Chapter 2

The Physical Layer

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?

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 occurrence of events;

Four Important Features

- **Mechanical Characteristics**
  - Specifies the size of the connector used in the physical connection, the number and arrangement of pins.
  - **Common Interface Standards:**
    - ISO 2110, 25-pin connector, EIA RS-232-C, EIA RS-366-A
    - ISO 2593, 34 core connector, V.35 broadband MODEM
    - ISO 4902, 37-pin and 9-pin connectors, EIA RS-449
    - ISO 4903, 15-pin connector, X.20, X.21, X.22
    - IEC (60) 603-7, 8-pin RJ45

Four Important Features

- **Electrical Characteristics**
  - Specifies the transmission mode, voltage level, coding, impedance matching, transmission rate and distance limit when transmitting the binary bit.
  - **Standards for Electrical Characteristics of CCITT**
    - CCITT V.10/X.26: New unbalanced electrical characteristics
    - CCITT V.11/X.27: New balanced electrical characteristics
    - CCITT V.28: Unbalanced electrical characteristics

Four Important Features

- **Functional Characteristics**
  - Define the function of each physical line, indicating the meaning 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

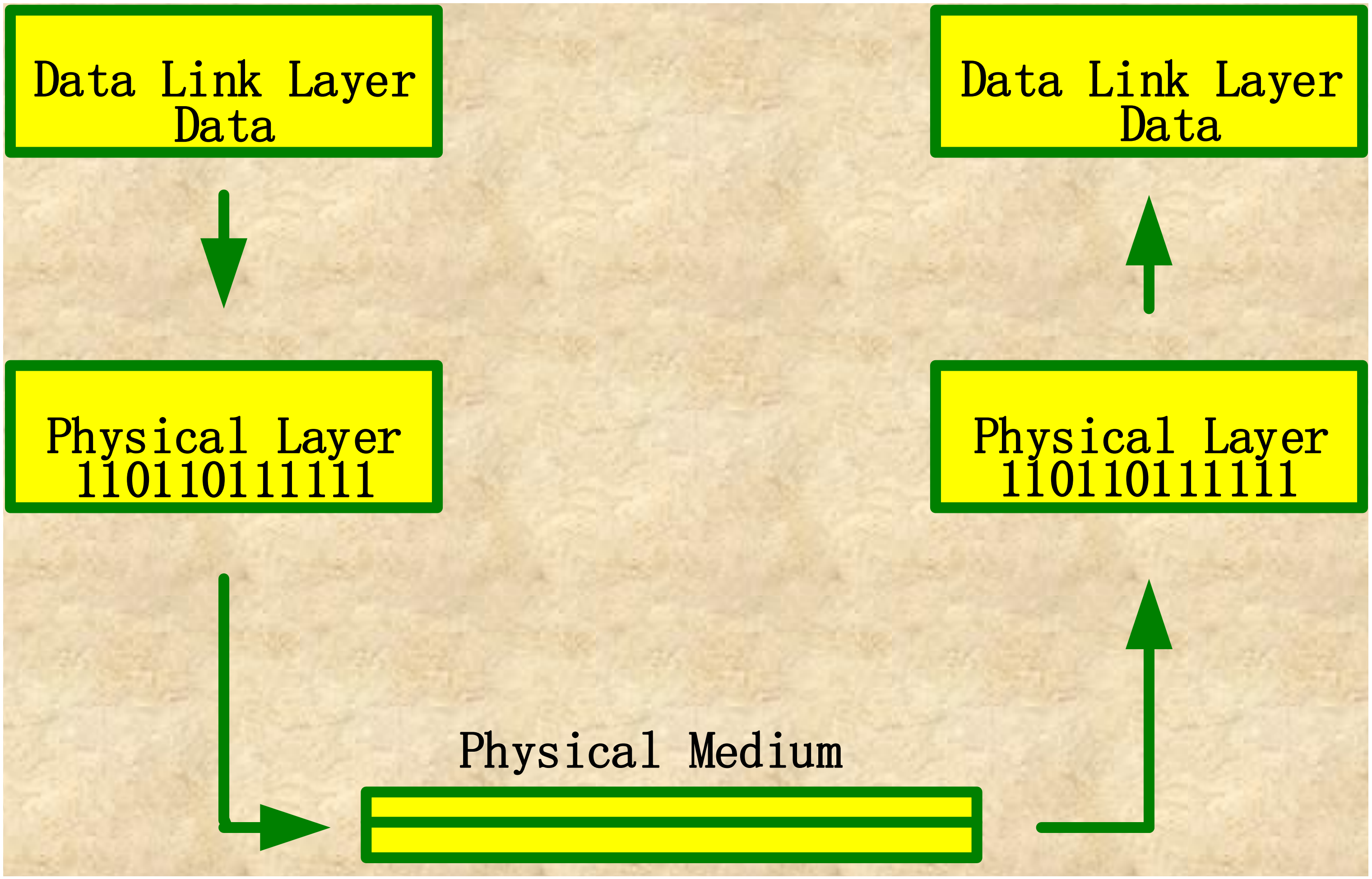
THE PHYSICAL LAYER

2 How to define the physical layer protocols?

2 Contents of Physical Layer Protocol

- The Lowest Level of the OSI / RM model.
- Responsible for reliably transmitting the bit data from one end of the physical medium to the other.
- The difference between the physical medium is masked from the data link layer.
- Providing reliable, transparent bit data transmission services for the data link layer.

The relationship between the physical layer and other levels

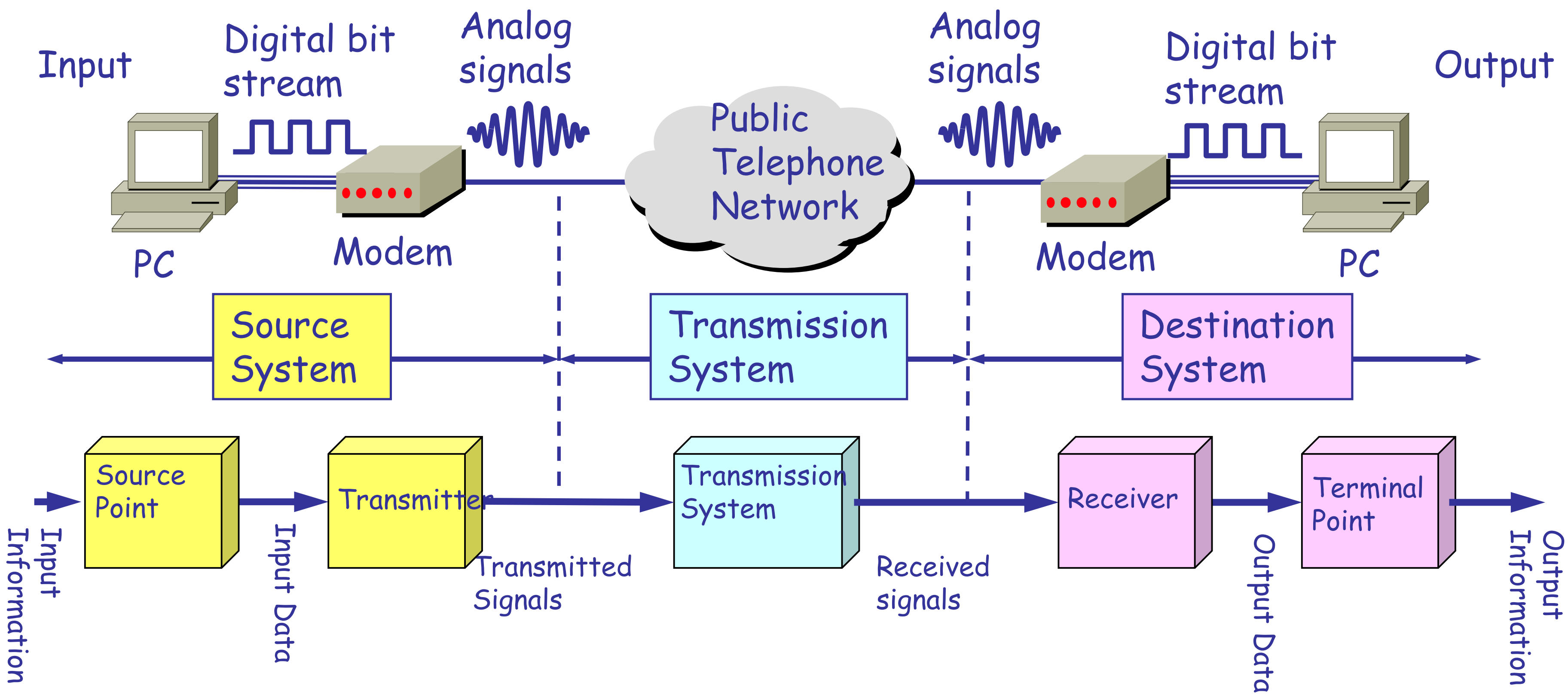


3 Basic theory of data communication

1 Basic concepts
2 To a specific physical communication channel, how much is the maximum transmission rate? infinite?
3 Bit in what way transmitting in the specific physical communication channel, 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

- **The General Model of Communication System**

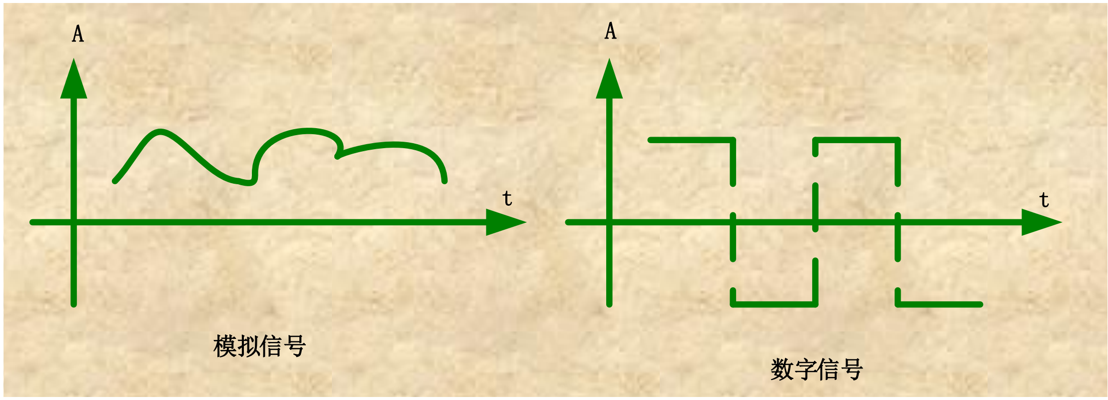


（1） Basic concepts

- **Data**
  - A physical symbol describing and documenting objective facts.
  - Can be numbers, text, language, graphics and images.
- **Information**
  - Information is a set, meaning and interpretation of Data.
- **Signal**
- The signal is the form of data transmission process, that is, the signal is the electronic coding or electromagnetic coding of the data.
- The signal can be divided into analog and digital signals.

Analog signal and digital signal

- Analog signal
  - Continuous in both time and amplitude values, and contains infinite number of signal values
  - Can an analog signal be transmitted over a digital channel?
- Digital signal
  - Discrete in time, Quantified in amplitude, only a limited number of signal values. The most common one is the binary signal.
  - Can digital signals be transmitted over analog channels?



Some concepts about the channel

- **Channel**
  - It is generally used to represent media that sends information in a certain direction.
  - Channels are not equivalent to circuits.
- **Channel classification**
  - Analog channel
    - Can only transmit analog signals
  - Digital channel
    - Can only transmit digital signals
- **Signal on the channel**
  - Baseband signal: **The digital signals "1" and "0" are represented by two different electrical levels.**
  - Broadband signal: **The modulated signal formed by modulating the baseband signal.**

Analog transmission and digital transmission

- **Analog transmission**
  - The signal transmitted in the channel is analog signal.
    - When the analog signal is to be transmitted, it can be transmitted directly.
    - When the digital signal is to be transmitted, modulated and converted to analog signals before entering the channel.
  - **Advantage:** The utilization ratio of the channel is high.
  - **Disadvantages:**
    - The signal will decay.
    - Will be interfered by noise
    - The noise will be amplified when the signal is amplified

Analog transmission and digital transmission

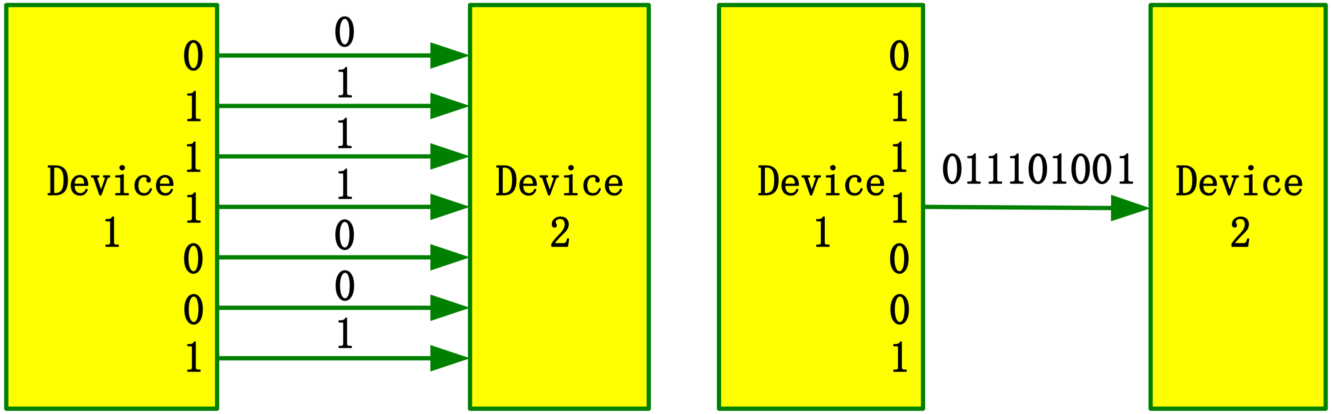
- **Digital transmission**
  - The signal transmitted in the channel is digital signal.
    - When the signal to be transmitted is a digital signal, it can be transmitted directly.
    - When the analog signal is to be transmitted, encoded, converted into digital signals before entering the channel.
  - **Advantages:**
    - Transmission is not distorted, the bit error rate is low, effective use of equipment through sharing use.
  - **Disadvantages:**
    - The frequency band required by transmitting of the digital signal is wider than that of the analog signal.

