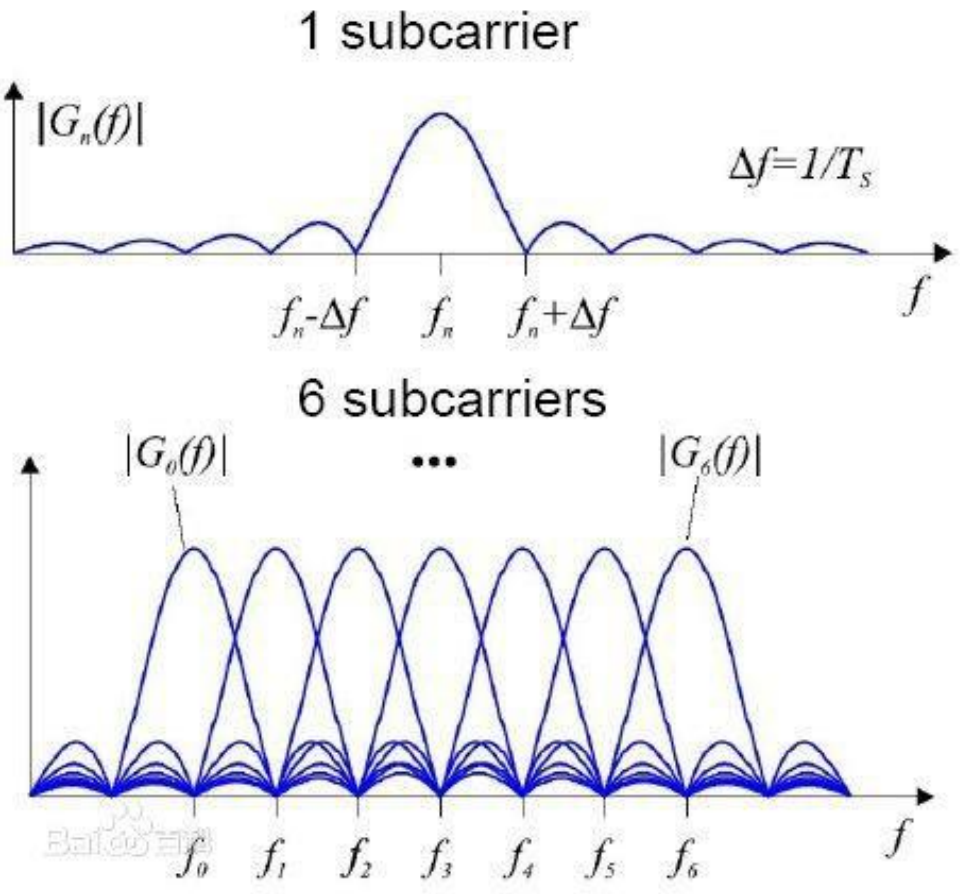



frequency bands
time

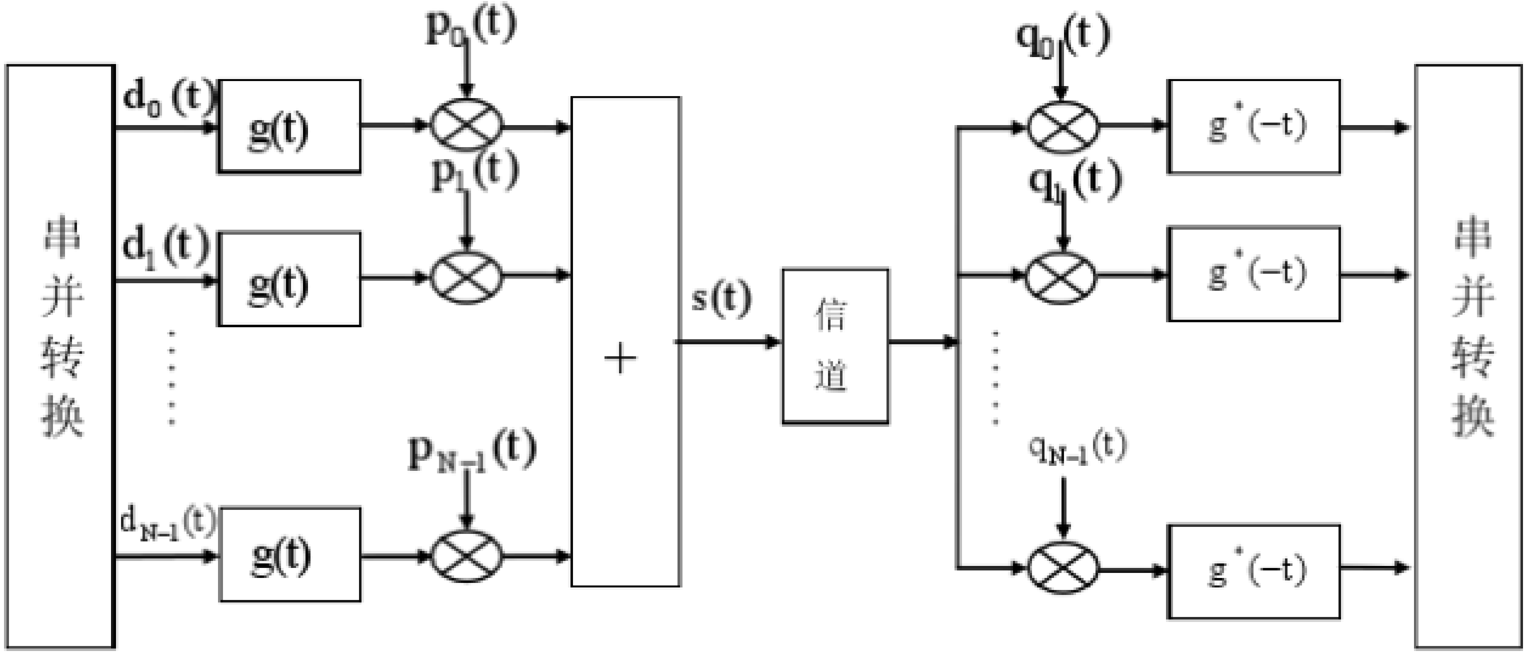
# *Multiplexing : Orthogonal frequency division multiplexing (OFDM) technology

- Basic principle:
  - Dividing the channel into a number of orthogonal sub-channels;
  - The high-speed serial data is decomposed into multiple parallel low-speed data, the use of multi-carrier FDM method to transfer, that is, the data allocated to a large number of sub-channels for transmission.
- Suitable for the high-speed data transmission through wireless channel under the presence of multipath propagation and Doppler shift.

