PMSCS 625P
Data Communication and Computer Networks

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Class link: https://classroom.google.com/c/ODM5MTg4MDg2OTI4?cjc=qczlesxp
Meet link: https://meet.google.com/khn-wxsq-xqf

Books

Computer Networks (5th Edition)
Andrew S. Tanenbaum

Data Communications and Networking (6th Edition)
Behrouz A. Forouzan

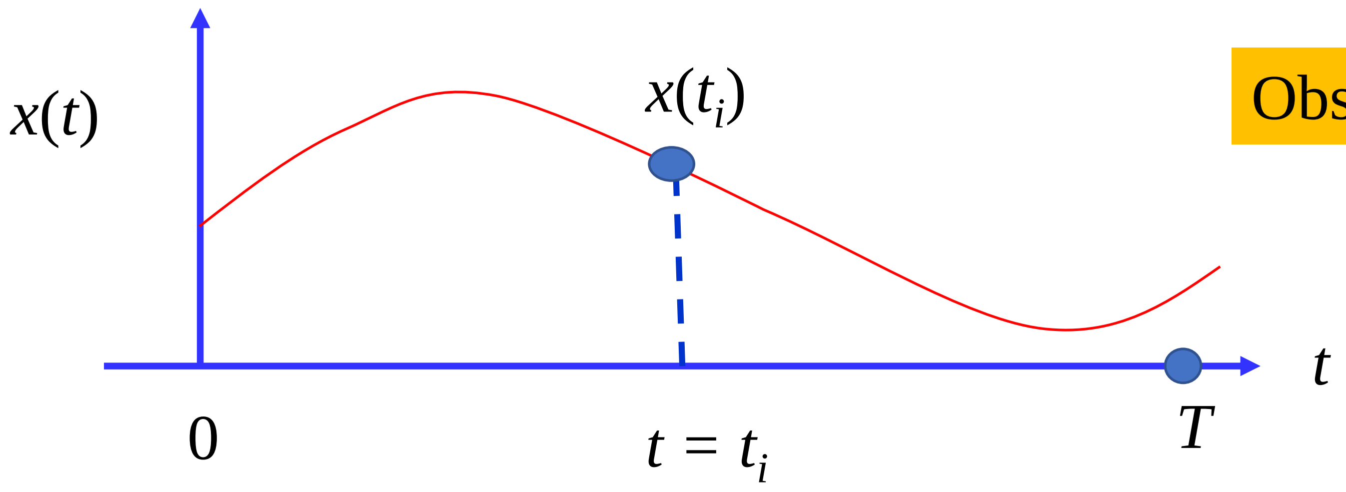
Data And Computer Communications
William Stallings

Computer Networking A Top-Down Approach
James F. Kurose and Keith W. Ross

Basic of Signal

- ✓ Any variable that conveys information is called **signal**. If $x(t)$ is a time dependent variable, may be voltage, current or power of a network indicating changes in amplitude with time.

- ✓ Usually, variation of signal is visualized in time domain but for complete analysis of any signal we need to know its frequency components.

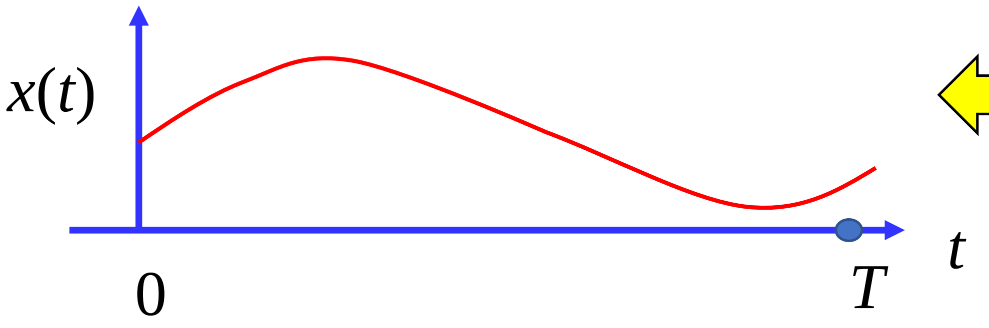


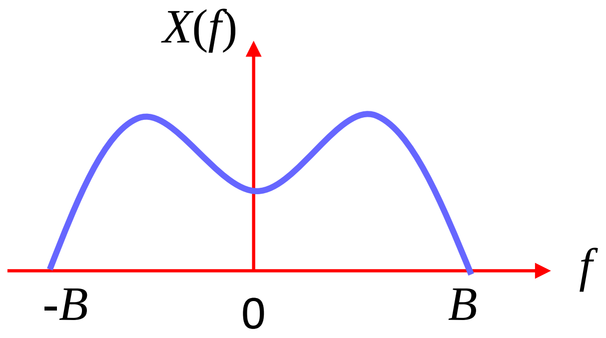
Observation time is $[0, T]$.

For periodic signal

For non-periodic signal

- ✓ Fourier series or Fourier transform is the basic mathematical method of conversion of a signal from time domain to frequency domain and vice versa.