（1） Basic concepts

- **Digital trend**
  - The computer can only store and process the digital data, so the text, sound, video, image and other analog data, must be converted to digital data before they can be stored in the computer, in order to deal with.
  - **Digital transmission can correctly transmitted the signal without distortion. The transmission quality is better than analog transmission.**
  - Data signals can also be compressed, encrypted, so that you can improve the efficiency and security of transmission.
  - Computers and other digital equipment are becoming cheaper.
  - **To sum up, using the digital equipment is the trend.**

（1） Basic concepts

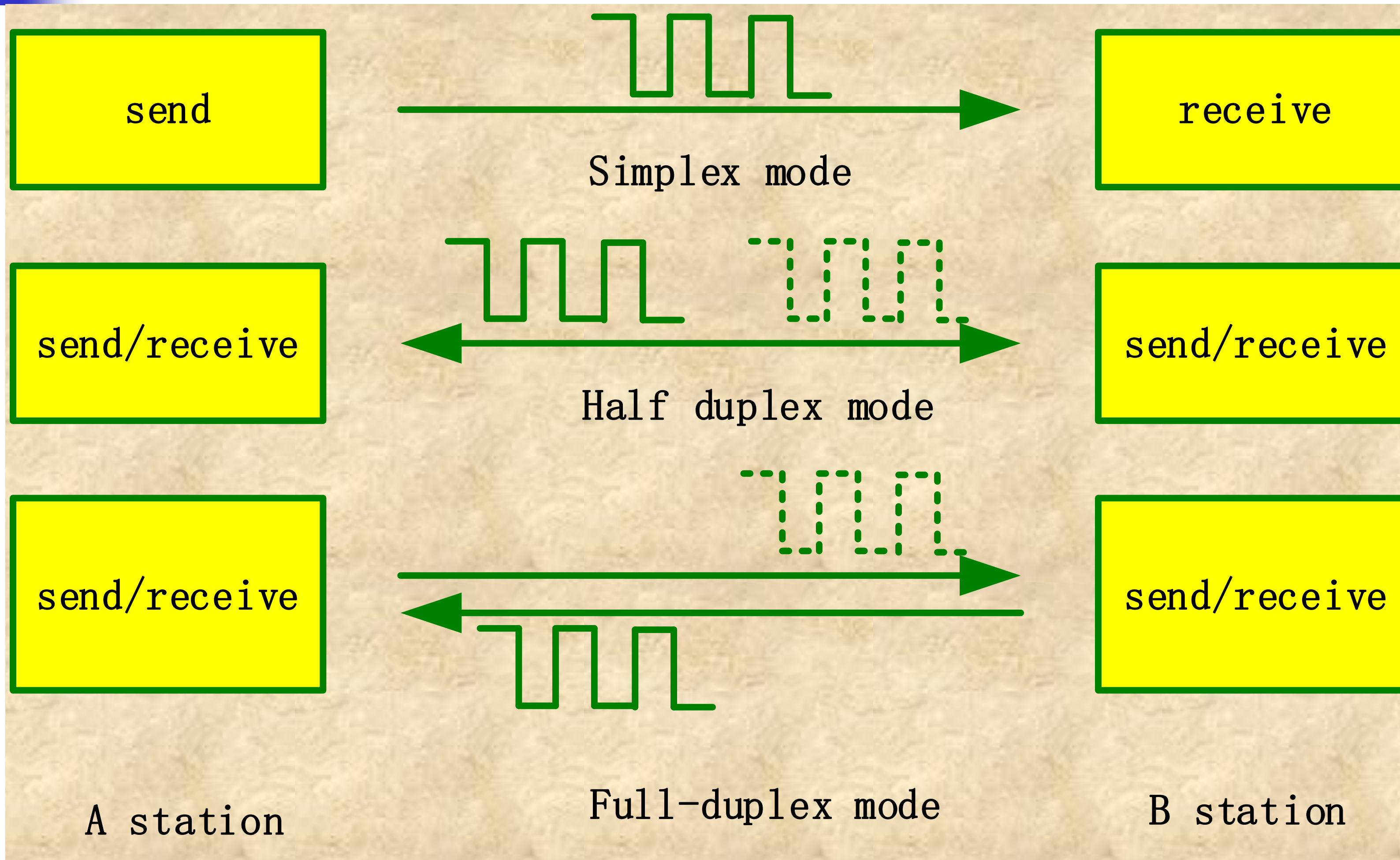
- **Serial transmission**
  - Use a line to transfer all bits one by one
  - Suitable for long distance communication
- **Parallel transmission**
  - While transmitting a set of bits, each bit using a separate line
  - Suitable for close communication



（1） Basic concepts

- Communication between the two sides of the way information exchange, communication can be divided into:
  - Simplex communication
    - Can only have a direction of communication without the opposite direction of the interaction.
  - Half duplex communication
    - Both parties can send messages, but they can not send them at the same time.
  - Full duplex communication
    - The two sides of the communication can send and receive information at the same time.

(1) Basic concepts



3 Basic theory of data communication

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Digital channel characteristic

- A digital pulse is called a symbol representing the basic waveform of a different discrete value.
  - If the ASCII code of the letter A is 1000001, it can be expressed by 7 pulses, which can be considered by 7 symbols.
- The amount of information carried by the symbol is determined by the number of discrete values taken by the symbol.
  - If the code takes "0" and "1" two discrete values, one symbol carries 1 bit (bit) information.
  - If the symbol is preferably four discrete values, one symbol carries 2 bits of information.
  - The number of information n (bits) carried by one symbol has the following relation to the number N of discrete values of the code:

$$n=\log_2 N$$

Digital channel characteristic

- Baud rate:
  - The number of times the signal changes every second, also known as the modulation rate, the symbol rate.
  - 1 baud sends one symbol per second.
- Bit rate:
  - The number of bits per second.
- The relationship between baud rate and bit rate :
  - Depends on the amount of information contained in the symbol n: bit rate (bit / s) = baud rate * n
  - If the amount of information for each symbol is 3 bits, the bit rate is three times the baud rate
  - If the amount of information for each symbol is 1 bit, the bit rate and baud rate are the same

Digital channel characteristic

- **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)**
  - Channel allows the frequency range of the signal (maximum frequency - minimum frequency), in Hz. Such as: people can hear the sound wave frequency of 20HZ ~ 20kHZ the hearing system bandwidth of 19980Hz Transmission delay

Digital channel characteristic

- **Nyquist's Law**：

(1) The highest symbol transmission rate under ideal low-pass channel = 2W Baud

W is the bandwidth of the ideal low-pass channel, in units of Hz (Hz), that is, the highest symbol transmission rate of the ideal low-pass channel per Hz bandwidth is 2 symbols per second.

(2) The highest symbol transmission rate under ideal band-pass channel = W Baud

That is: the highest symbol transmission rate for each band of bandwidth is 1 symbol per second。

Digital channel characteristic

Example:

The frequency band of a standard telephone channel is 300 ~ 3400Hz,That is, the bandwidth is 3100Hz, then under the ideal low-pass channel, what is the high symbol transfer rate?

Solution:

From Nyquist's Law: The highest symbol transmission rate under ideal low-pass channel = 2W Baud

So: the highest symbol transfer rate = 2 * 3100 = 6200

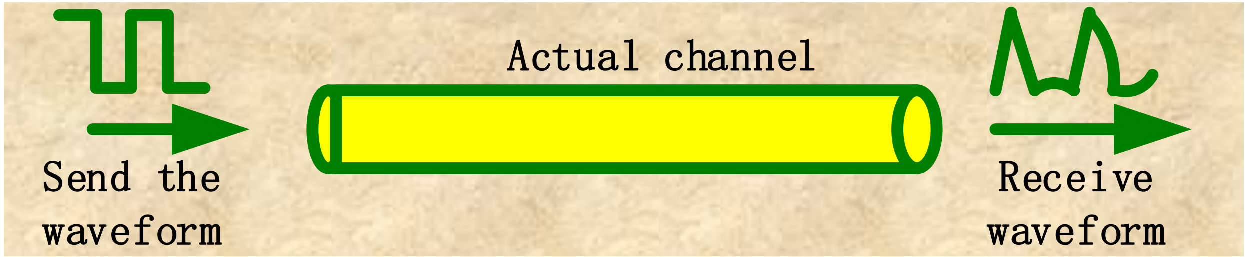
Digital channel characteristic

- Any actual channel is not ideal, the transmission of signals will produce a variety of distortion and bring a variety of interference.

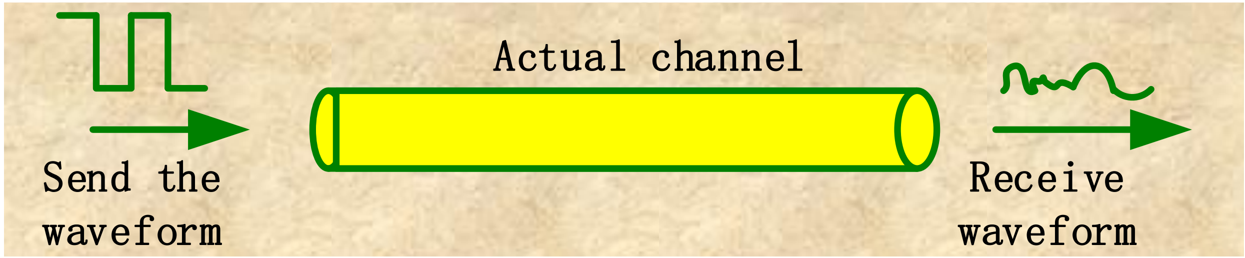
- The higher the rate of symbol transmission, or the farther the distance of signal transmission, the more serious distortion of the waveform will occur at the output of the channel.

Digital channel characteristic

- There is distortion, but can be identified



- Distortion is large and unrecognizable



Digital channel characteristic

- **Shannon formula: limit information transmission rate C of channel can be expressed as:**

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

- H-channel bandwidth, in Hz
- S-The average power of the signals transmitted in the channel
- N-The Gaussian noise power in the channel
- S/N-signal to noise ratio, in db (decibels)

$$10\log_{10} S/N$$

Notes to unit db: When S / N = 10, the signal to noise ratio is 10db
When S / N = 1000, the signal to noise ratio is 30db

Digital channel characteristic

- Shannon formula's meaning:
  - The larger the bandwidth of the channel or the noise ratio in the channel, the higher the limit transmission rate of the information is.
  - The information transmission rate that can be achieved on the actual channel is much lower than the Shannon's limit rate because the Shannon formula does not take into account the loss of the signal during transmission.
  - As long as the information transmission rate is lower than the channel's limit information transmission rate, it is possible to find a way to achieve error-free transmission.

Digital channel characteristic

Example:

For 3.1 kHz bandwidth, the standard telephone channel, if the Signal to Noise ratio S/N = 2500, then the information transmission rate can be achieved 50kb/s?

Solution:

Put H = 3.1kHz, S / N = 2500 into the Shannon formula

Available: the limit value of information transmission is 35kb/s, so it is impossible to reach 50kb/s.

If you want to achieve this value, you can only try to improve the signal to noise ratio in the channel, or increase the channel transmission bandwidth.

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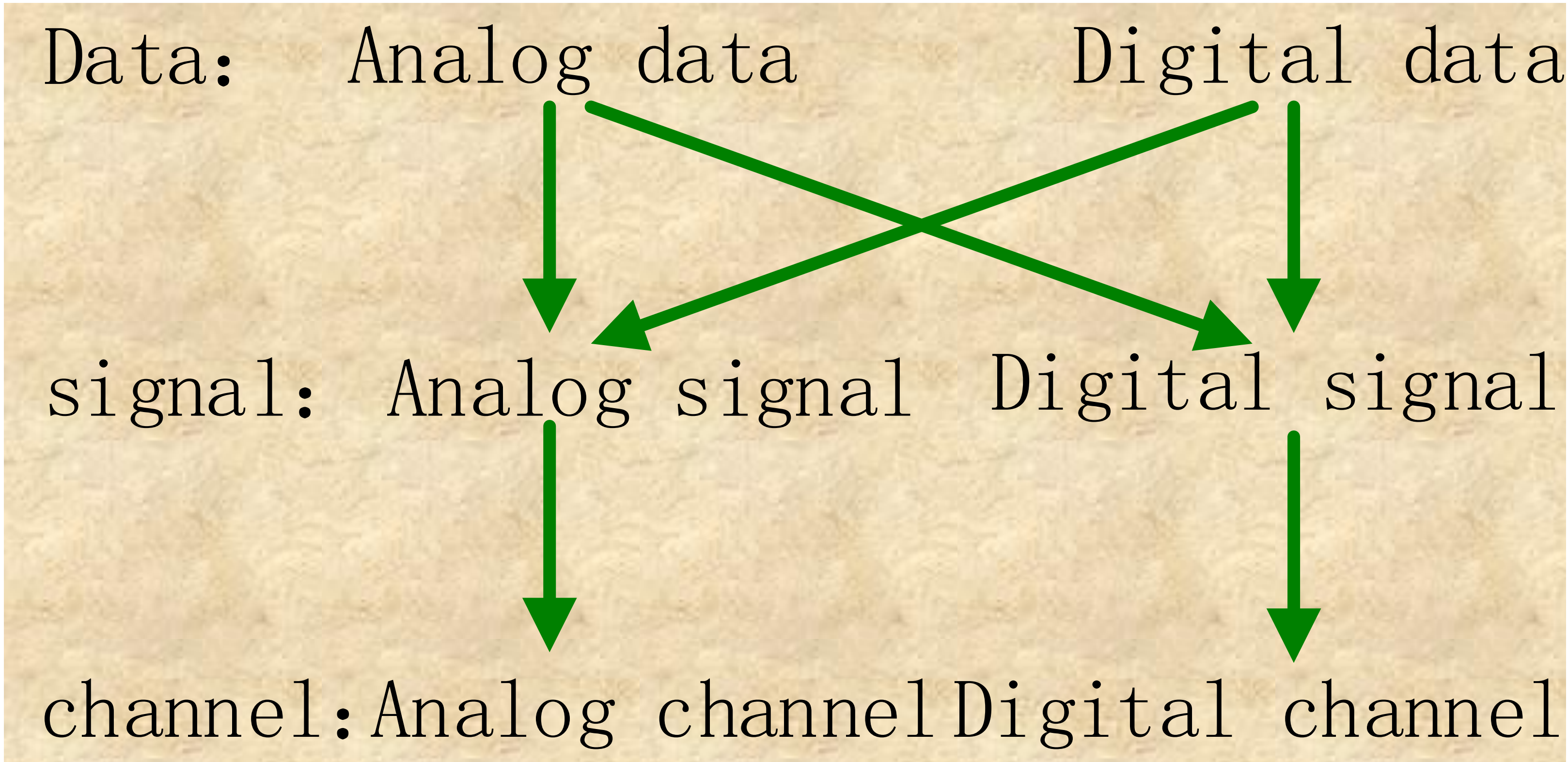
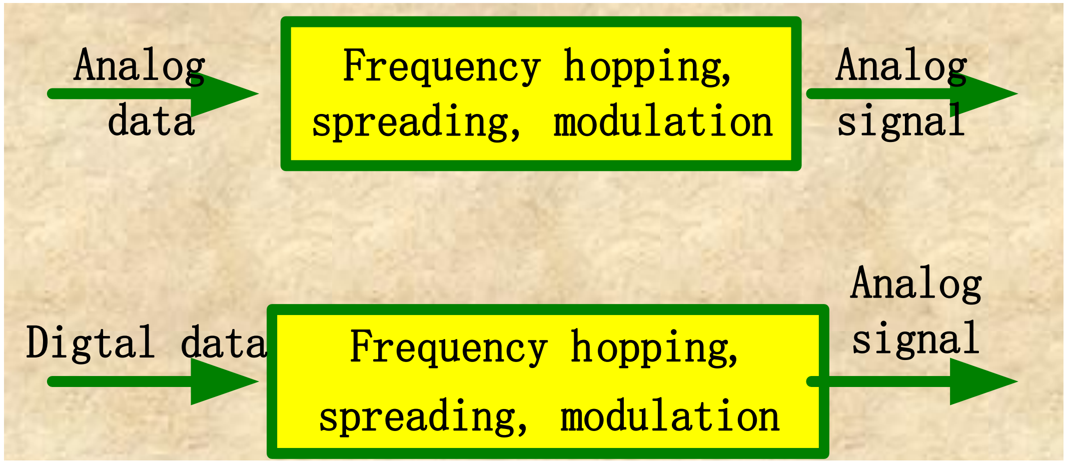
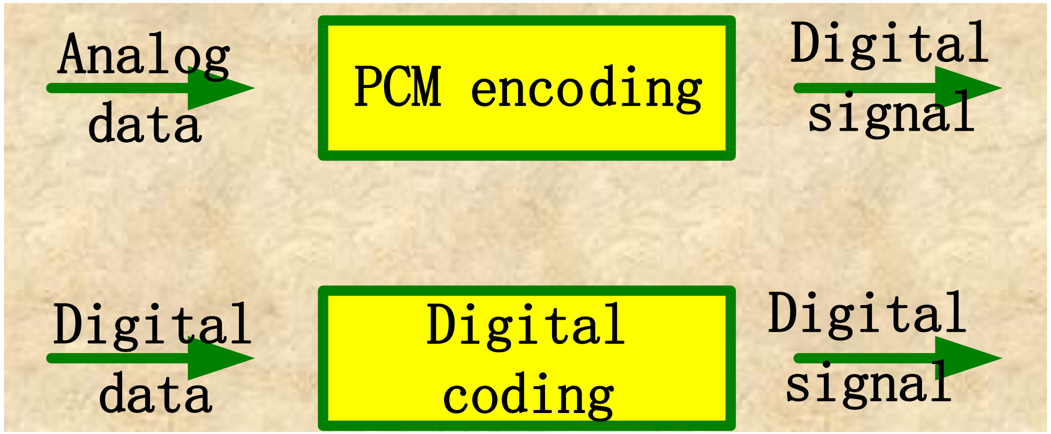
Different signals over different channels