# *Multiplexing : Orthogonal frequency division multiplexing (OFDM) technology


1 subcarrier
|G_n(f)|
Δf=1/T_S
f_n-Δf
f_n
f_n+Δf
f
6 subcarriers
|G_0(f)|
...
|G_6(f)|
f_0
f_1
f_2
f_3
f_4
f_5
f_6
f

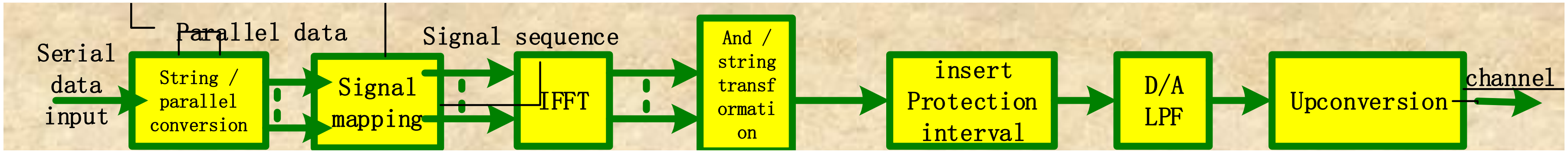
# *Multiplexing : Orthogonal frequency division multiplexing (OFDM) technology


串并转换
$d_0(t)$
$d_1(t)$
$d_{N-1}(t)$
g(t)
g(t)
g(t)
$p_0(t)$
$p_1(t)$
$p_{N-1}(t)$
+
s(t)
信道
$q_0(t)$
$q_1(t)$
$q_{N-1}(t)$
$g^*(-t)$
$g^*(-t)$
$g^*(-t)$
串并转换

$$\int_0^{T_s} P_m(t) q_m(t) dt = c\delta_{mn} = \begin{cases} 0 & m \neq n \\ C & m = n \end{cases}$$