$$x(t) \leftrightarrow X(f)$$

Highest frequency of the signal

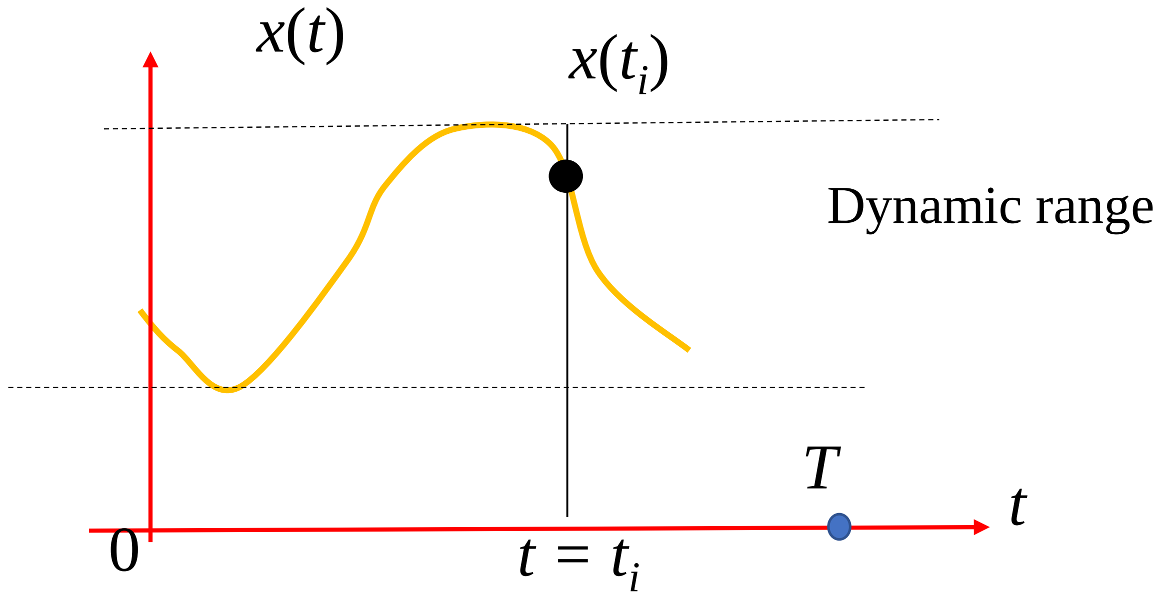
Classification of Signals

Continuous time, discrete time and digital signal

Continuous time signal

A continuous time signal $x(t)$ is continuous along both time and amplitude axis. The signal $x(t)$ provides an amplitude for any time instant $t = t_i$ visualized from fig. below. The signal also provides continuity of is amplitude over the dynamic range. The continuous time signal is also called analog signal.

Observation time is [0, T].
We have to observe whether any missing of signal is found within the observation time/period.



Continuous time signal

Discrete time signal

- A discrete time signal is expressed as a function of $t = nT$ like, $x(nT)$, where $n = 0, \pm1, \pm2, \pm3, \ldots$ and T is the sampling period of the signal (for discrete argument case it is called sequence).

- The sequence $x(nT)$ is continuous along amplitude axis (because amplitude axis is not sampled) but discrete along time axis shown in fig.4 known as discrete time signal.

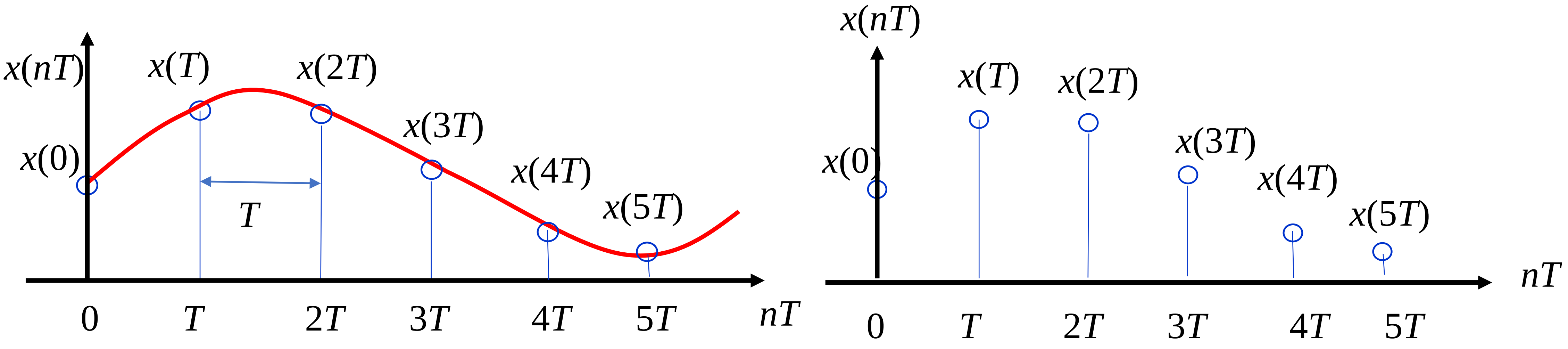
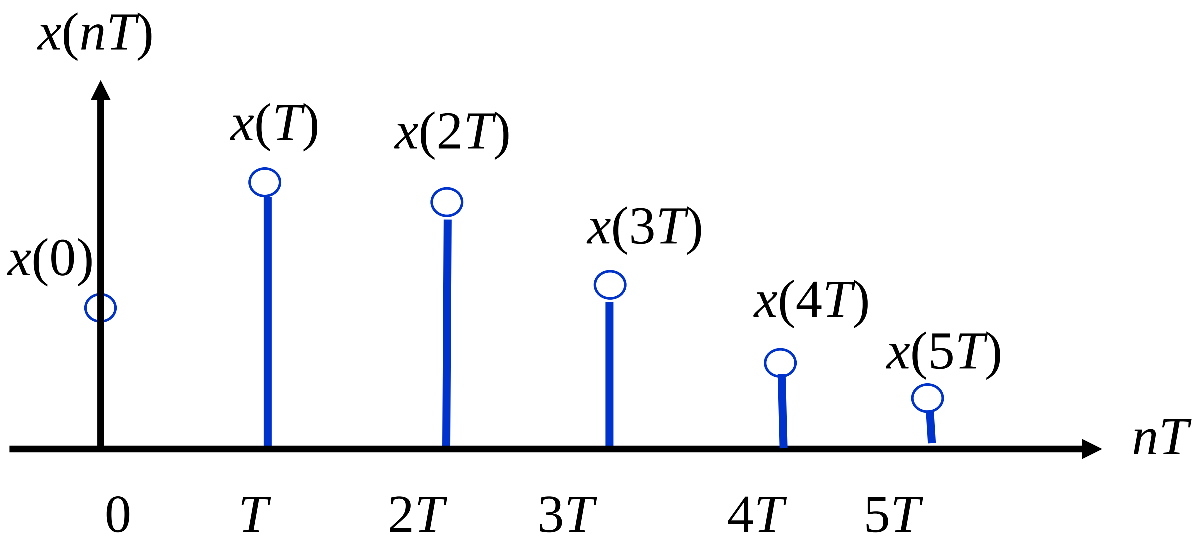


Fig.4. Discrete time signal

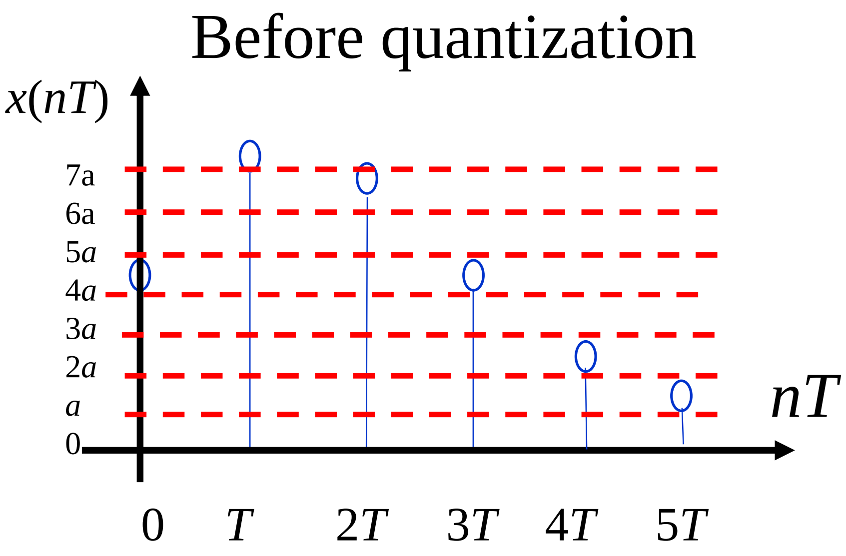
❖If a continuous time signal is sampled periodically it becomes a discrete time signal. If someone asks about discrete time signal ‘what lies between two adjacent sampling instant?,’ the answer will be ‘undefined’.