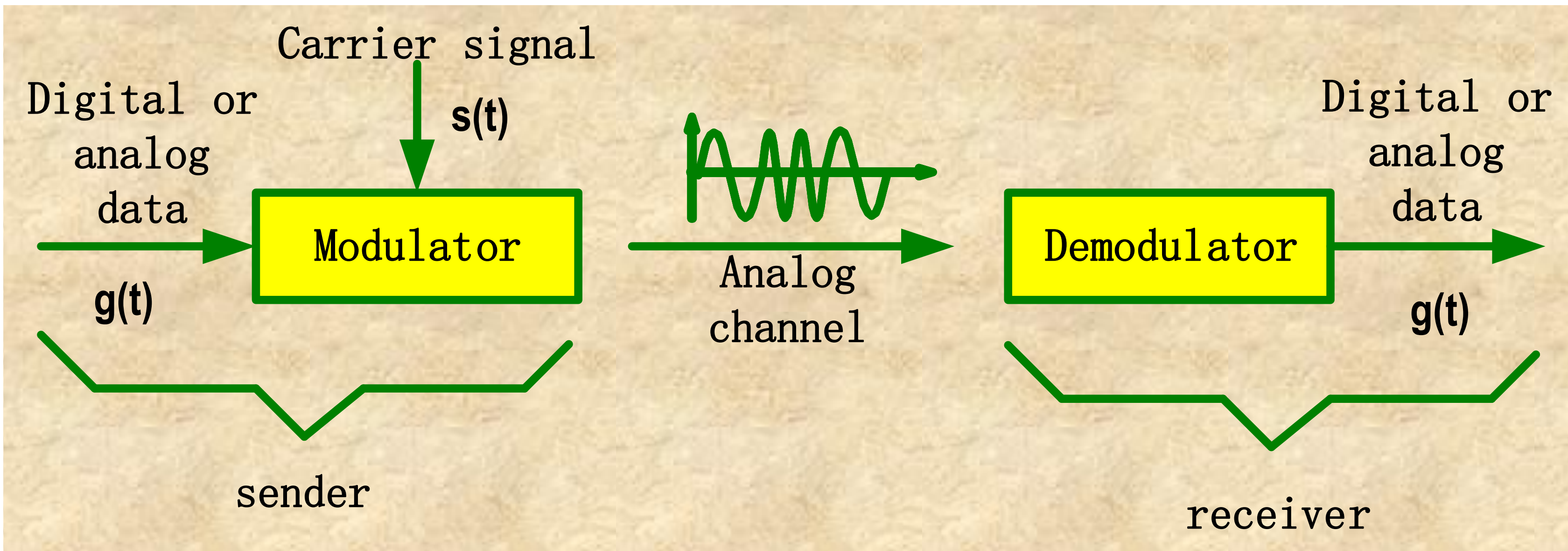


Techniques in analog/digital transmission

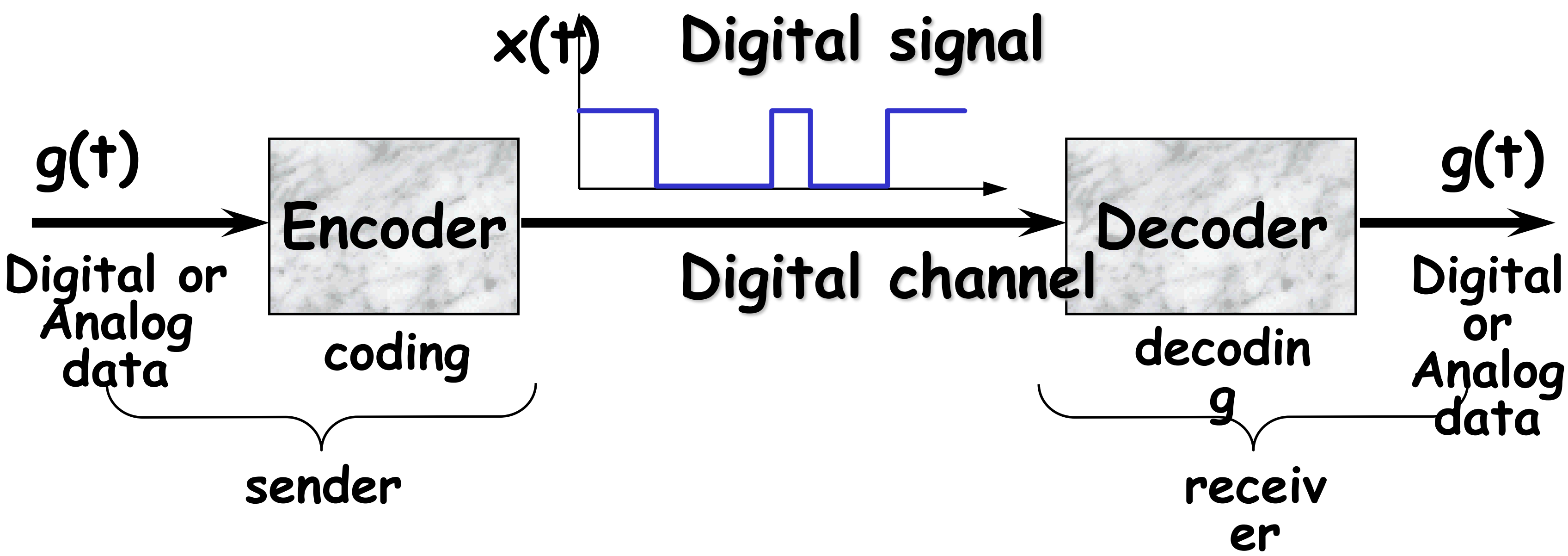




Modulation / demodulation system model

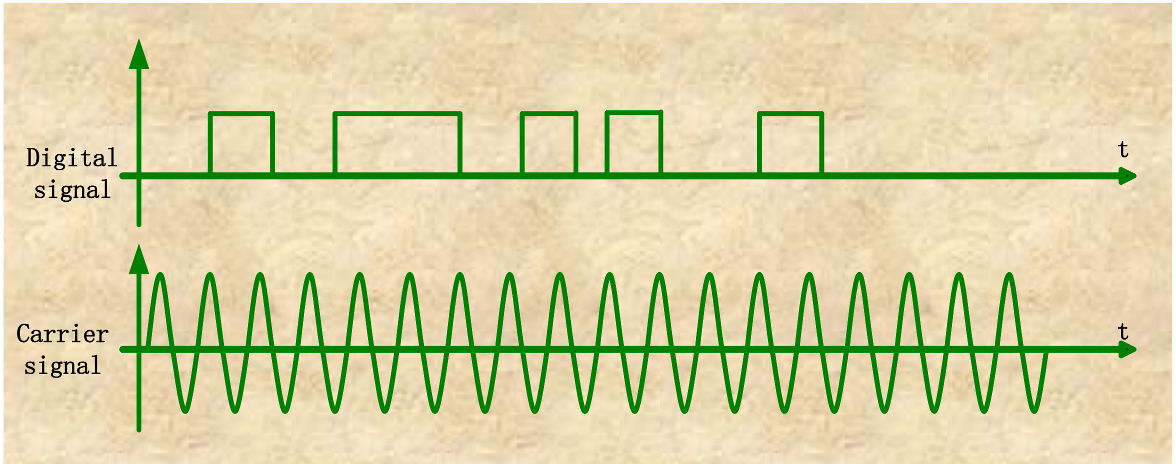


Coding / decoding system model



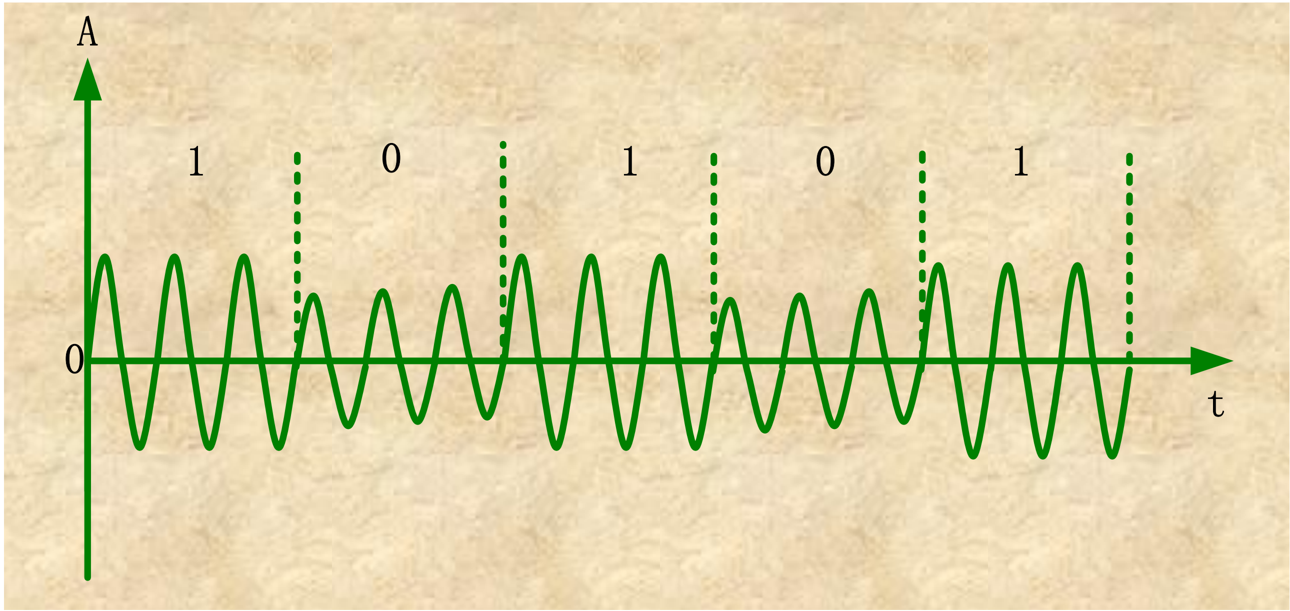
Modulation technology: (digital to analog signals)

- The basic binary modulation methods are as follows:
  - AM (AM): The amplitude of the carrier varies with the baseband digital signal.
  - FM (FM): The frequency of the carrier varies with the baseband digital signal.
  - Phase modulation (PM): The initial phase of the carrier varies with the baseband digital signal.



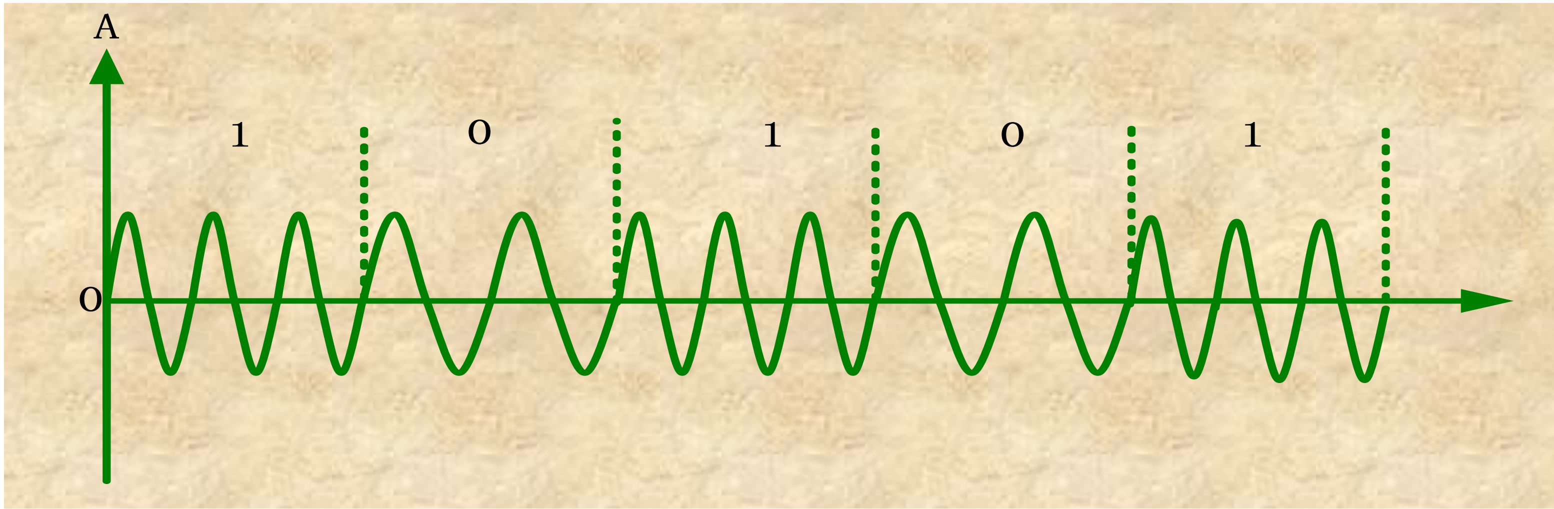
Modulation technology: (digital to analog signals)

- **Amplitude Shift Keying (ASK)**
  - The amplitude of the carrier signal is changed to represent the digital signals "0" and "1"
  - Susceptible to noise



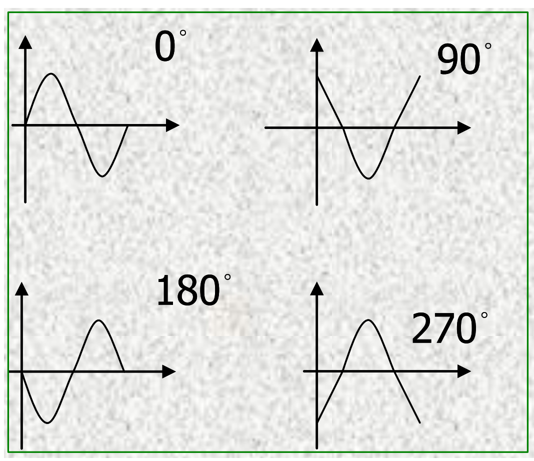
Modulation technology: (digital to analog signals)

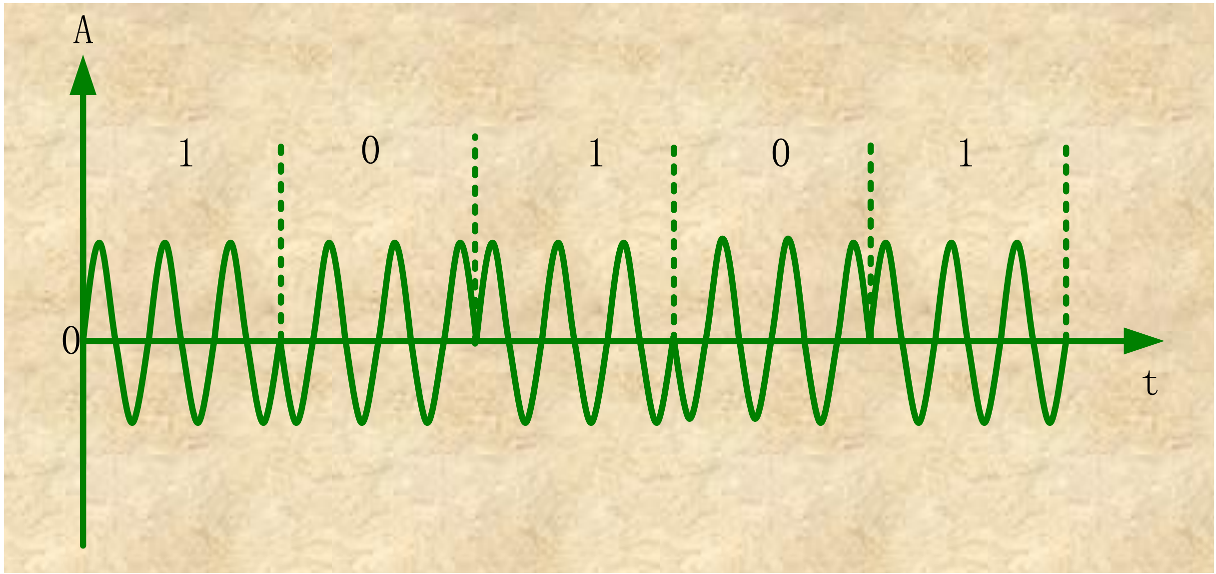
- **Frequency Shift Keying (FSK)**
  - The frequency of the carrier signal is changed to represent the digital signals "0" and "1"



Modulation technology: (digital to analog signals)

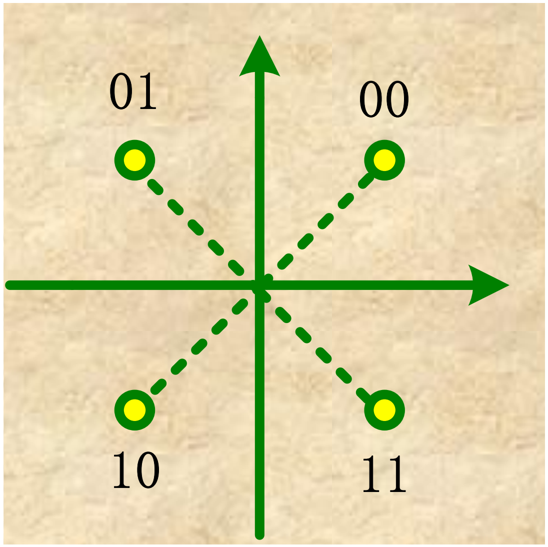
- Phase Shift Keying (PSK)
  - The phase of the carrier signal is changed to represent the digital signals "0" and "1"
  - Example: Phase 0 ◦ means "0", phase 180 ◦ means "1"





Modulation technology: (digital to analog signals)

- Quadrature Amplitude Modulation QAM Technology
  - The use of PM and AM technology.
  - If there are x kinds of changes in the phase, the amplitude also has y changes, then the phase modulation and amplitude modulation technology, there are x * y possible changes.
  - The coordinate plot formed by the combination of amplitude and phase is called the QAM-constellation table.
  - QAM technology in the field of wireless communications has been widely used.