# *Multiplexing : Orthogonal frequency division multiplexing (OFDM) technology

- FFT based OFDM Transmit System



Serial data input

Parallel data

Signal sequence

String / parallel conversion

Signal mapping

IFFT

And / string transformation

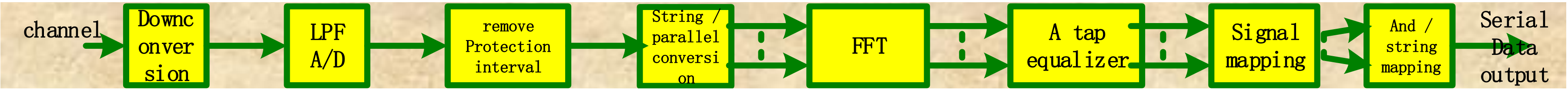
insert Protection interval

D/A LPF

Upconversion

channel

- FFT based OFDM Receiving System



channel

Downconversion

LPF A/D

remove Protection interval

String / parallel conversion

FFT

A tap equalizer

Signal mapping

And / string mapping

Serial Data output

# *Multiplexing : Orthogonal frequency division multiplexing (OFDM) technology

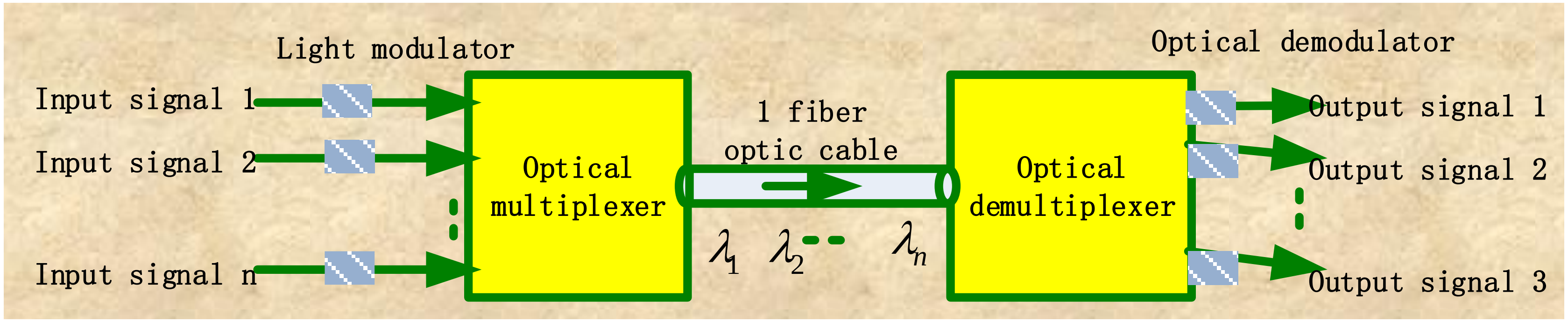
- Advantages:
  - Reduce the influence of inter-symbol interference;
  - Reduce the effect of frequency selective fading;
  - Improve the band utilization, to avoid the crosstalk between sub-channels;
  - Nearly eliminate inter-symbol interference;
  - Anti-interference coding technology can be used to effectively recover the error;
  - The parallel data can be modulated and demodulated by discrete Fourier transform DFT, which reduces the complexity of system implementation.

# *Multiplexing : Orthogonal frequency division multiplexing (OFDM) technology

- Applications of OFDM technology:
  - ADSL
  - Digital Audio Broadcasting (DAB)
  - HDTV
  - Wireless LAN (WLAN)
  - Broadband radio access network
  - 3G mobile communication network and other fields.

# *Multiplexing : Wavelength division multiplexing (WDM)

- Transmission of multiple optical carriers with different wavelengths in a fiber at the same time
- WDM is actually a variant of FDM for fiber channel multiplexing.