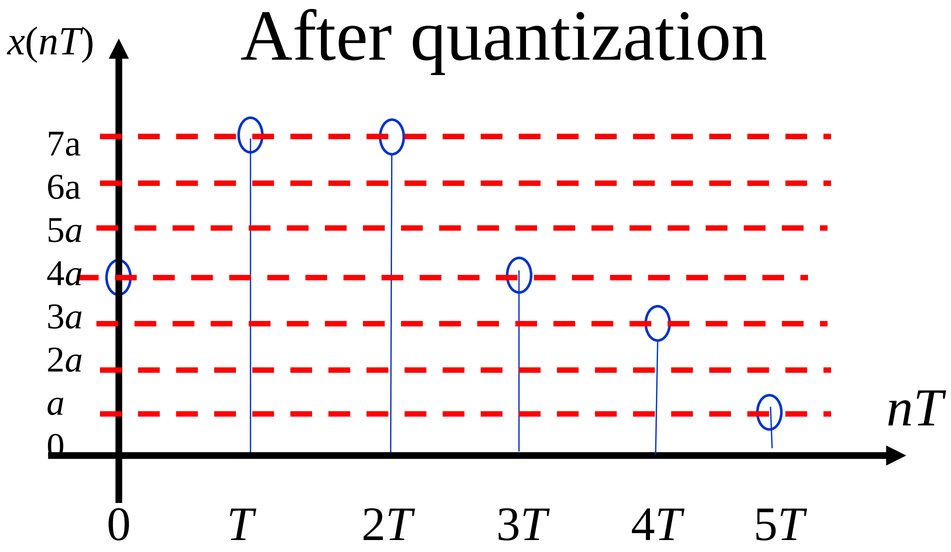
If the time axis of a signal is discrete but its amplitude axis remains continuous then it is called **discrete time signal**.

Digital signal

- ✓ If both time and amplitude axis of a signal is discrete, it is called digital signal.
- ✓ Amplitude axis is marked with several discrete levels with level spacing of a. If a sampled signal is quantized (amplitude of each sample is adjusted with nearest discrete level), it becomes digital signal.



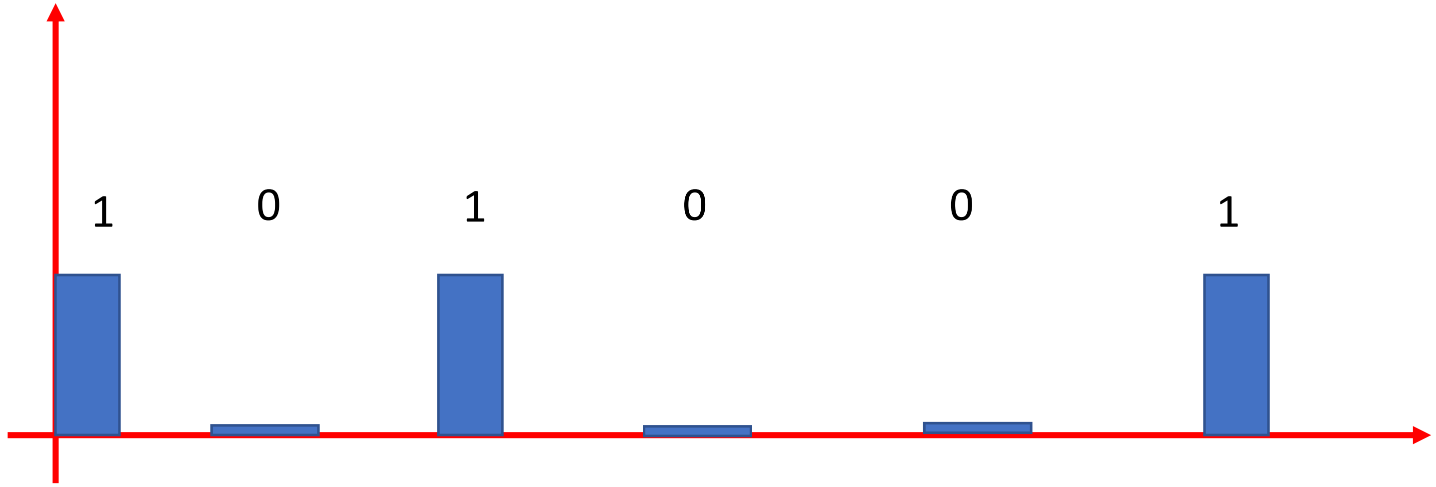
Discrete Time Signal



Digital Signal

$T \longrightarrow$ sampling period
$a \longrightarrow$ Level spacing

✓ For example binary data of logic 0 and 1 is a digital signal with two discrete levels, *n*-ary digital signal contains *n* distinct amplitude levels etc.