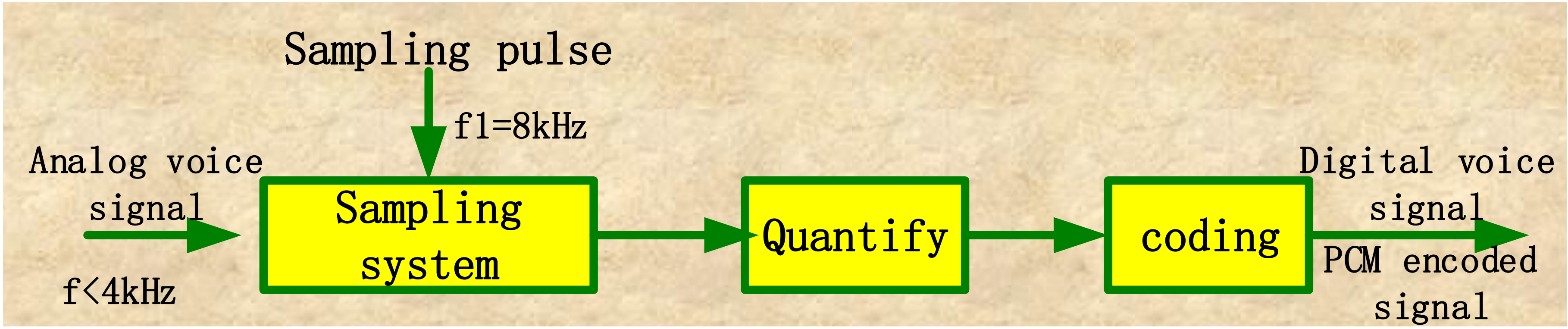
4-QAM constellation table

Analog data to digital signals — Pulse code modulation PCM Technology

- 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 (Pulse Code Modulation) of the three processes
  - Sampling: Sampling the signal at regular intervals
  - Quantify: round each sample to the quantization level
  - Encoding: Each rounded sample is encoded

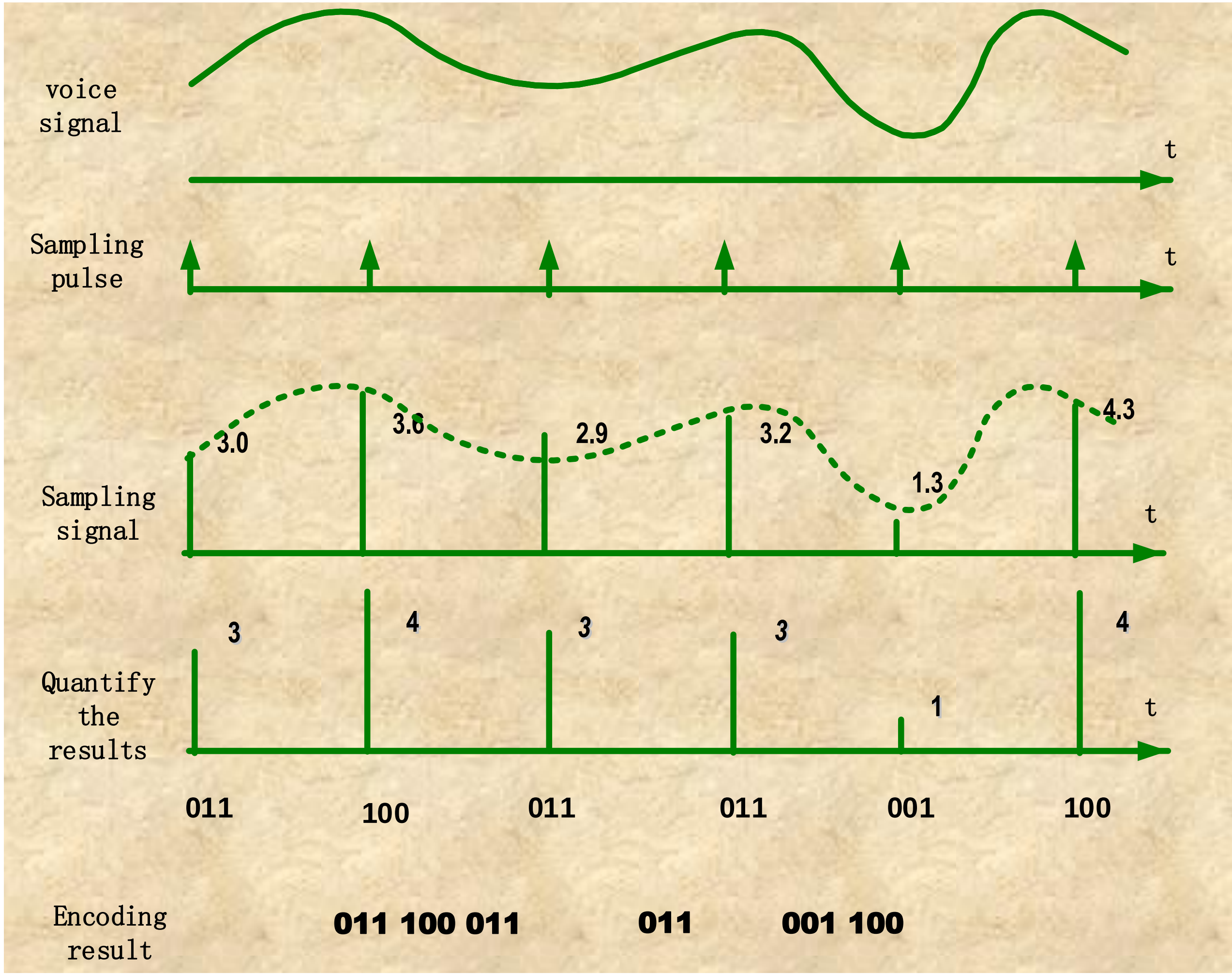
Pulse code modulation PCM

- Voice signal digitization
  - Voice 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

PCM encoding process example

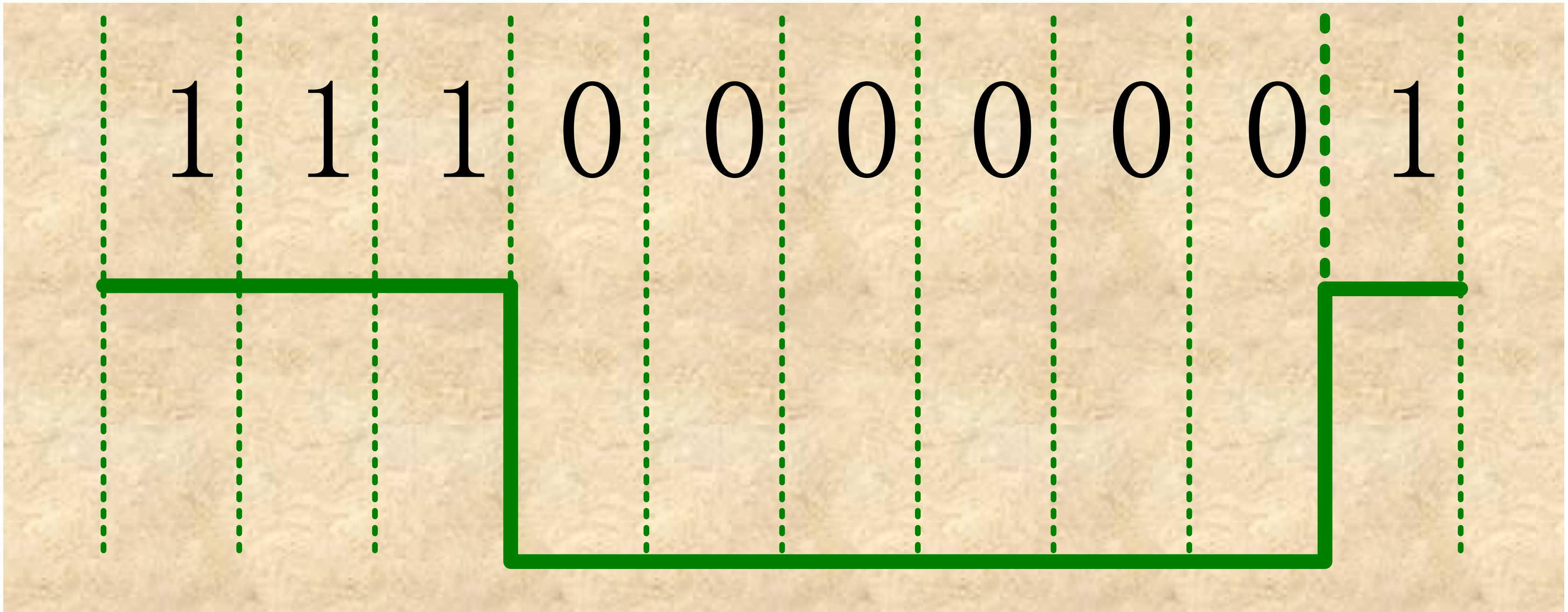


Digital signal coding technology (digital to digital)

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

Non return to zero level coding (NRZ-L)

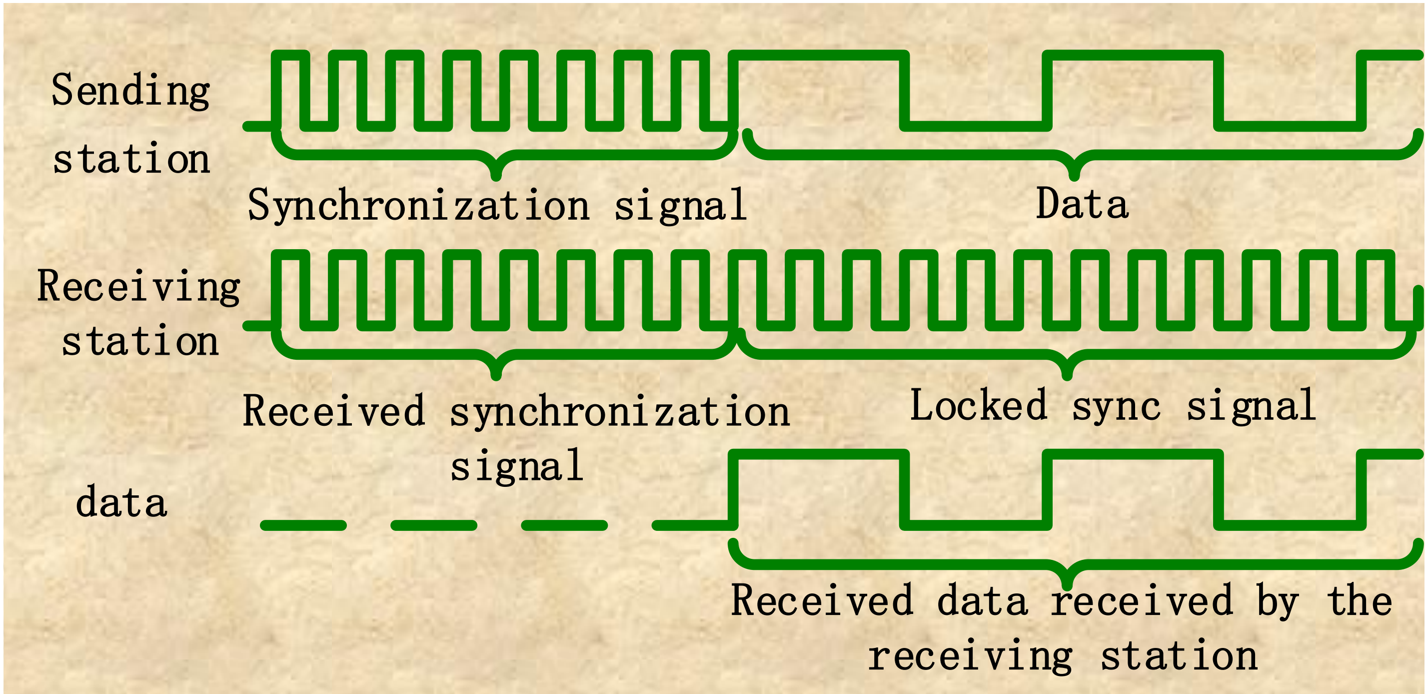
- 1 = high potential 0 = low potential



Digital signal coding technology (digital to digital)

- **Non-return-to-zero level coding (NRZ-L):**
  - The binary information "0" and "1" are represented by two different levels, the low level means "0", the high level means "1"
- **Disadvantages:**
  - It is 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:**
  - The transmitting side sends the sync pulse signal before sending the data, and the receiver uses the received synchronization signal to lock its own clock pulse frequency.

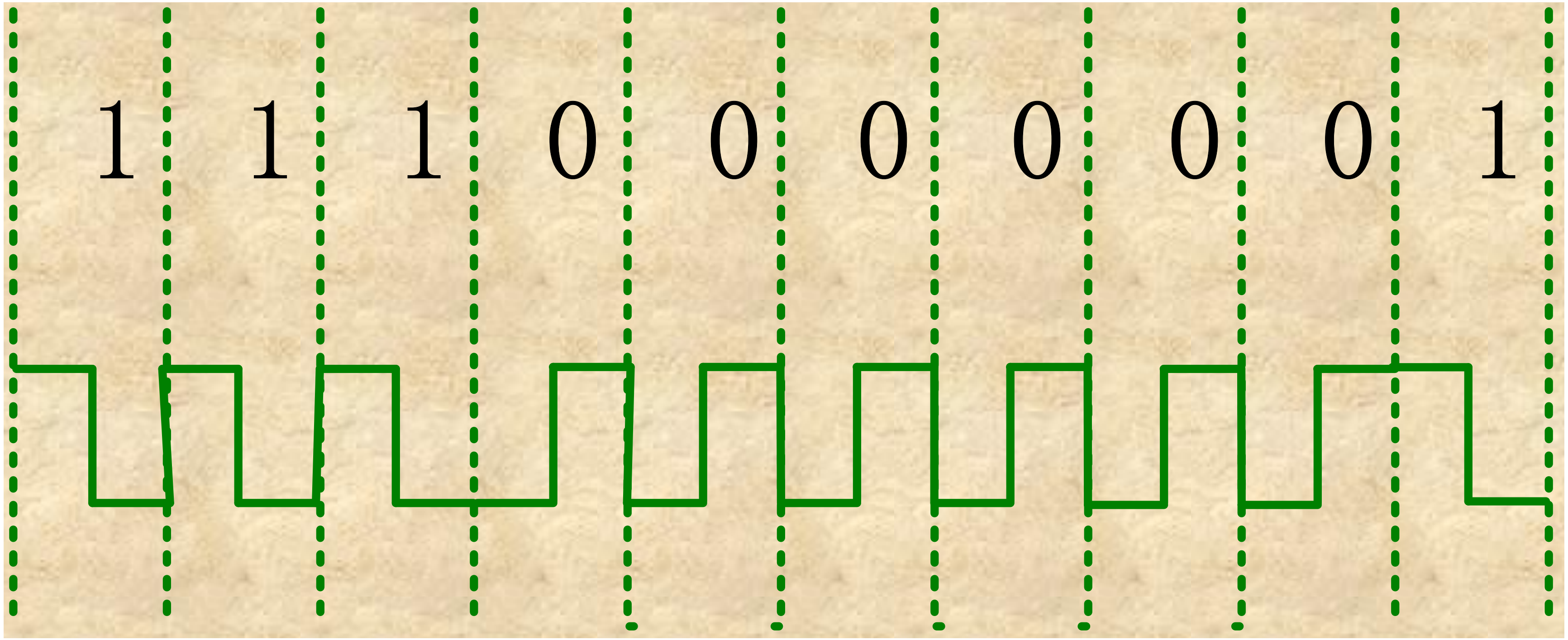


- **Self-synchronization:**
  - By the special code, the data encoded signal contains the synchronization signal, the receiver extracts the synchronization signal from the data encoded signal to lock their own clock pulse frequency.