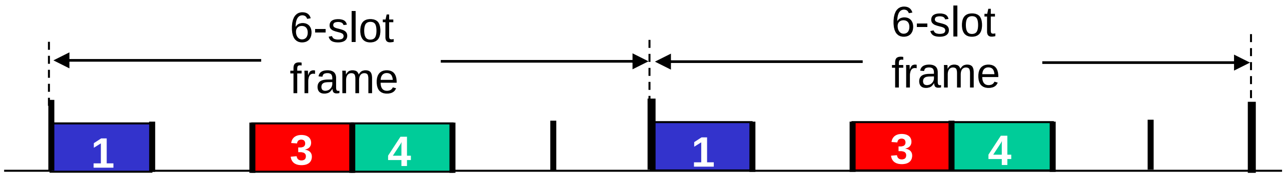


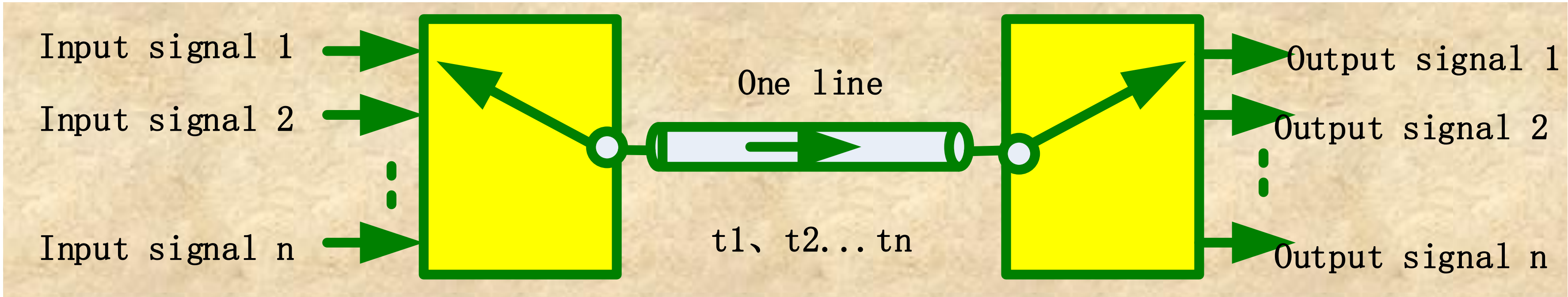
Light modulator
Optical demodulator
Input signal 1
Input signal 2
Input signal n
Optical multiplexer
1 fiber optic cable
$\lambda_1$ $\lambda_2$ $\lambda_n$
Optical demultiplexer
Output signal 1
Output signal 2
Output signal 3

# *Multiplexing : TDMA

## TDMA: time division multiple access

- access to channel in "rounds"
- each station gets fixed length slot (length = pkt trans time) in each round
- unused slots go idle
- example: 6-station LAN, 1,3,4 have pkt, slots 2,5,6 idle


6-slot frame
6-slot frame
1
3
4
1
3
4


Input signal 1
Input signal 2
Input signal n
One line
t1、t2...tn
Output signal 1
Output signal 2
Output signal n