Binary pulse train

2. Deterministic and Random Signal

Let us consider a signal expressed as a function of t by,

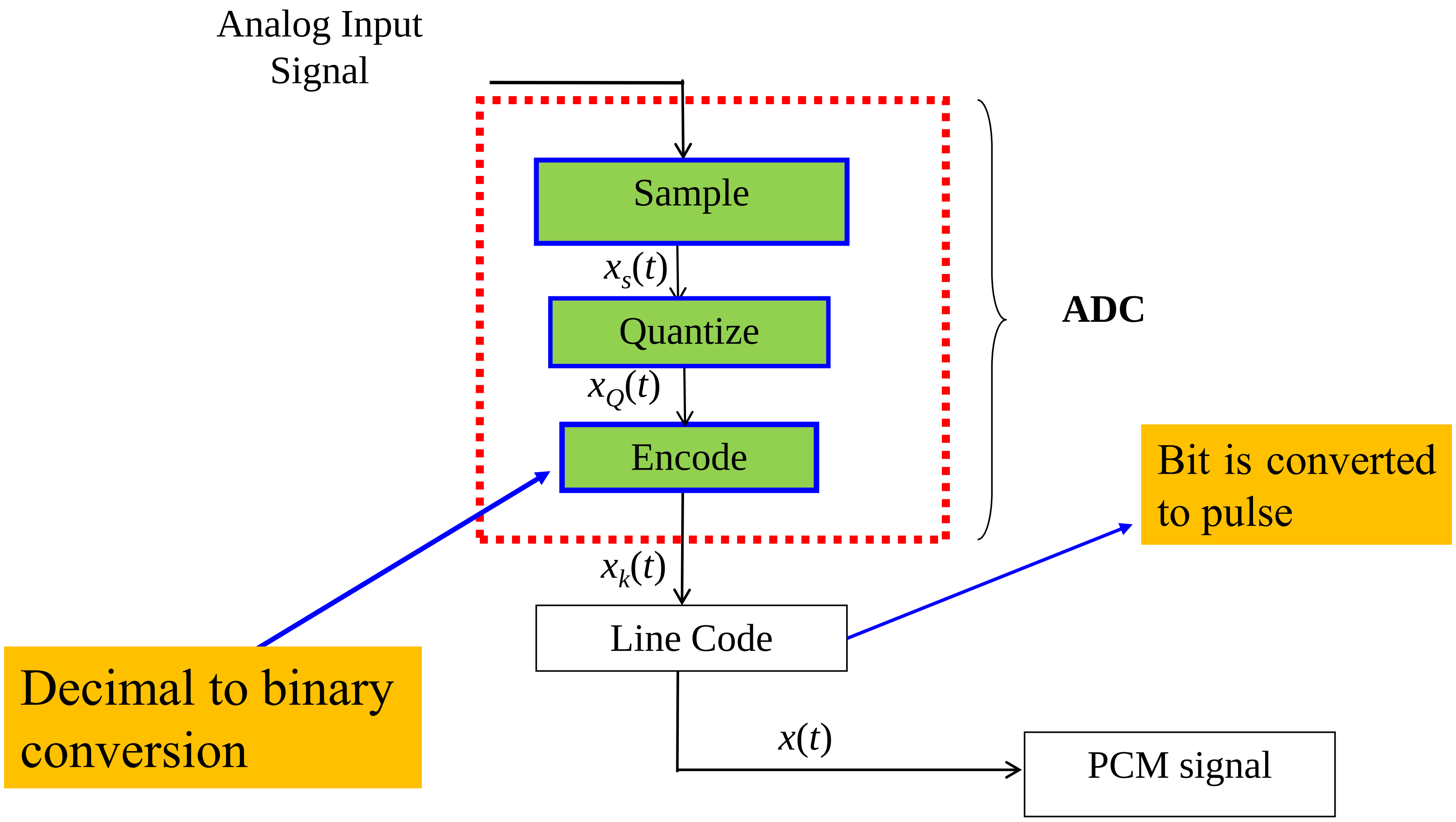
$$x(t) = 3e^{-0.5t} + 2\cos(2\pi f t + \varphi)$$

The amplitude of the signal at any instant τ can be determine, putting $t = \tau$ in above equation. Therefore the amplitude of the signal is known at any instant. Anyone can tell the amplitude of the signal before its occurrence. Such signal is called **deterministic signal**. Similarly for a discrete time signal, a sequence is deterministic if its equation is known.

- ✓ On the other hand amplitude of a **random signal** can’t be determined before its occurrence; such signal is random in nature. Random signal can’t be expressed by a mathematical equation directly but can be predicted based on **probability density function** (pdf).

- ✓ For example, thermal noise in devices, fading in wireless channel, additive white Gaussian noise (awgn) in a communication link, offered traffic of a network etc.

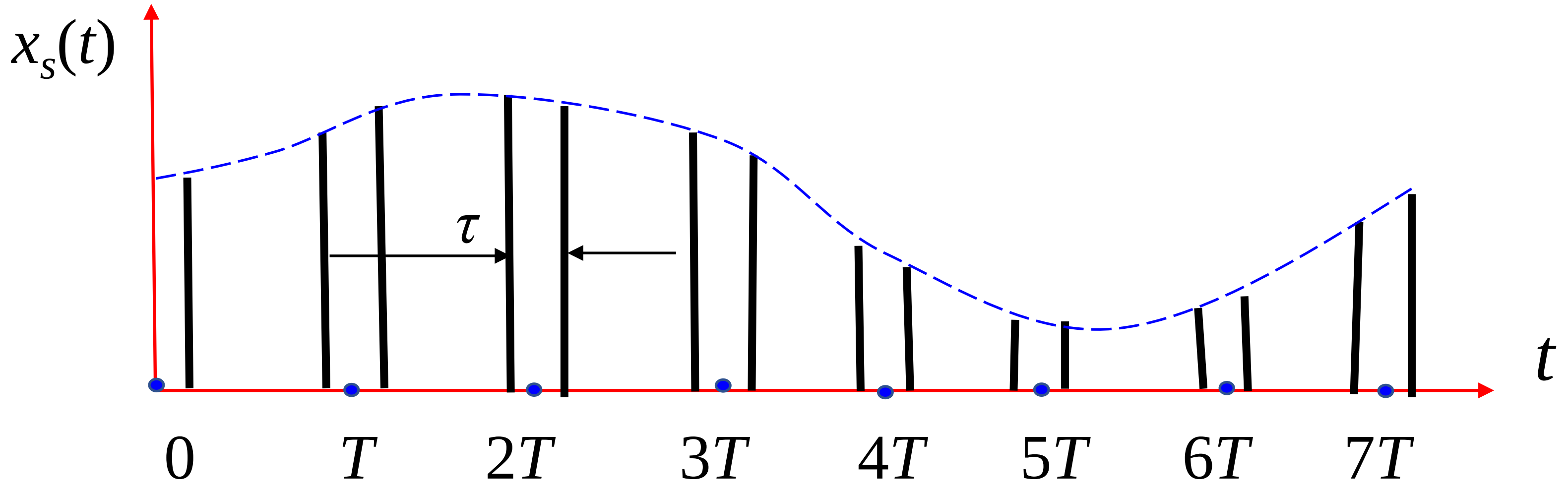
Analog to Digital Conversion



1. Sampling of Continuous Time Signal

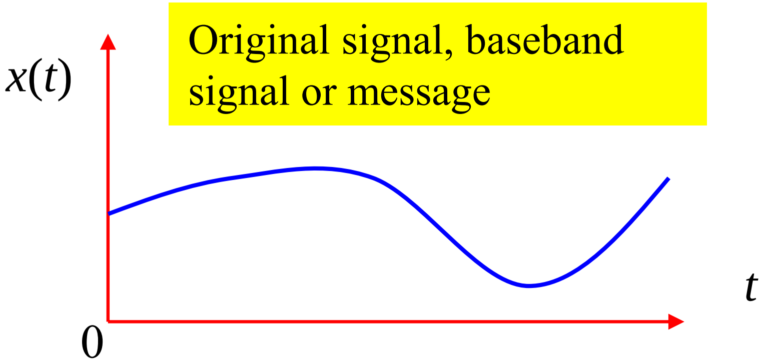
✓First step of analog to digital conversion is the periodic sampling of continuous analog signal.