Digital signal coding technology (digital to digital)

- Manchester code
  - Each symbol is divided into two equal intervals.
  - Symbol "1": the previous interval is high and the next interval is low.
  - Symbol "0": the previous interval is low and the next interval is high.
  - Features: to ensure that in the middle time of each symbol there is a level hop.

Manchester code example:



Digital signal coding technology (digital to digital)

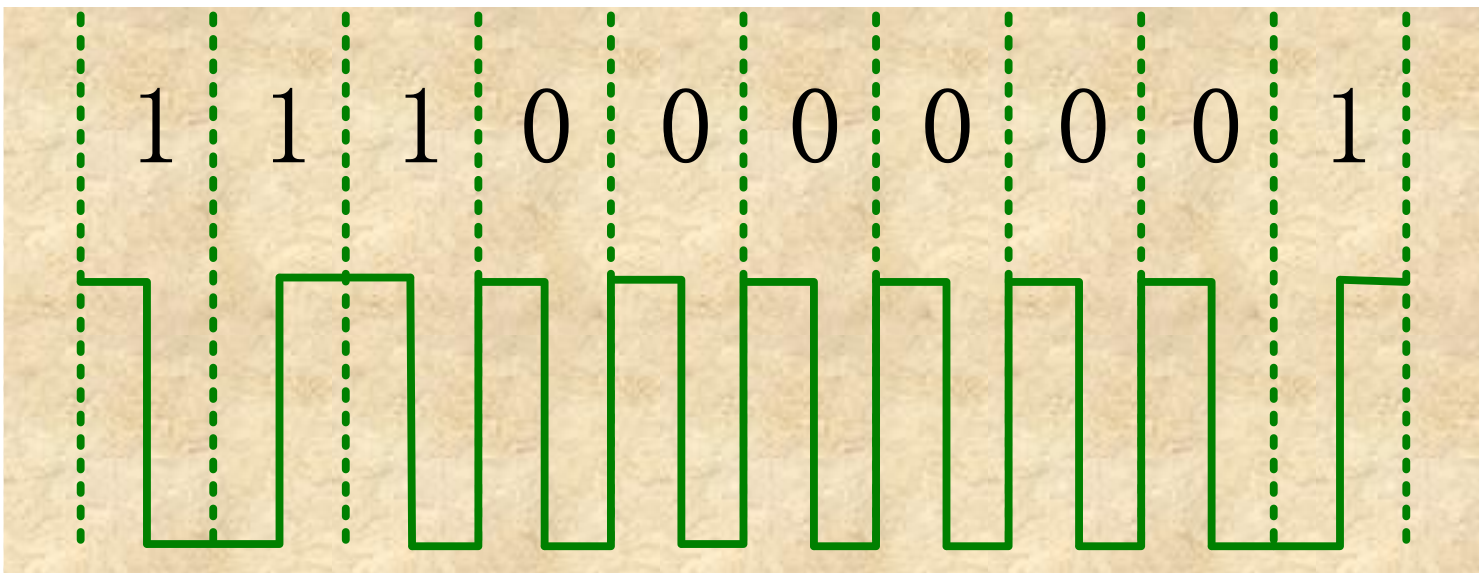
- Advantage:
  - Overcoming the lack of NRZ code.
  - Each middle of the jump can be used as data, but also as a clock, to self-synchronization.
- Disadvantages:
  - Since the time division of a symbol is divided into two times, the bandwidth occupied by the signal is twice as large as that of the original baseband signal, thus doubling the bandwidth requirement of the transmission channel;
  - After the frequency increases, the high-frequency noise in the line also increases, susceptible to noise interference;
  - The result of the coding is ambiguous.

Digital signal coding technology (digital to digital)

- Differential Manchester encoding
  - The duration of each data symbol is divided into two equal intervals, each of which uses a level hop.
  - Symbol "1": the level of the first half of the symbol is the same as the level of the second half of the previous symbol;
  - Symbol "0": the level of the first half of the symbol is opposite to the level of the second half of the previous symbol.

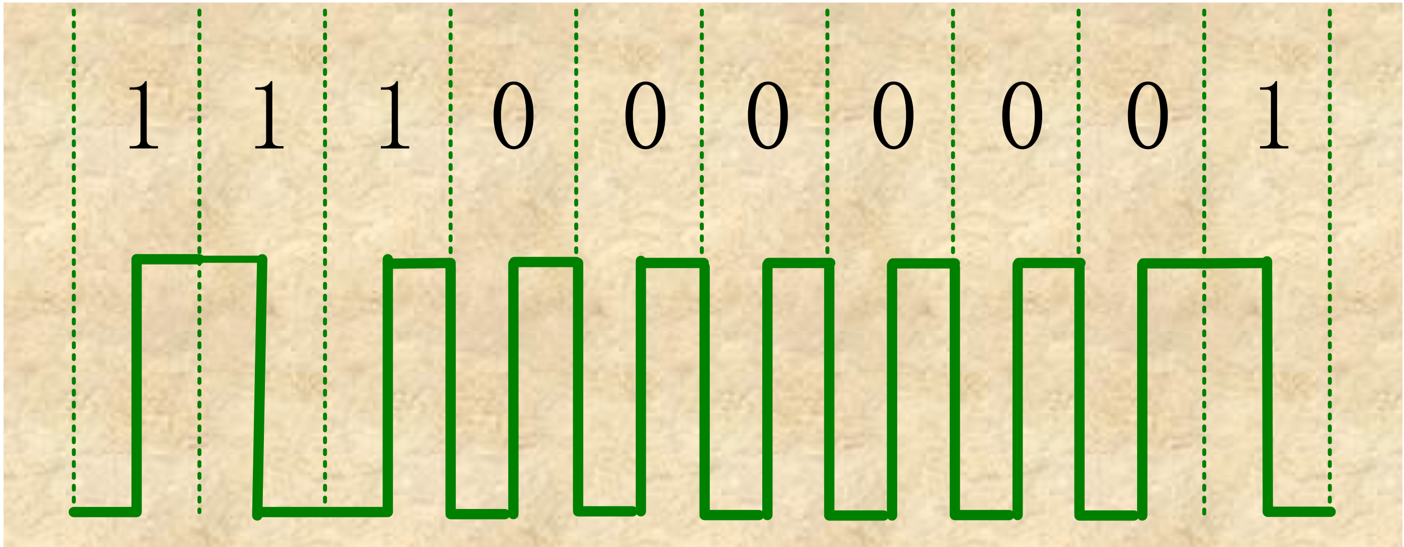
Differential Manchester code waveform -1

- Regardless of whether the previous bit is 1 or 0, assuming that the previous bit rises from the low potential to the high potential



Differential Manchester code waveform -2

- Regardless of whether the previous bit is 1 or 0, assuming that the previous bit drops from the high potential to the low level



Digital signal coding technology (digital to digital)

- **Advantage:**
  - Regardless of whether the symbol is "1" or "0", there must be a level hop at the middle of each symbol.
  - Better anti – interference performance;
  - Separation between bit clock and data, easy data extraction;
  - Since the transition of the coding technique is uniquely determined by the latter half of the previous symbol, the ambiguity in Manchester coding is eliminated.
- **Disadvantages:**
  - Since the time division of a symbol is divided into two times, the bandwidth occupied by the signal is twice as large as that of the original baseband signal, thus doubling the bandwidth requirement of the transmission channel;
  - After the frequency increases, the high-frequency noise in the line also increases, susceptible to noise interference.

Digital signal coding technology (digital to digital)

Exercise:

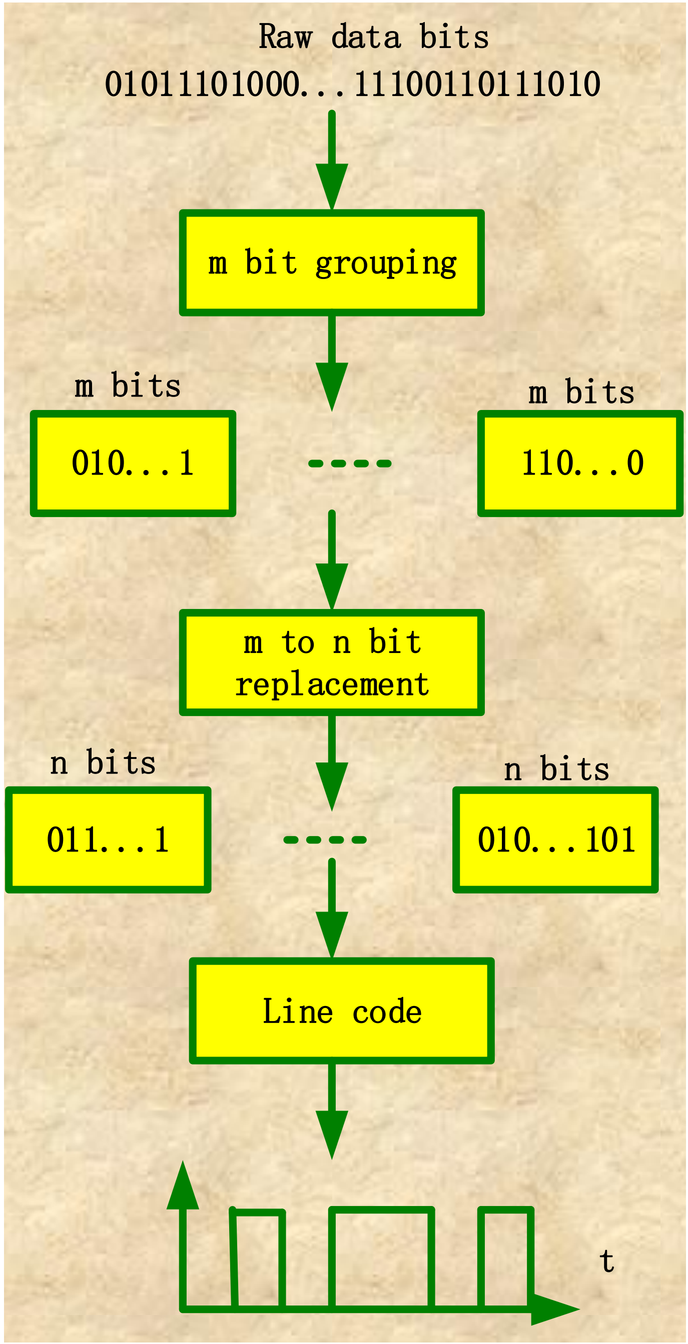
Draw the waveform of "001101" with NRZ, Manchester encoding, differential Manchester encoding.

Digital signal coding technology (digital to digital)

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

Step: (mB / nB, m <n)

- **Grouping**:
  - Divide the data sequence into multiple blocks of m bits
- **Substitution**:
  - Substitute m bits by n bits
  - The extra bit sequence can be used for error detection, synchronization or other controls, or not used
- **Line coding**:
  - Use a simple line coding mechanism (such as NRZ-I) to generate signals



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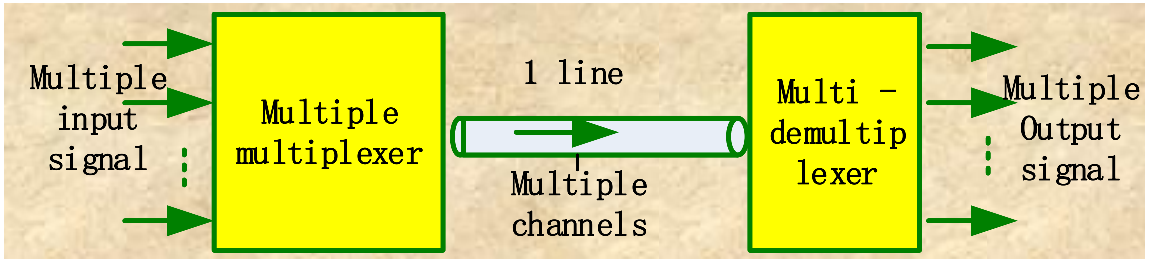
Multiplexing

- **Definition:**
  - In order to save communication equipment and costs, often in a physical channel at the same time to send multiple information, this technology is called multiplexing (Multiplexing) or called multi-pass.

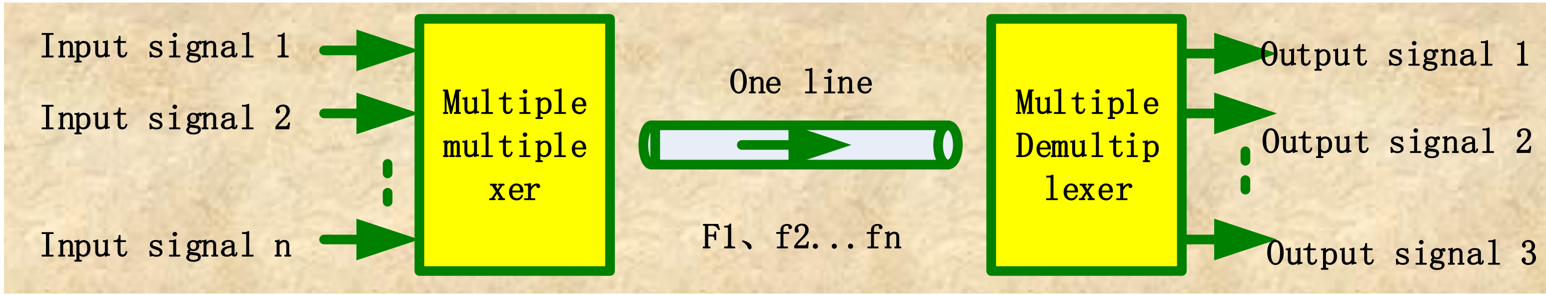


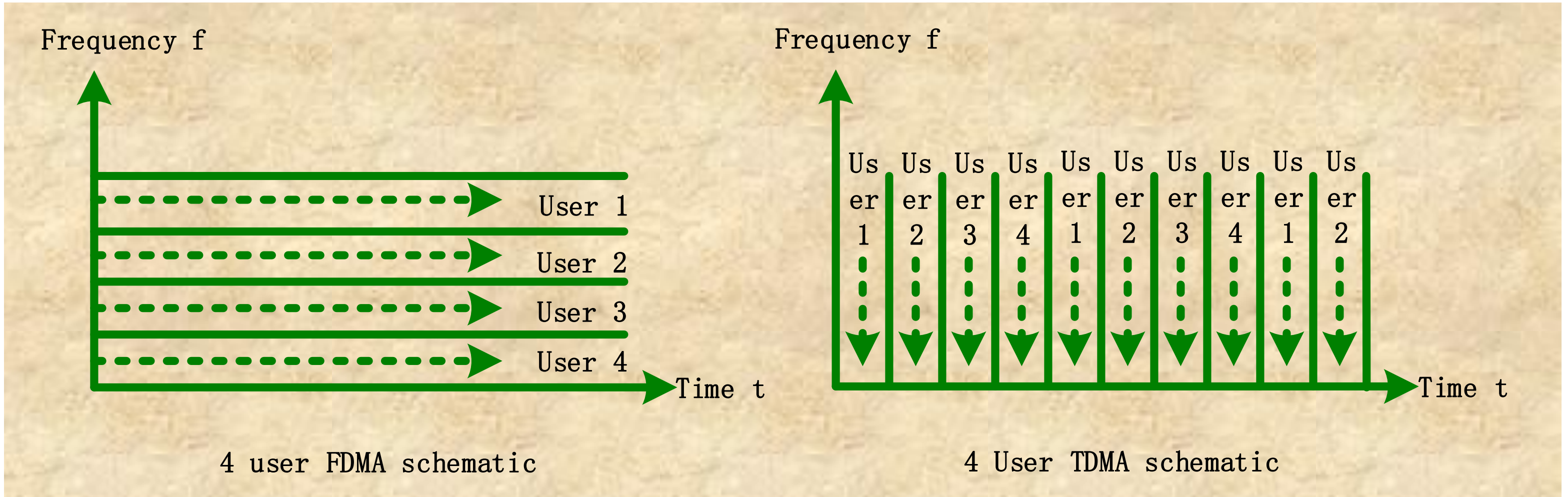
- **Commonly used programs are:**
  - Frequency division multiplexing (FDM); Time division multiplexing (TDM)
  - Wavelength division multiplexing (WDM); Code division multiplexing (CDM)

Multiplexing

- (1) Frequency division multiplexing (FDM)
  - **Principle:**
    - The frequency of the different signals is modulated to a different frequency range.
    - The available frequency bandwidth of the channel is divided into several non-overlapping bands, each signal occupying a frequency band.
    - Transmit the modulated multi-channel signals together.
    - The receiver get the original multi-channel signal through the demodulation of the signal.