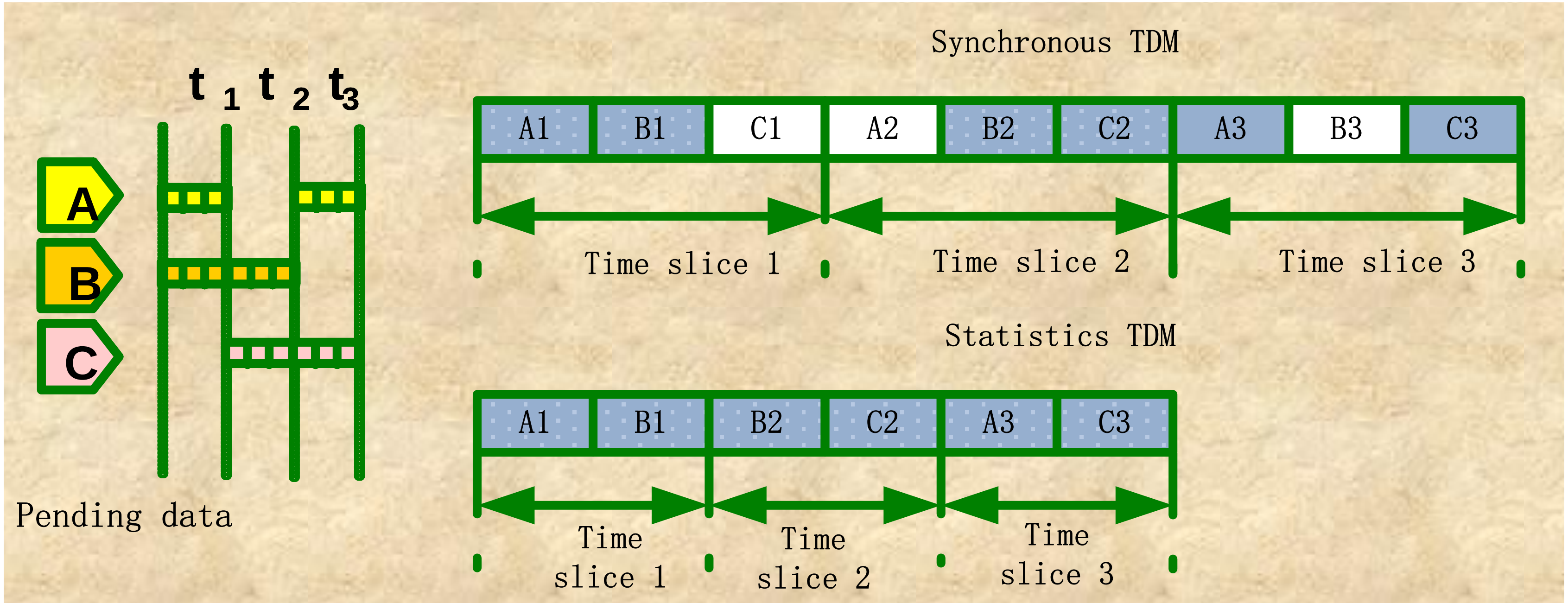
# *Multiplexing : TDMA

- Classification of TDM
  - Synchronous TDM:
    - Time slice fixed allocation, suitable for fixed rate transmission
    - The time slice of the physical channel is fixedly allocated to several users for data transmission, and each user uses the channel for data transmission when its corresponding time slice arrives.
  - Advantages: **simple implementation.**
  - Disadvantages: **there is a waste of bandwidth.**
  - **Synchronous TDM technology is suitable for fixed rate data communication system.**

# *Multiplexing : TDMA

- Asynchronous TDM:
  - The time slot of the physical channel is fixedly allocated for several, and the user does not occupy a certain time slice.
  - When a user needs to carry out data transmission, to assign a time slice;
  - If the user does not have the data transmission requirements, the system does not allocate the time slice to the user, the corresponding time slice can be allocated to other users.
- Advantages: **On-demand distribution of channel time slices, high utilization rate.**
- Disadvantages: **complex implementation.**
- **Asynchronous TDM technology is suitable for variable rate communication systems.**

# *Multiplexing : TDMA


Synchronous TDM
t 1 t 2 t3
A
B
C
A1
B1
C1
A2
B2
C2
A3
B3
C3
Time slice 1
Time slice 2
Time slice 3
Statistics TDM
A1
B1
B2
C2
A3
C3
Time slice 1
Time slice 2
Time slice 3
Pending data