✓Consider an analog signal $x(t)$ is sampled with period T (sampling frequency, $f_c = 1/T$ samples/sec). The width of each sample is τ shown in fig. below.

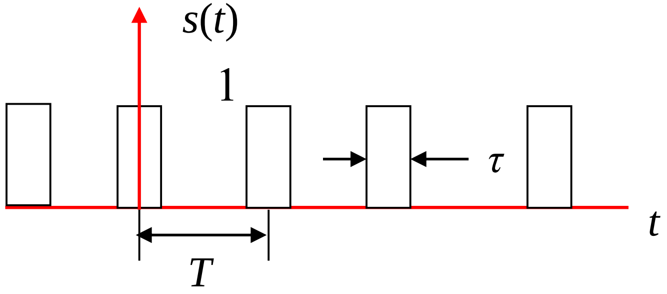


Sampled signal

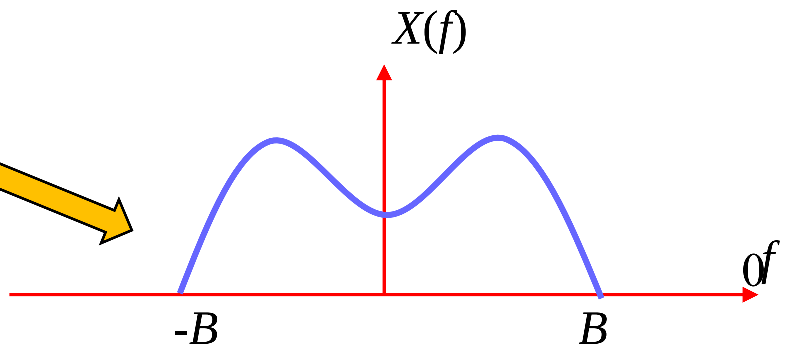
The sampled signal $x_s(t)$ can be expressed as the product of $x(t)$ and a unit amplitude pulse train $s(t)$ of period T and width of each pulse of τ shown in fig.(c). Sampled form $x_s(t)$ of $x(t)$ is shown in fig.(d).



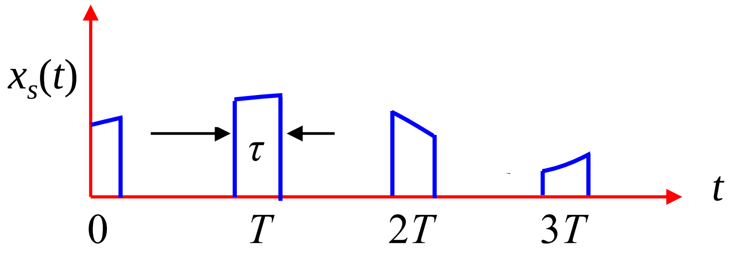
(a) Continuous base band signal



(b) Unit amplitude pulse train

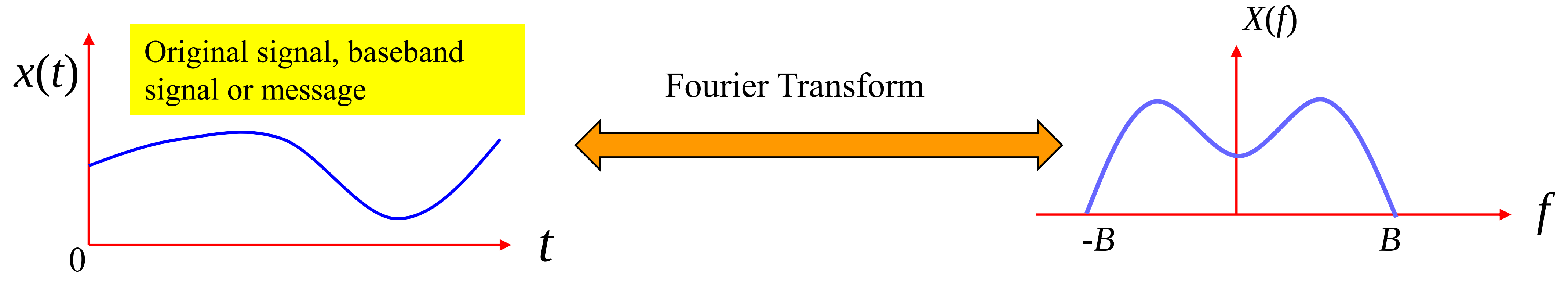


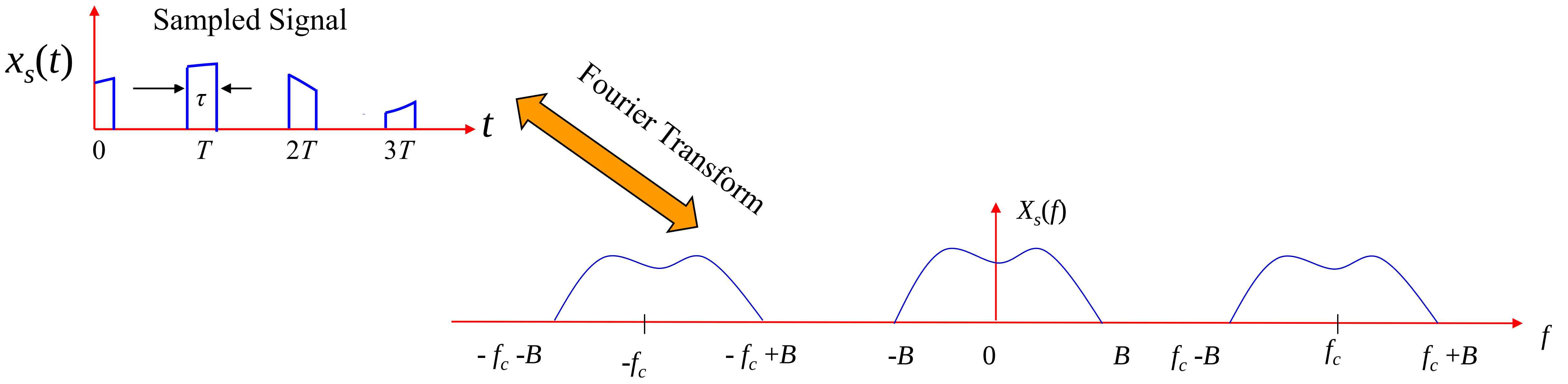
(e) Spectrum of $x(t)$



(d) Sampled signal

Spectrum?