Multiplexing





Multiplexing

- FDM's main question:
  - Mutual interference (known as crosstalk) is common between the signals.
  - Signal distortion and unacceptable reception.
- Solution:
  - Requires a sufficiently large guard interval between multiplexed spectrums
  - Requiring modulation and demodulation system has a very good linear filtering function.
- FDM applications:
  - Radio and television, cable television, digital data transmission

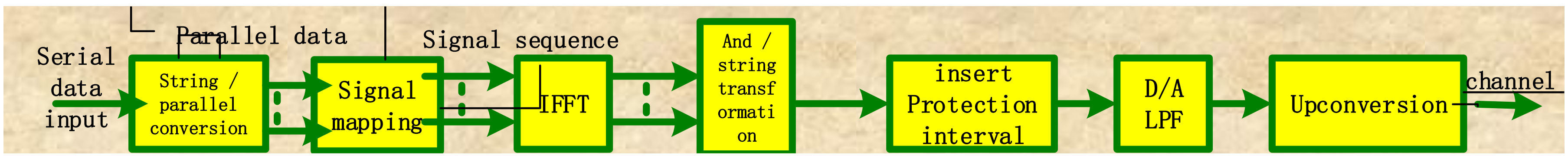
Orthogonal frequency division multiplexing (OFDM) technology

- **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.

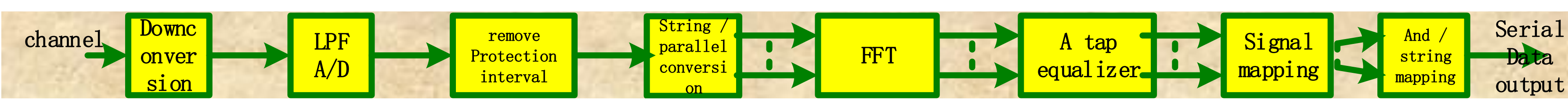
- **Suitable for the high-speed data transmission through wireless channel under the presence of multipath propagation and Doppler shift.**

Orthogonal frequency division multiplexing (OFDM) technology

- FFT based OFDM Transmit System



- FFT based OFDM Receiving System



Orthogonal frequency division multiplexing (OFDM) technology

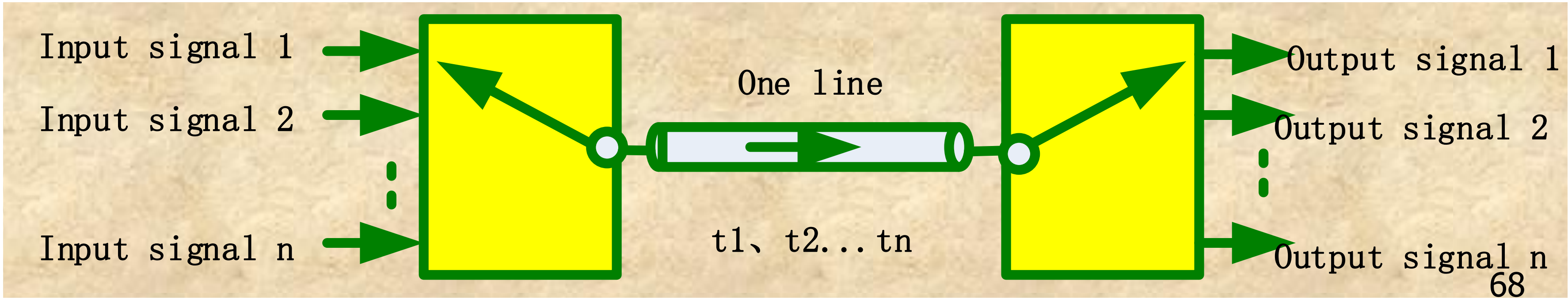
- **Advantages:**
  - Reduce the influence of inter-symbol interference;
  - Reduce the effect of frequency selective fading;
  - Improve the band utilization, to avoid the crosstalk between sub-channels;
  - Nearly eliminate inter-symbol interference;
  - Anti-interference coding technology can be used 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.

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

- (2) Time Division Multiplexing (TDM)
  - Applicable to digital technology, using time-sharing technology.
- Principle:
  - Each channel is assigned a time slot
  - Users can send data when their time slot arrives.
  - There is a need for synchronization between both parties
  - Time division multiplexing work diagram:



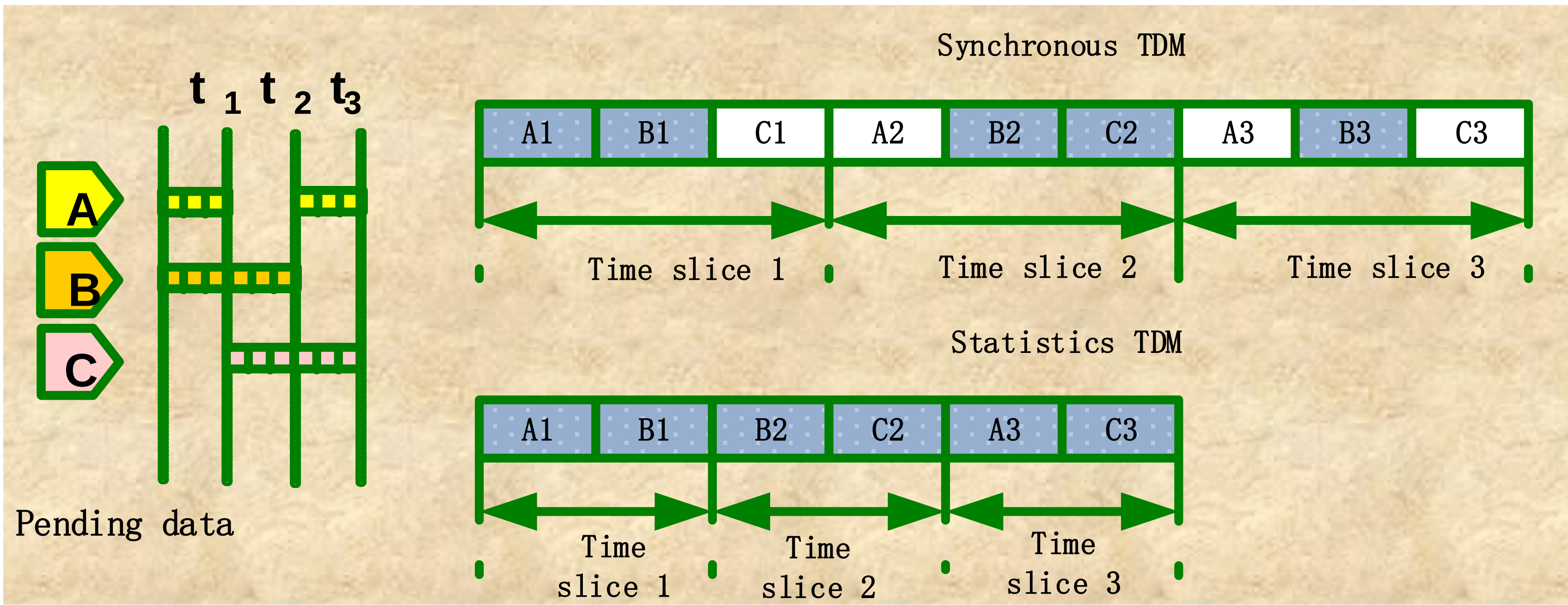
Multiplexing

- 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.**

Statistical (asynchronous) TDM - STDM

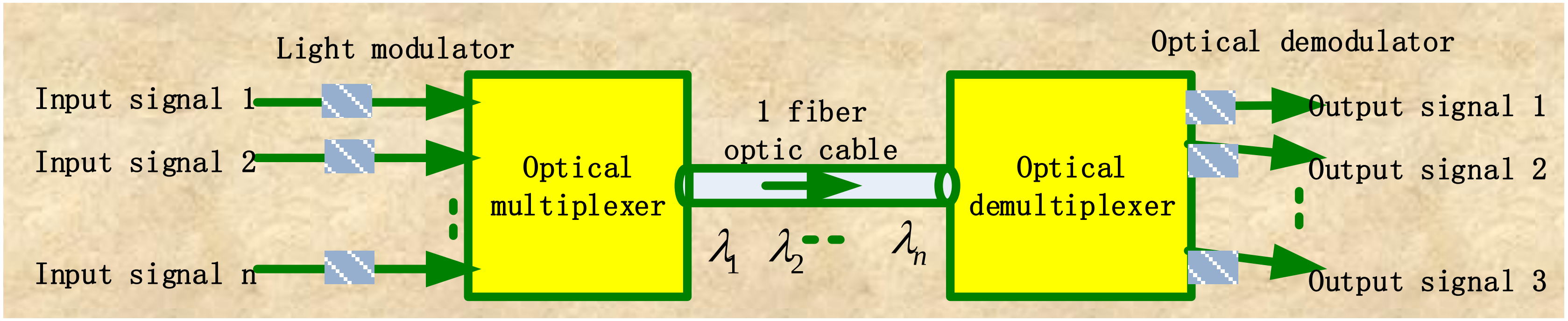
- Asynchronous TDM:
  - The time slot of the physical channel is fixedly allocated for several, and the user does not occupy a certain time slice.
  - When a user needs to carry out data transmission, to assign a time slice;
  - If the user does not have the data transmission requirements, the system 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.

TDM Technology



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.**



Code division multiplexing (CDM)

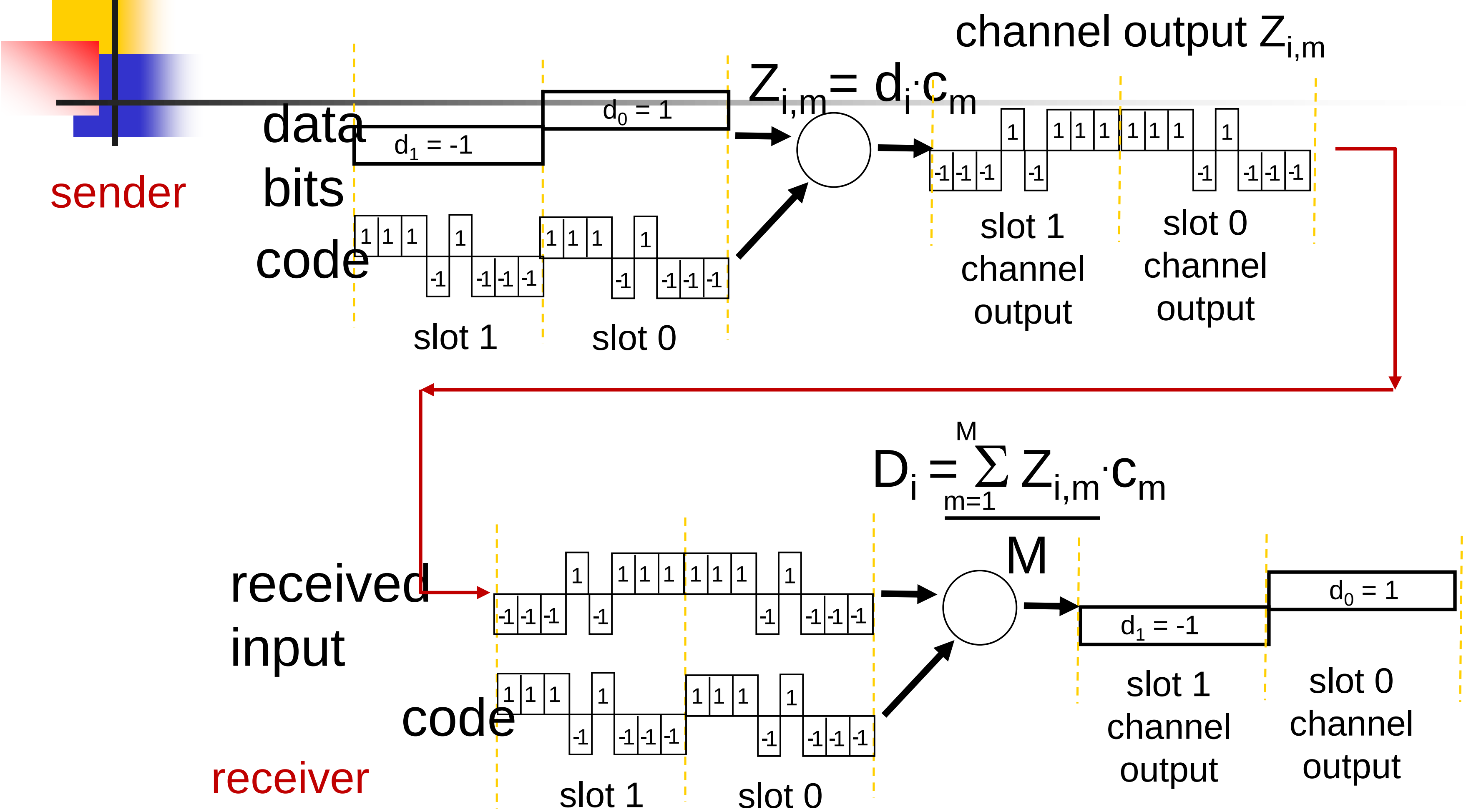
- Code Division Multiple Access (CDMA)
- unique “code” assigned to each user
- all users share same frequency, but each user has own “chipping” sequence (i.e., code) to encode data
- Each station is assigned a unique m bit chip sequence.
  - If sending bit 1, send its own m bit chip sequence
  - If bit 0 is transmitted, the binary inverse of the sequence of chips is transmitted
- encoded signal = (original data) X (chipping sequence)
- decoding: inner-product of encoded signal and chipping sequence

Code division multiplexing (CDM)

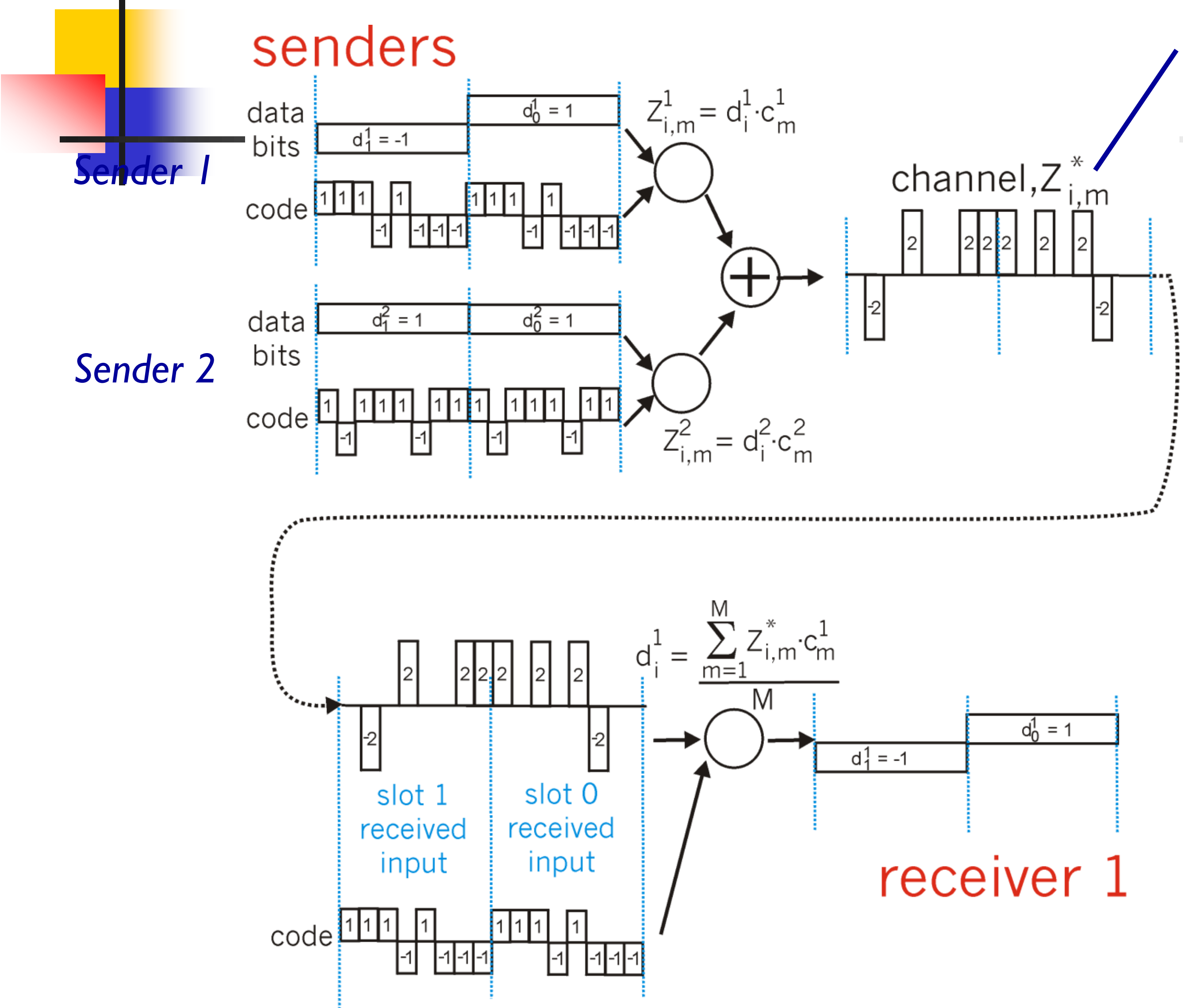
- allows multiple users to “coexist” and transmit simultaneously with minimal interference (if codes are “orthogonal”)
  - Let vector S denote the chip vector of station S, let T be the chip vector of any other station.
  - Two different chip sequences of different stations are orthogonal, that is, the normalized inner product of vector S and T is 0:

$$\mathbf{S} \bullet \mathbf{T} \equiv \frac{1}{m} \sum_{i=1}^{m} S_i T_i = 0$$

CDMA encode/decode



CDMA: two-sender interference



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!