# *Multiplexing : Code Division Multiple Access (CDMA)

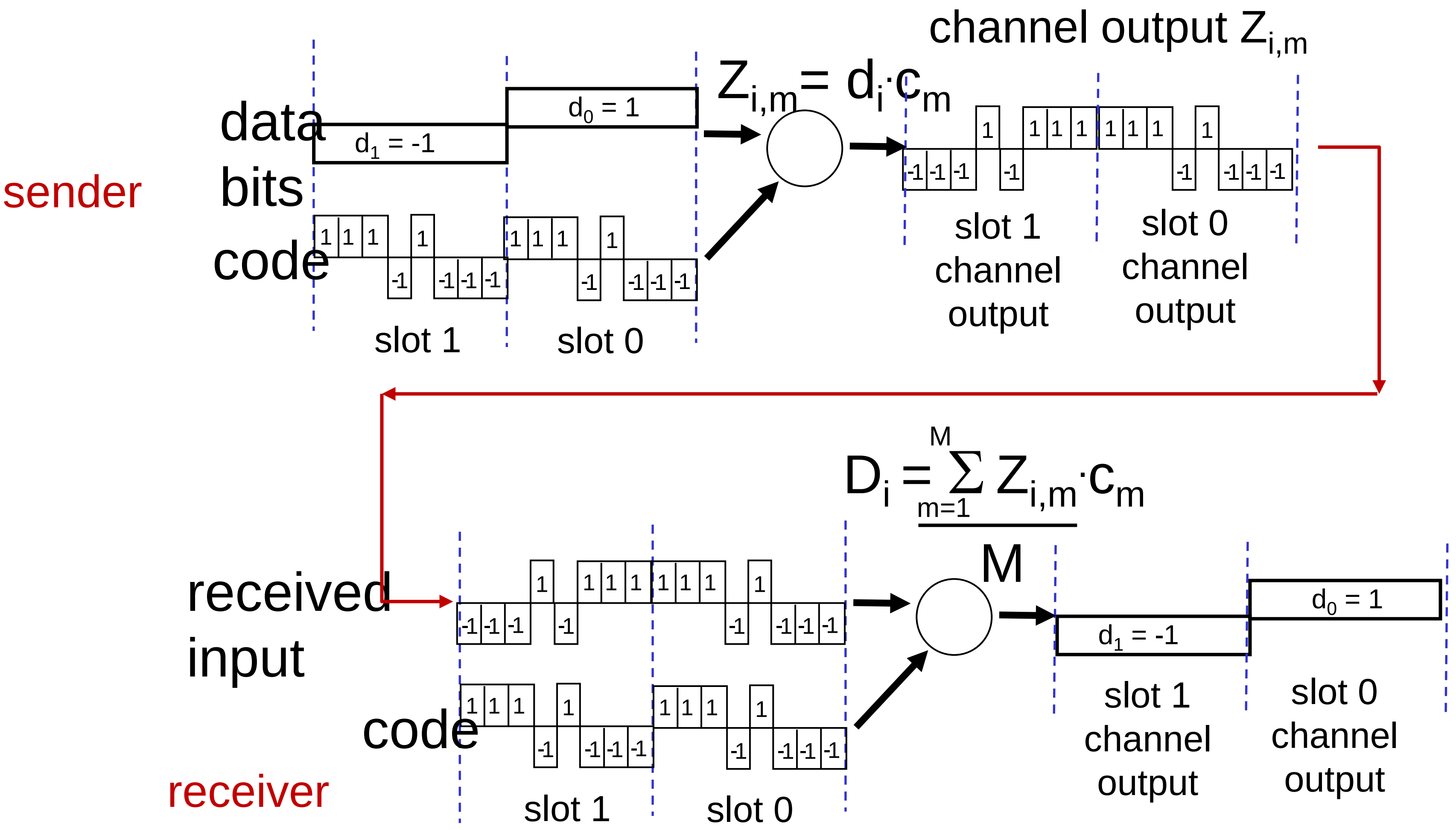
- unique "code" assigned to each user; i.e., code set partitioning
  - all users share same frequency, but each user has own "chipping" sequence (i.e., code) to encode data
  - allows multiple users to "coexist" and transmit simultaneously with minimal interference (if codes are "orthogonal")
- *encoded signal* = (original data) X (chipping sequence)
- *decoding:* inner-product of encoded signal and chipping sequence