T, Sampling period $\quad f_c = 1/T$, Sampling frequency

Nyquist sampling criteria:

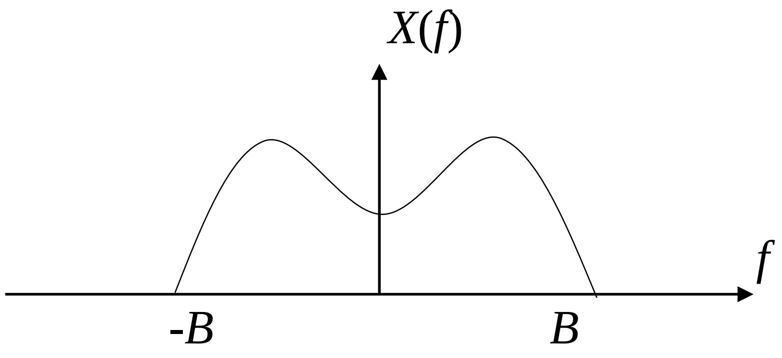
The sampling frequency of a baseband signal should be at least twice of its highest frequency to recover the baseband signal from the sampled signal.

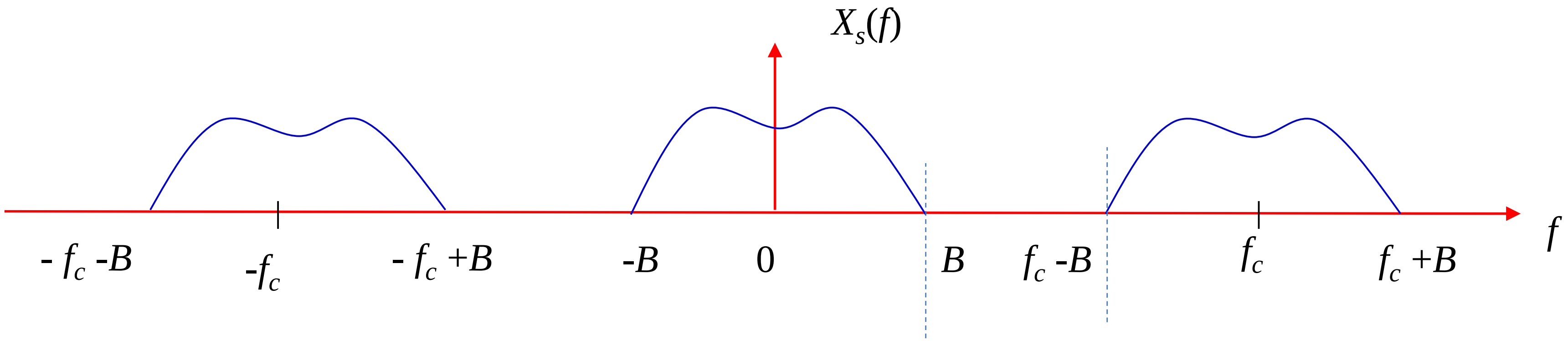
Example:

An analog signal of highest frequency of B = 3.4 KHz sampled maintaining a guard band of 1200Hz, find sampling rate f_c and sampling period T.

The sampling rate (or frequency), $f_c = G.B+2B = 1.2+2\times3.4 = 8\ KHz$

Sampling period, $T = 1/f_c = 1/(8*1000)$
$= 0.125\times10^{-3}$ sec = 0.125 ms

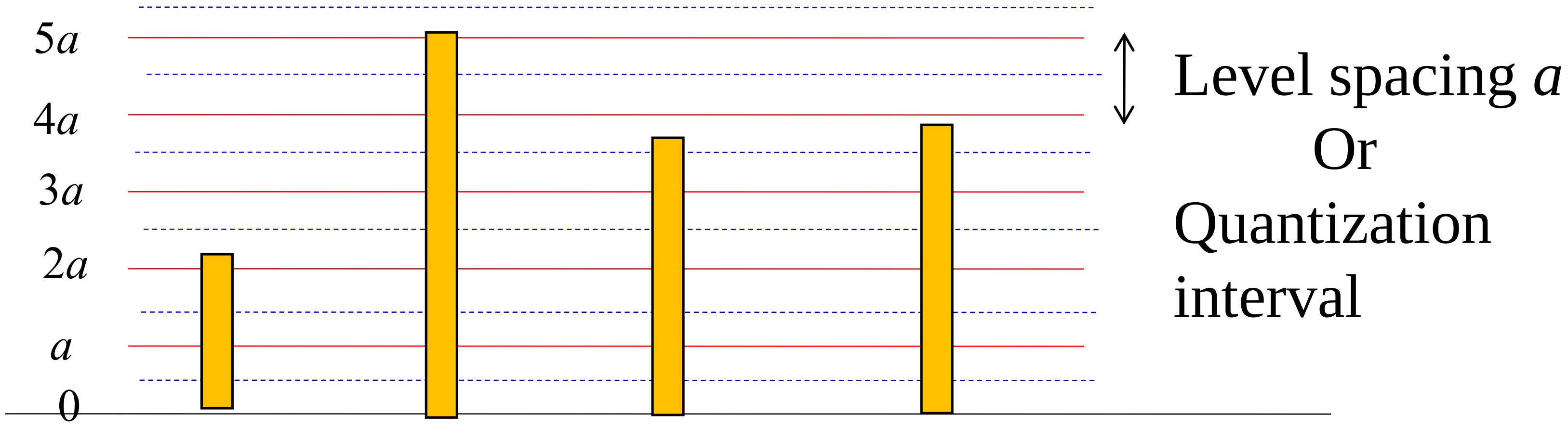




2. Quantization of Sampled Signal

✓ Second step of digitations of an analog signal is quantization (the amplitude of a sample is adjusted with its nearest discrete level) of sampled signal into some known discrete amplitude levels.

✓Due to quantization the signal losses its originality and an error is introduced with the signal known as quantization error.



How quantization is done and what its impact on received signal?