Code division multiplexing (CDM)

- Each user uses a specially selected different pattern, so each other will not cause interference
- This system sends the signal has a strong anti-interference ability, the spectrum is similar to the white noise, not easily found by the enemy.
- Each bit time is divided into m short intervals, belonging to an application of spread spectrum communication technology

TDM—Digital Carrier Standard

- T-standard
  - North America, Japan
- E-standard
  - Europe, China, South America
- Synchronous Fiber Network SONET
- Synchronous Digital Hierarchy SDH

T- standard

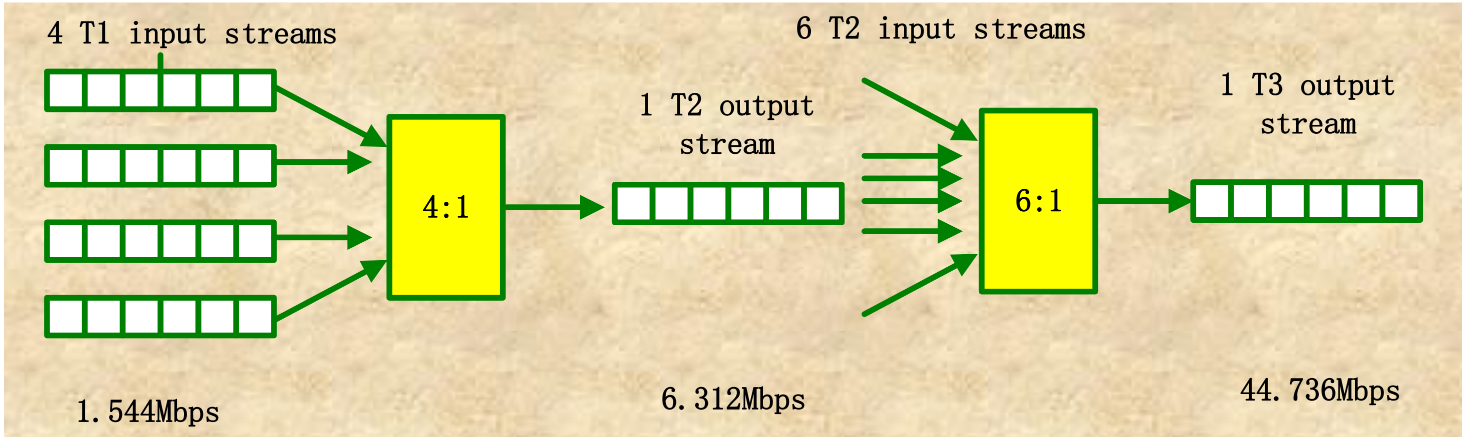
- T1 standard line bandwidth calculation:
  - Taking the T1 carrier of the Bell system as an example, the Bell system multiplexes 24 audio channels together.
  - According to Nyquist theorem, the frequency bandwidth of 4KHz audio channel, as long as 8000 times per second sampling (that is, 125us mining once) can capture all of its information.
  - Each time the sample is quantized to generate a 7-bit data, 24 audio channels of a sampling data into a frame, the frame length of 193bit, each logical channel 8bit (7bit data, 1bit control signal), the first 193bit In frame synchronization.
  - T1 carrier to send 8,000 such frames per second, so the physical channel capacity is greater than 193 * 8000bit / s = 1.544Mbit / s

E- standard

- E1 standard line bandwidth calculation:
  - Every 125us for a time slice, each film time is divided into 32 channels (for 32 users in turn use), then each channel occupies 125us / 32 = 3.90625us
  - Each channel transfers 8 bits of binary data at a time, that is, each bit occupies 3.90625 / 8 = 0.48828125us
  - So the E1 rate = 1 / 0.48828125 = 2.048Mb / s

T-standard

- 4 T1 channels can be multiplexed into the T2 channel; 6 T2 streams can be multiplexed into the T3 channel; 7 T3 streams can be combined into the T4 channel.
- The multiplexing on T2 and higher lines is carried out in bits.
  - T2 line data transmission rate of 6.312Mbps
  - T3 line data transmission rate of 44.736Mbps
  - T4 line data transmission rate of 274.176Mbps.



T- standard and E-standard

- There are many drawbacks to the digital transmission system defined by the T and E standards:
  - The use of electrical media, signal distortion, poor anti-interference performance, poor confidentiality.
  - The rate standard is not uniform
  - Not synchronous transmission

Synchronous optical network SONET

- SONET standard: Four design goals
  - Different lines can be interconnected and work reliably;
  - Unified the digital system standards of United States, Europe and Japan and other regions;
  - Capable of multiplexing multiple digital channels together;
  - Support operation, management and maintenance.

Synchronous optical network SONET

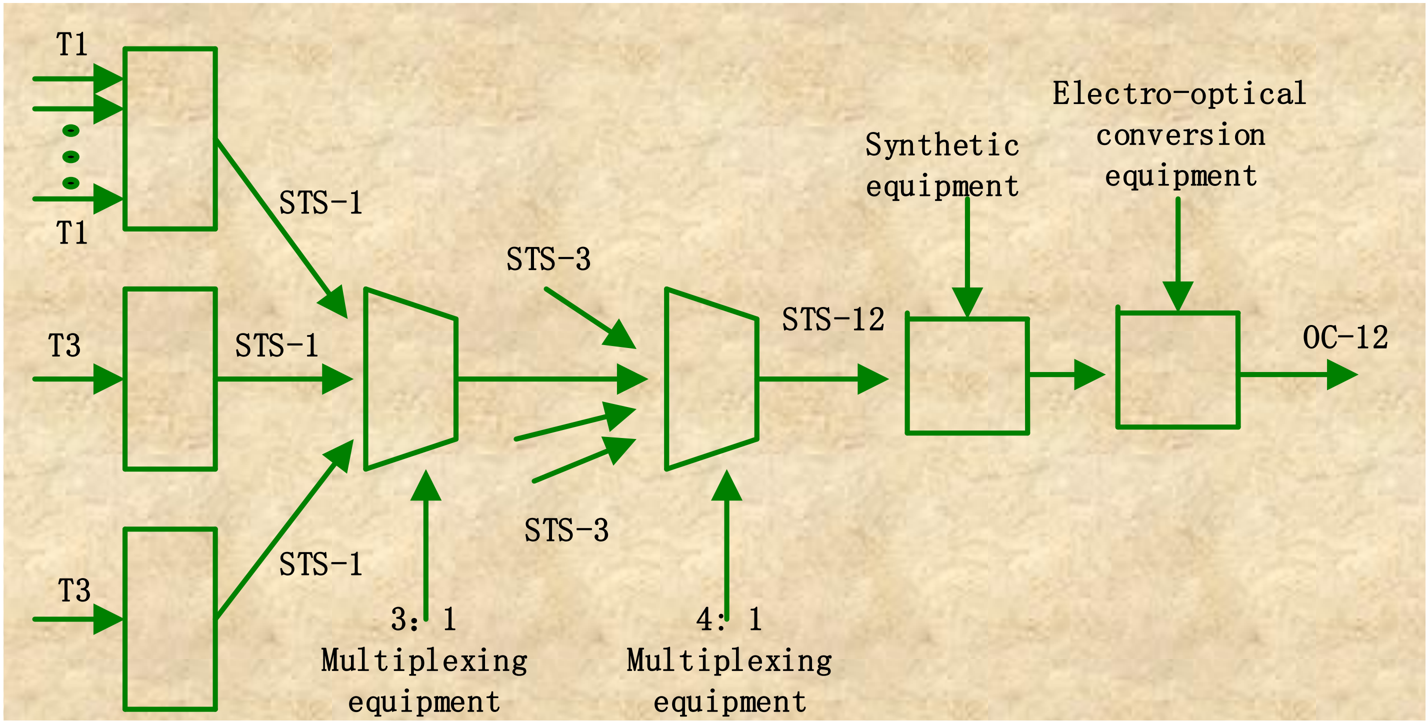
- TDM based optical fiber multiplexing system.
- Synchronous system.
- The clocks at all levels come from a very precise master clock.
- SONET system consists of switches, multiplexing equipment and repeaters, and use optical fiber in connection.

Synchronous optical network SONET

- The basic SONET frame is 810 bytes, the sampling frequency is 8000 times / sec, the system uses synchronous TDM technology, therefore, the total data transfer rate:
- $$810 \times 8 \times 8000 = 51.84 Mb / s$$
- The basic SONET channel is also known as the synchronous transmission signal STS-1.
- SONET defines the rate from STS-1 to STS-48, and the fiber line corresponding to STS-n is called OC-n.

Synchronous optical network SONET

- **Multiplexing of multiple data streams**



Synchronous digital hierarchy SDH

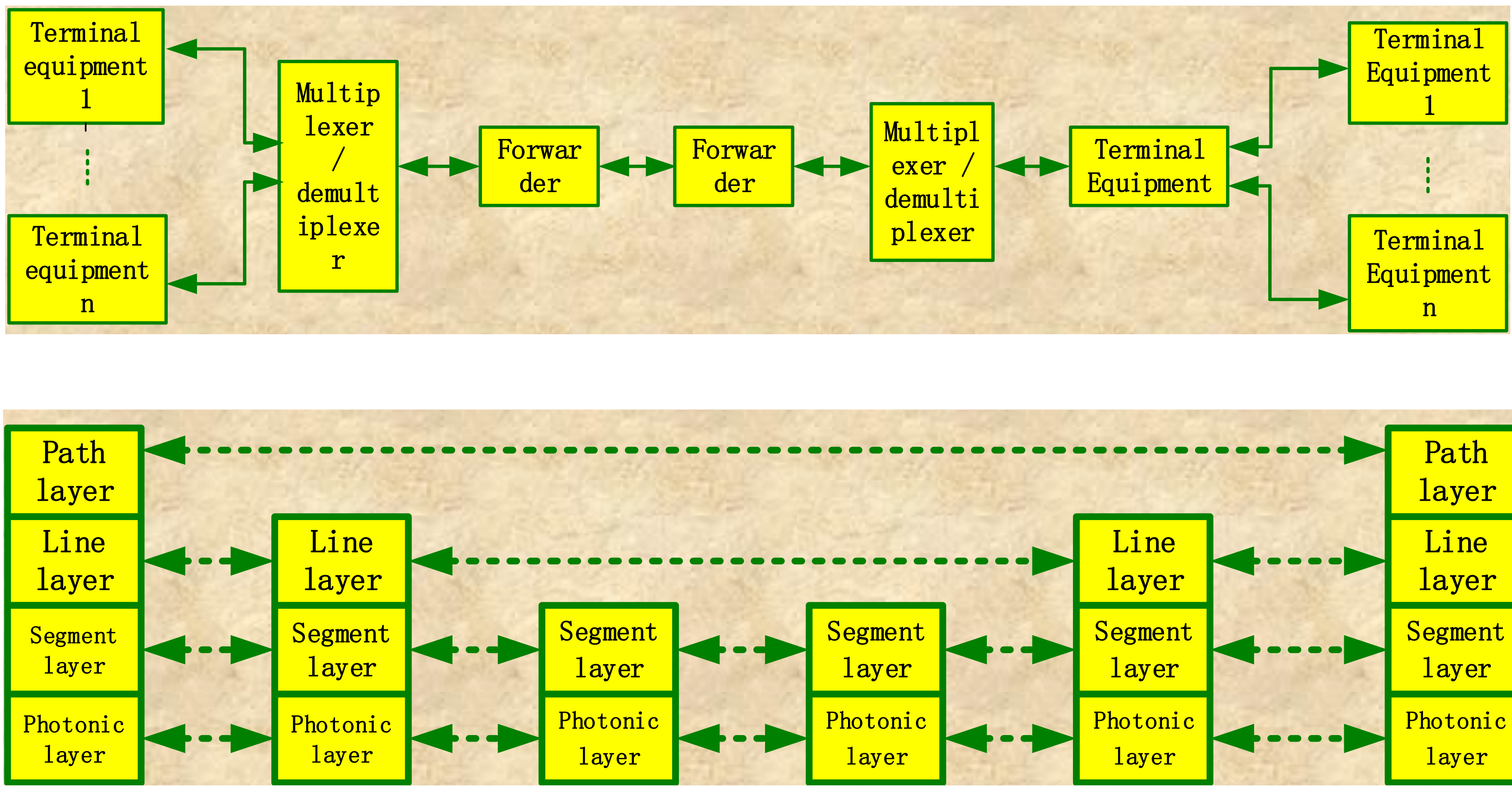
- ITU-T based on the US standard SONET, developed the international standard synchronous digital series SDH (Synchronous Digital Hierarchy).

- The basic rate of SDH is 155.52 Mb/s, which is called the Synchronous Transfer Module (STM-1), equivalent to the OC-3 rate in the SONET system.

Commonly used rate in SONET system

Line rate （Mb/s）	SONET symbol	ITU-T symbol	Represents a common approximation of line rates
51.840	OC-1/STS-1	---	
155.520	OC-3/STS-3	SMT-1	155Mb/s
466.560	OC-9/STS-9	SMT-3	
622.080	OC-12/STS-12	SMT-4	622Mb/s
933.120	OC-18/STS-18	SMT-6	
1244.160	OC-24/STS-24	SMT-8	
2488.320	OC-48/STS-48	SMT-16	2.5Gb/s
4976.640	OC-96/STS-96	SMT-32	
9953.280	OC-192/STS-192	SMT-64	10Gb/s
39813.120	OC-768/STS-768	SMT-256	40Gb/s

The architecture of SONET



The significance of SDH/SONET standards

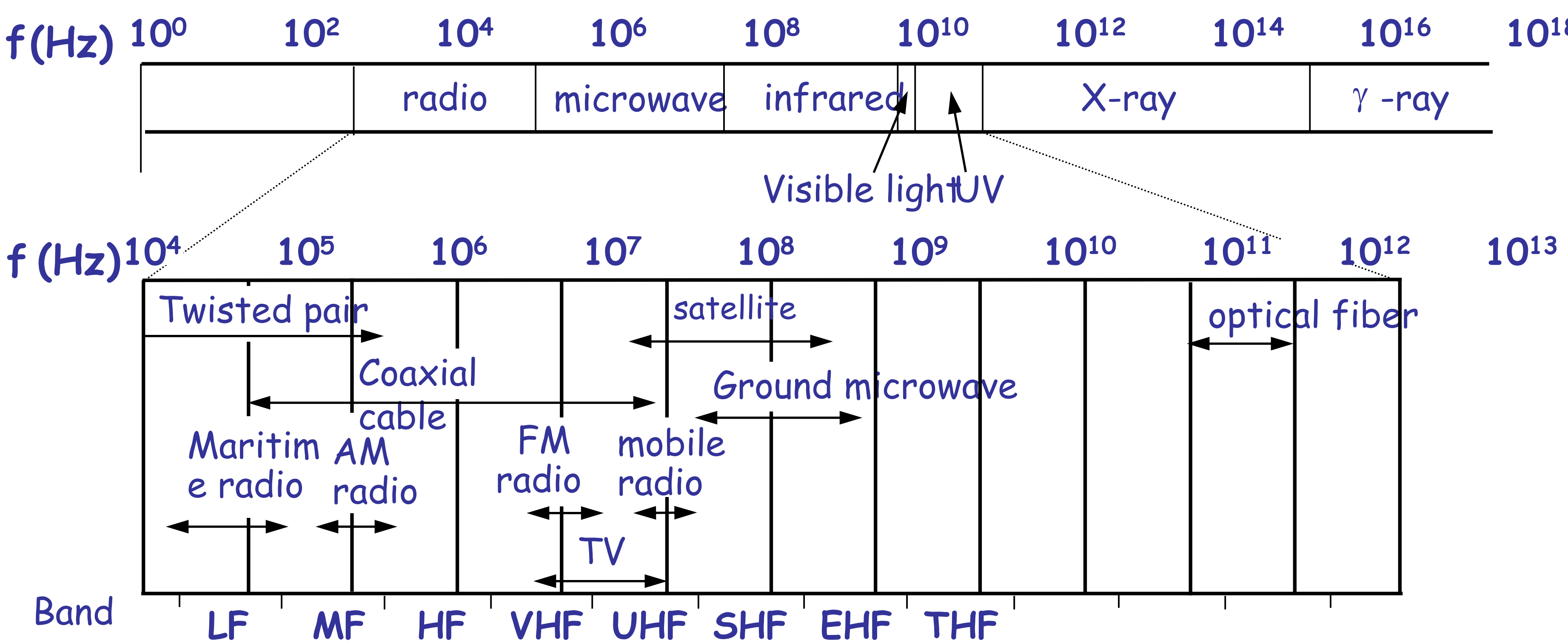
- So the different digital transmission standards in North America, Japan and Europe and other regions are unified in the STS-1 level.
- Truly realizing the worldwide digital transmission standard for the first time, and is of great significance to the development of the world telecommunication networks.