$$\mathrm{S} * \mathrm{T} = \frac{1}{m} \sum S_i * T_i = 0$$

$$\mathrm{S} * \mathrm{S} = \frac{1}{m} \sum S_i * S_i = 1$$

$$\mathrm{S} * \bar{S} = \frac{1}{m} \sum S_i * \bar{S}_i = -1$$

# *Multiplexing : CDMA encode/decode



sender

data bits

code

$Z_{i,m} = d_i \cdot c_m$

channel output $Z_{i,m}$

slot 1 channel output

slot 0 channel output

received input

code

receiver

$$D_i = \frac{\sum_{m=1}^{M} Z_{i,m} \cdot c_m}{M}$$

slot 1 channel output

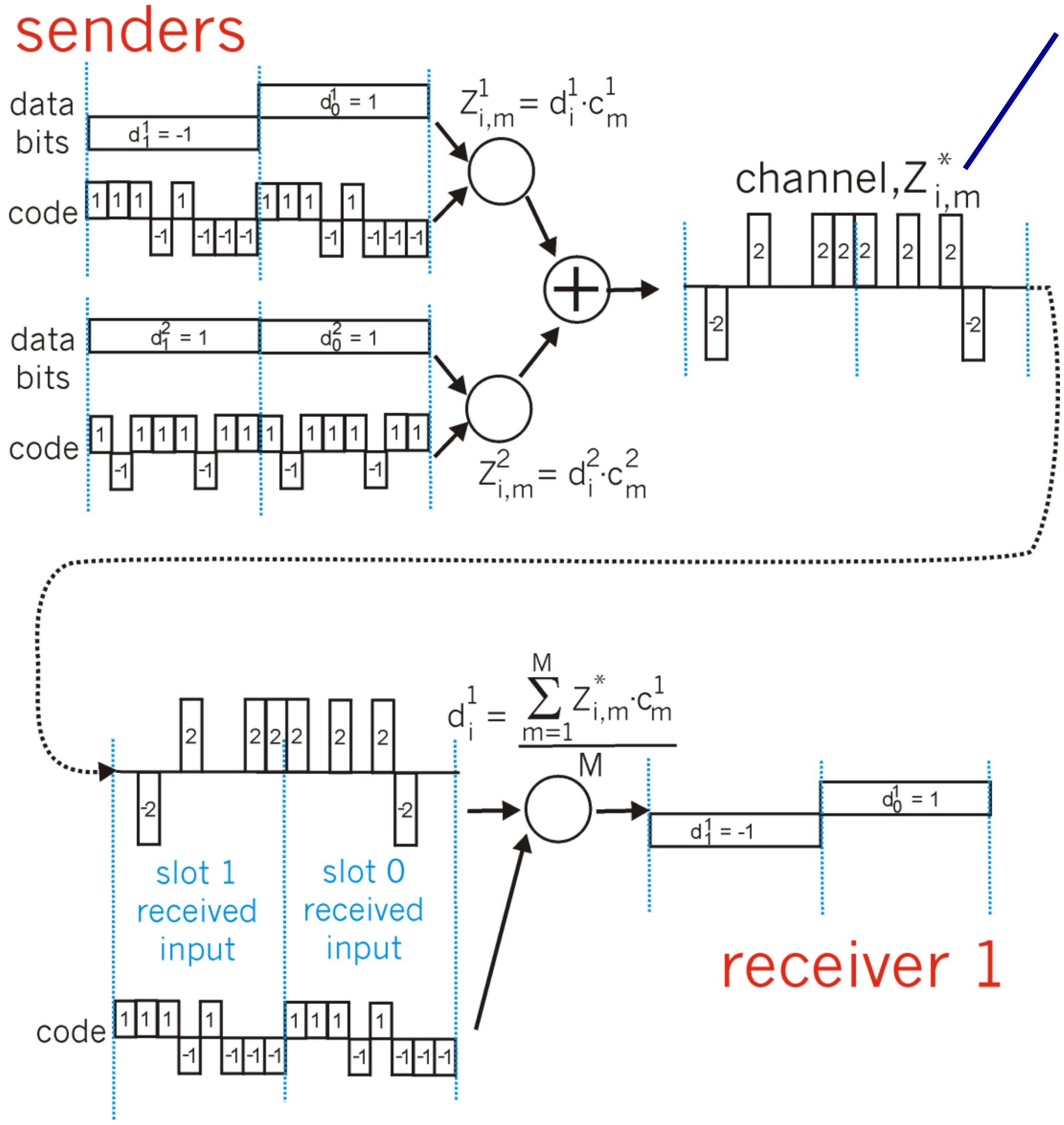
slot 0 channel output

$d_1$ = -1
$d_0$ = 1
1 1 1 1 -1 -1 -1 -1
1 1 1 1 -1 -1 -1 -1
slot 1
slot 0
-1 -1 -1 1 -1 1 1 1
1 1 1 -1 1 -1 -1 -1
slot 1
slot 0
$d_1$ = -1
$d_0$ = 1

# *Multiplexing : CDMA: two-sender interference

*Sender 1*

*Sender 2*


senders
data bits
$d_1^1 = -1$
$d_0^1 = 1$
code
1 1 1 -1 1 -1 -1 -1
1 1 1 -1 1 -1 -1 -1
$Z^1_{i,m} = d^1_i \cdot c^1_m$
data bits
$d_1^2 = 1$
$d_0^2 = 1$
code
1 -1 1 1 1 -1 1 1
1 -1 1 1 1 -1 1 1
$Z^2_{i,m} = d^2_i \cdot c^2_m$
channel, $Z^*_{i,m}$
-2 2 2 2 2 2 2 -2
2
-2
slot 1 received input
slot 0 received input
code
1 1 1 -1 1 -1 -1 -1
1 1 1 -1 1 -1 -1 -1
$d^1_i = \frac{\sum_{m=1}^{M} Z^*_{i,m} \cdot c^1_m}{M}$
$d_1^1 = -1$
$d_0^1 = 1$
receiver 1

*channel sums together transmissions by sender 1 and 2*

*using same code as sender 1, receiver recovers sender 1's original data from summed channel data!*