3. Pulse Code Modulation

- ✓ Pulse Code Modulation (PCM) is essentially final step of analog to digital conversion where each quantized sample in converted to equivalent binary pulses, resembles to decimal to binary conversion.

Fig. 8(a) Quantized sample of 8 levels quantization

N = 8

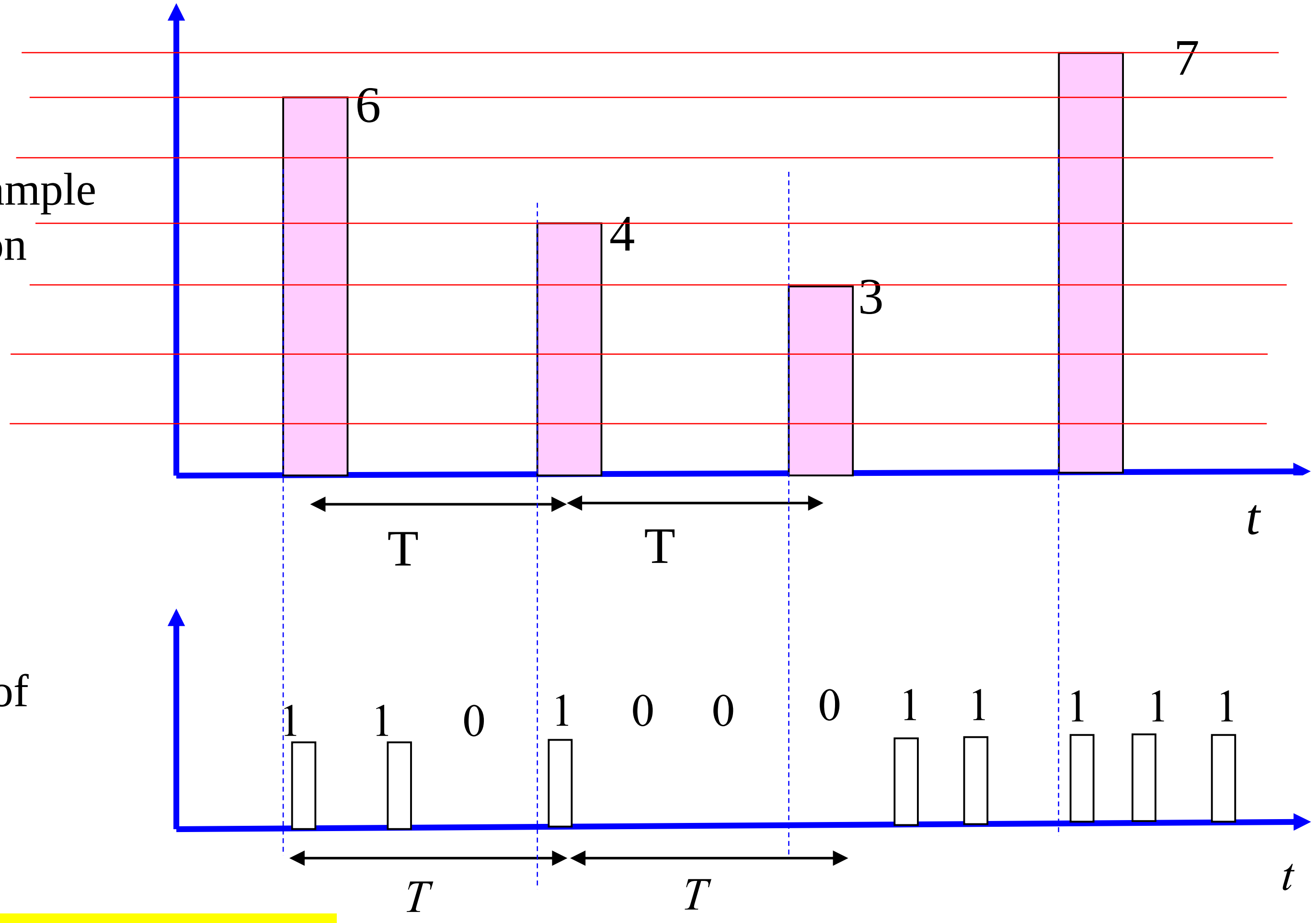
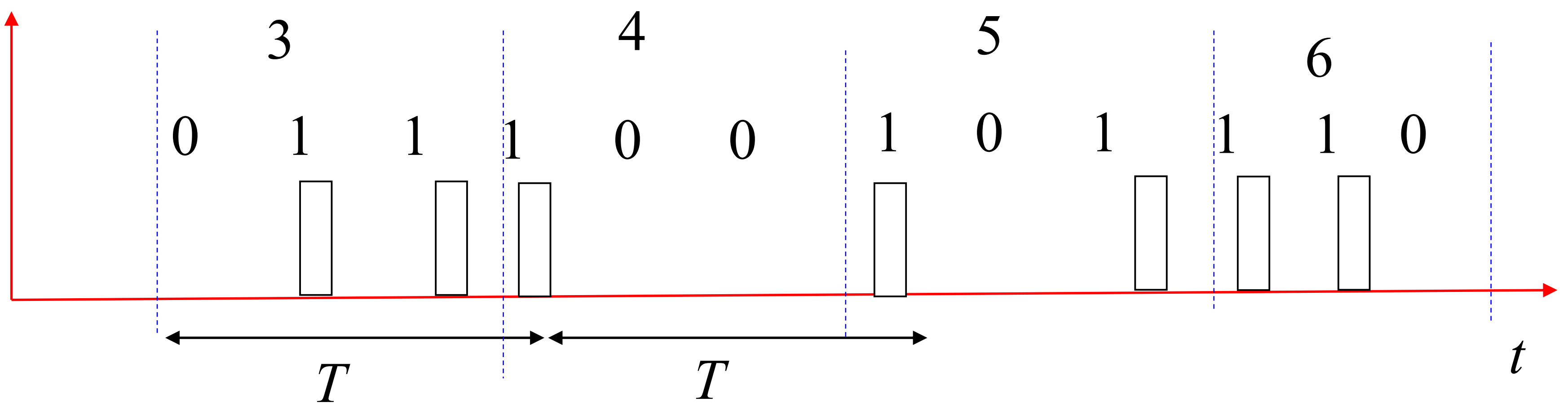


Fig.8(b) PCM data of fig. 8(a)

Show PCM technique with diagram.

- ✓ Fig.8 show 8 levels PCM technique. In PCM Gray code is preferable compare to ordinary binary code to combat variable number of bit error for adjacent levels like 3 and 4, 7 and 8 etc. when sampled pulses are transmitted directly.