3 What is the theoretical basis for the physical layer?

4 What are the commonly used transmission media?

5 The commonly used physical layer interface standards

The spectrum of electromagnetic waves used in Telecommunications



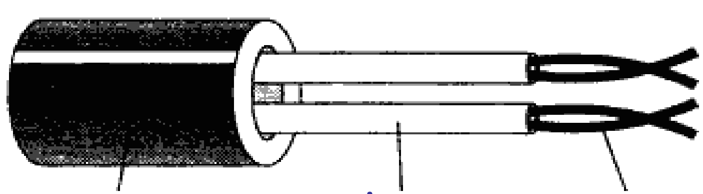
Transmission medium (guided transmission medium)

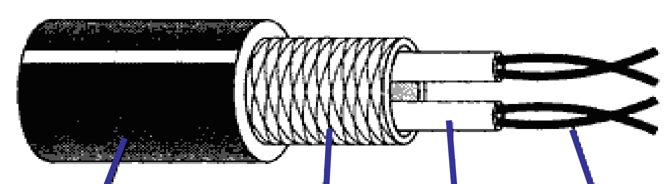
- Twisted Pair
  - Can be used for both analog and digital transmission
  - Bandwidth depends on the wire diameter and the transmission distance
  - UTP（Unshielded Twisted Pair）
    - Twisted pair without any shielding
    - Divided into Category 1 to Category 7
    - Category 3：transmission characteristics 16MHz, the data rate up to 16Mbps
    - Category 5：transmission characteristics of 100MHz, the data rate of up to 100Mbps

Transmission medium (guided transmission medium)

- Twisted Pair
  - Shielded twisted pair STP (Shielded Twisted Pair)
    - Twisted pair is wrapped by the aluminum foil, used to shield the interference signal
    - The price is relatively expensive, mainly for IBM network products

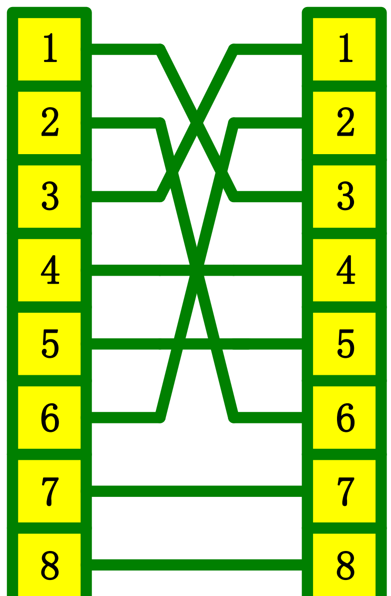
Unshielded Twisted Pair Shielded twisted



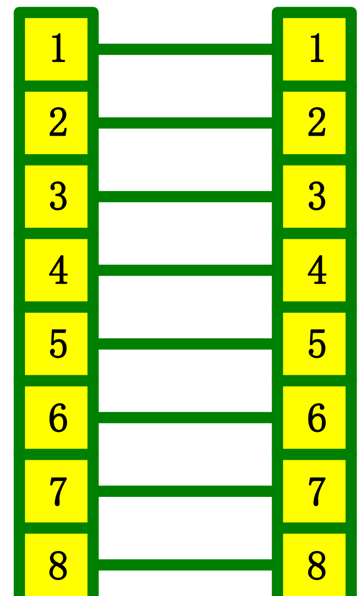


- **Connection standard for twisted pair**
  - **Cross line:**
    - Switch - Switch, PC-PC, HUB-HUB (standard port)
  - **Straight line:**
    - PC / router - switch / HUB, HUB-HUB (cascade port)

Line pair	Color code
1	White blue, blue
2	White orange, orange
3	White green, green
4	White brown, brown



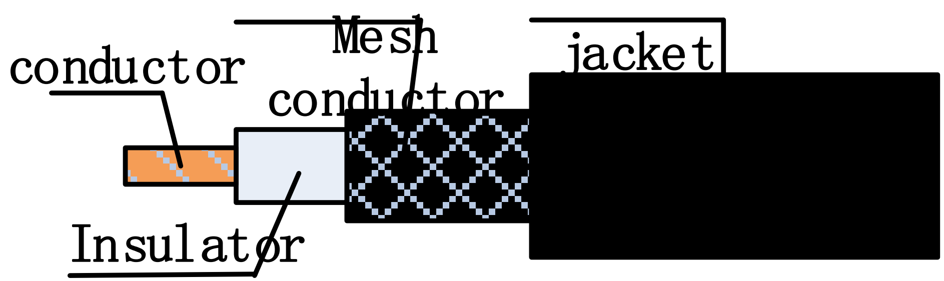
Cross line
EIA-568B



Direct line
EIA-568A

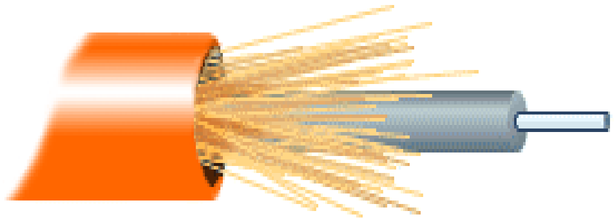
Transmission medium (guided transmission medium)

- Coaxial cable
  - Baseband Coaxial Cable
    - Transmit digital signal, one channel
    - Impedance 50 Ω, rate 10Mbps
  - Broadband Coaxial Cable
    - Transmission of different frequencies of analog signals
    - Impedance 75 Ω, 300M or 450Mbps, 100km
  - Thick Cable, Thin Cable

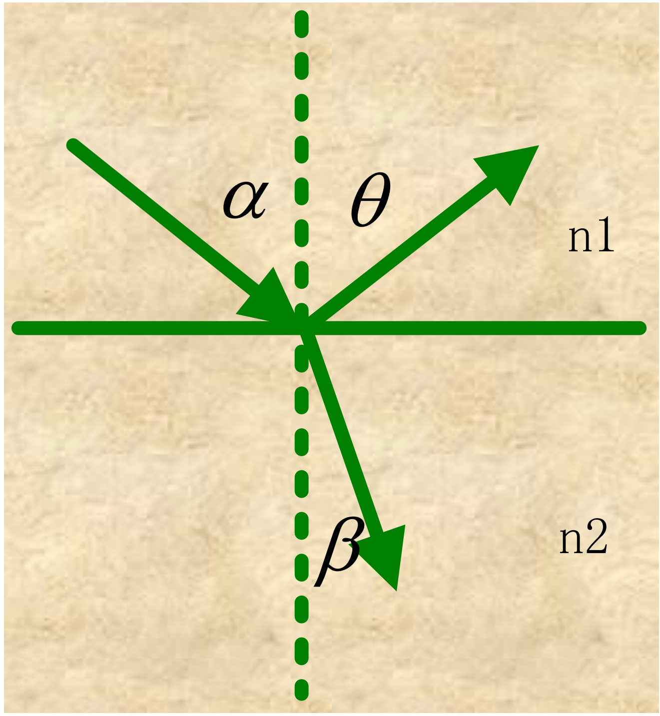


Transmission medium (guided transmission medium)

- Fiber Optics
  - Features
    - Use light to carry information
    - High transmission rate, large communication capacity
    - Transmission loss is small, suitable for long distance transmission
    - Anti-lightning and electromagnetic interference performance is good, good confidentiality
    - light

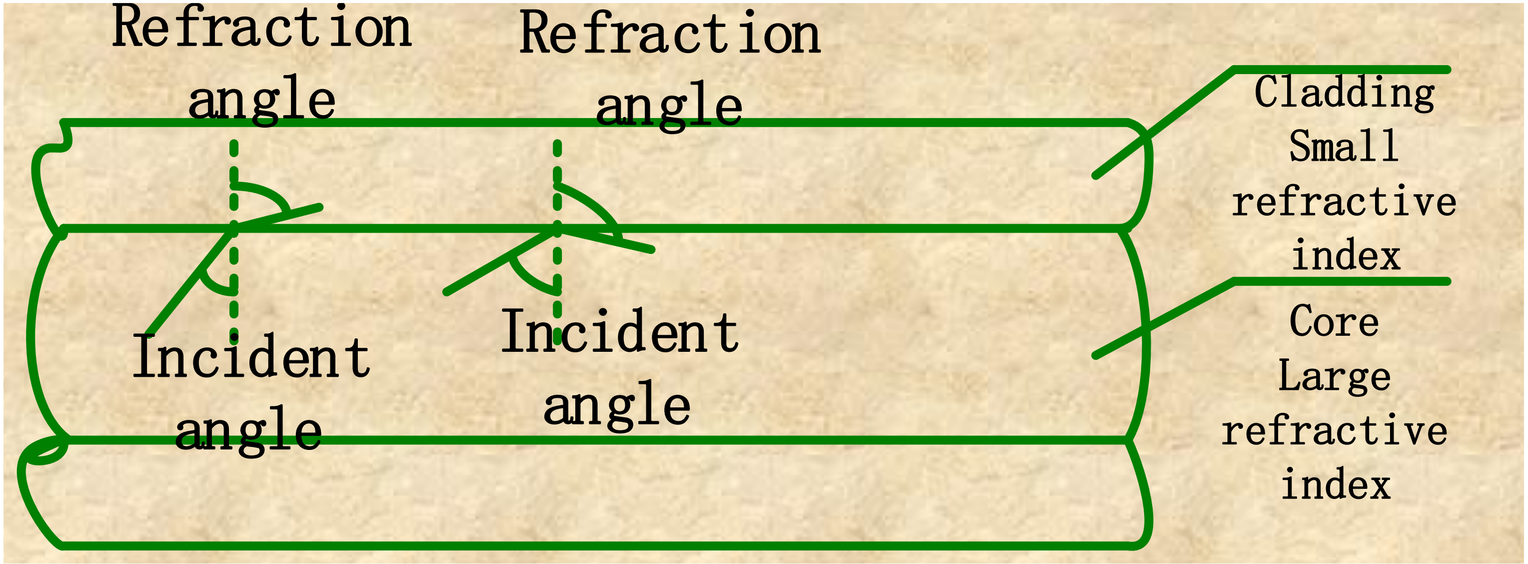


The law of refraction and the law of reflection of light

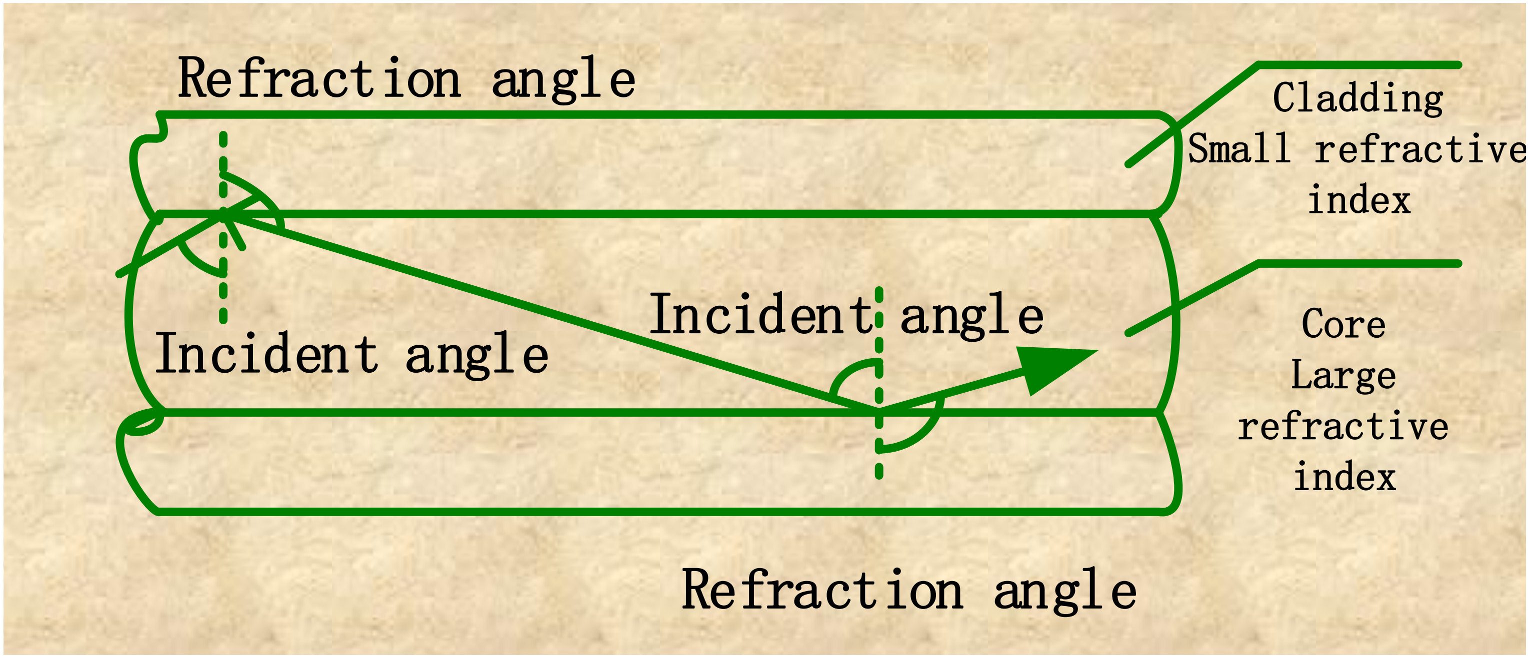


$$\frac{\sin(\alpha)}{\sin(\beta)} = \frac{n2}{n1}$$

Refraction and reflection of light in an optical fiber



Propagation of light in optical fiber



Transmission medium (unguided transmission medium)

- Wireless media
  - Use electromagnetic waves or light to carry information
- Advantages and disadvantages:
  - No physical connection required
  - Applicable to long distance or inconvenient wiring occasions
  - Susceptible to interference
  - Reflex, obstructed by obstacles
- Main types:
  - Radio, ground microwave
  - Communication satellite
  - Infrared

Transmission medium (unguided transmission medium)

- Radio
  - The communication between the base station and the terminal uses a wireless link
  - Application areas: mobile communications, wireless local area network (WLAN)
- Ground microwave
  - Through the ground station between the relay transmission
  - Distance between relay stations: 50 -100 km
  - Rate: 45 Mb/s per channel

Transmission medium (unguided transmission medium)

- Earth Synchronous Satellite
  - Position is fixed relative to the ground station
  - Three satellites can cover the worldwide communication
  - Transmission delay time is long (≈270ms)
  - Broadcast transmission
  - Application areas:
    - TV
    - Long-distance call
    - Dedicated network
    - WAN

Comparison of commonly used media

Transmission medium	Transfer method	Rate/ Band	Transmission distance	Performance	Price	Application
Twisted pair	Broadband Baseband	≤1Gb/s	Anolog: 10km 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

3 What is the theoretical basis for the physical layer?

4 What are the commonly used transmission media?

5 The commonly used physical layer interface standards

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
- ....

Summary

- 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