# *Comparison of commonly used media

| Transmission medium | Transfer method | Rate/ Band | Transmission distance | Performance | Price | Application |
|---|---|---|---|---|---|---|
| Twisted pair | Broadband<br>Baseband | ≤1Gb/s | Anolog: 10km<br>digtal: 500m | Better | Low | Analog / digital signal transmission |
| 50Ω Coaxial cable | Baseband | 10Mb/s | <3km | Better | Lower | Baseband digital signal |
| 75Ω Coaxial cable | Broadband | ≤450MHz | 100km | Better | Lower | Analog TV, data and audio |
| Optical fiber | Baseband | 40Gb/s | 20km以上 | Very good | Higher | Long - distance high - speed data transmission |
| Microwave | Broadband | 4-6GHz | Several hundred km | Good | Medium | Remote communication |
| Satellite | Broadband | 1-10GHz | 18000 km | Very good | High | Remote communication |

# *Commonly used physical layer interface standards

- EIA-232-E interface standard
- RS-449 interface standard
- RS-485 interface standard
- CAN interface standard
- PROFIBUS interface standard
- …….

# Recap of the Physical Layer

- The function of the physical layer and the issues to be considered
- Four important characteristics of the physical layer
- The contents of the physical layer protocol
- Some Basic Concepts in Data Communication
- Nyquist's Law and Shannon's Formula
- Signal Coding Technology and Multiplexing Technology
- Commonly used transmission medias
- Commonly used physical layer interface standards

# Exercise-1

1.In the physical layer interface characteristics, the time sequence used to describe the completion of each function is

A. Mechanical Characteristics

B. Electrical Characteristics

C. Functional Characteristics

D. Procedural Characteristics

2. Among the following options, that do not belong to the definition scope of physical layer interface specification is

A. interface shape B. pin function

C. physical address D. signal level

# Exercise-2

1. Under the condition of no noise, if the frequency bandwidth of a communication link is 3kHz and QAM modulation technology with four phases and four amplitudes in each phase is adopted, the maximum data transmission rate of the communication link is

A. 12kbps B. 24kbps C. 48kbps D. 96kbps

2. If the data transmission rate of a communication link is 2400bps and 4-phase modulation is adopted , the baud rate of the link is

A. 600 baud B. 1200 baud

C. 4800 baud D . 9600 baud

# Exercise-2

3. If the frequency bandwidth connecting R2 and R3 link is 8kHz and the signal-to-noise ratio is 30dB, and the actual data transmission rate of the link is about 50% of the maximum data transmission rate, the actual data transmission rate of the link is about

A. 8kbps B. 20kbps C. 40kbps D. 80kbps

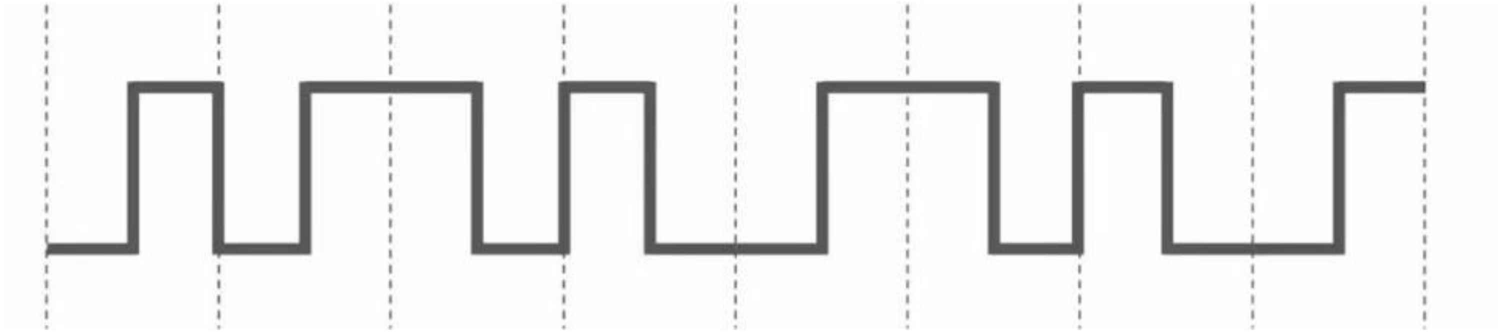
2. Among the following factors, which will not affect the channel data transmission rate is

A. signal to noise ratio B. frequency bandwidth

C. symbol speed D. signal propagation speed

# Exercise-3

1.If the following figure shows the signal waveform received by the 10Base-T network interface card, the bit string received by the network interface card is



A. 00110110 B. 10101101 C. 01010010 D. 11000101