- ✓ In Gray code there is only one bit difference between adjacent decimal numbers hence there is only possibility of single bit error per sample instead of variable number of bit error during reception of each sample.



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

PAM, PWM and PPM

✓In all of above pulse modulation techniques unit amplitude pulse train is used as carrier wave.

✓In pulse **amplitude** modulation (**PAM**) the amplitude of the carrier pulses are made proportional to instantaneous amplitude of continuous base band signal $x(t)$ shown in fig.11.

✓In pulse width modulation (**PWM)** the **width** (or time) of a pulse is proportional to the instantaneous amplitude of continuous base band signal.

✓In pulse position modulation (**PPM)** the **position** of the pulse i.e. distance from a reference instant is proportional to the instantaneous amplitude of continuous base band signal.

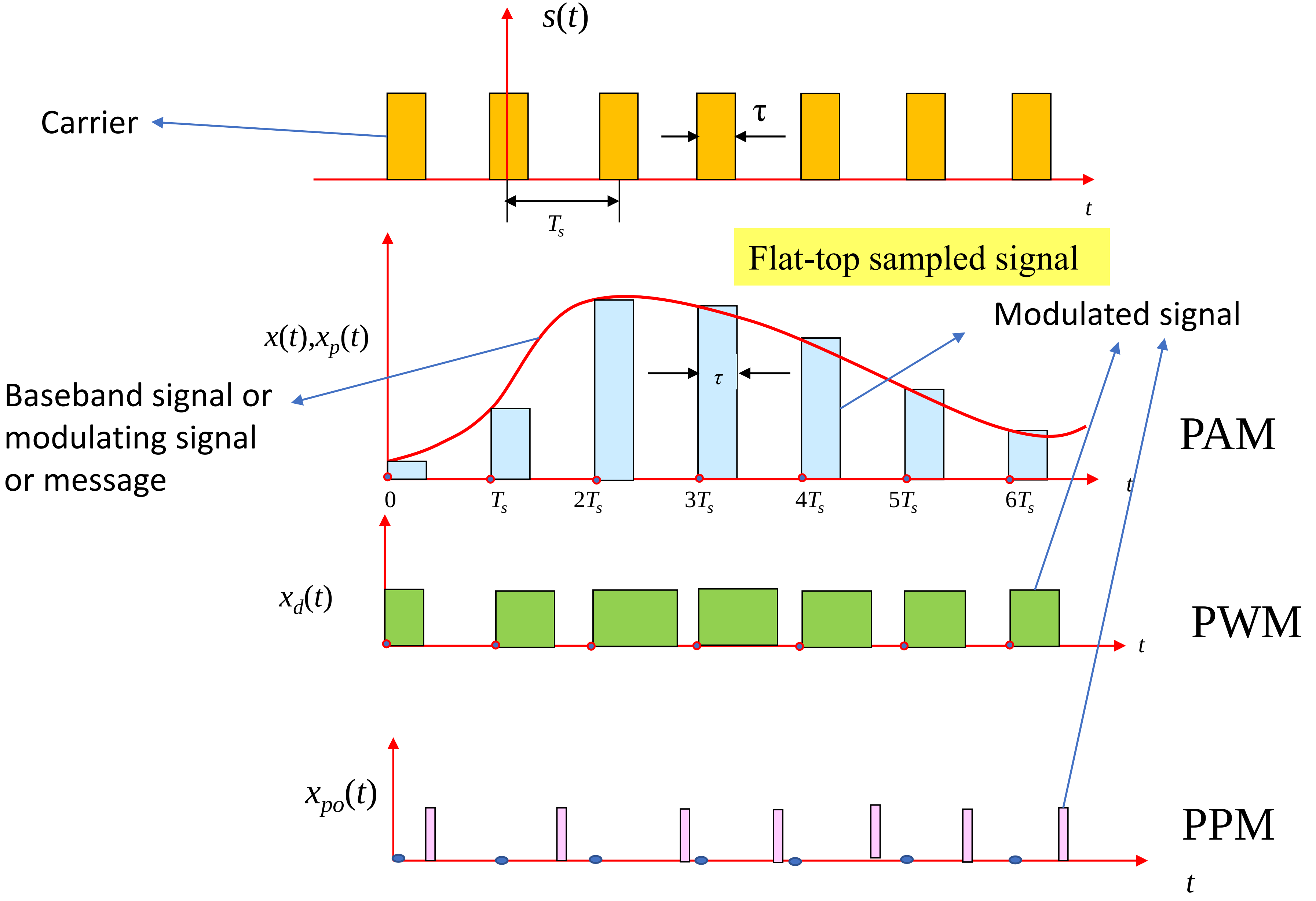


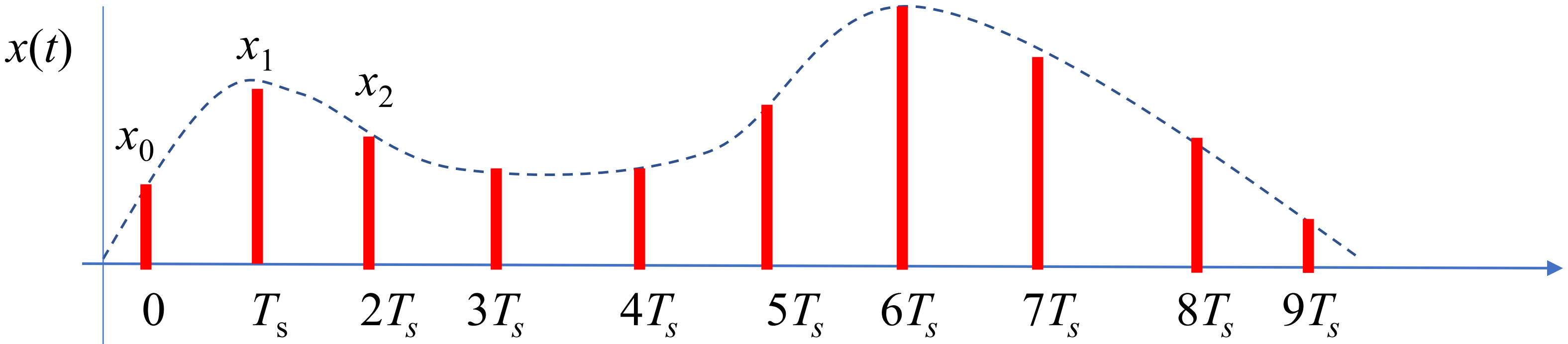
Fig. 11 PAM, PWM and PPMwave

Differential Pulse Code Modulation (DPCM)

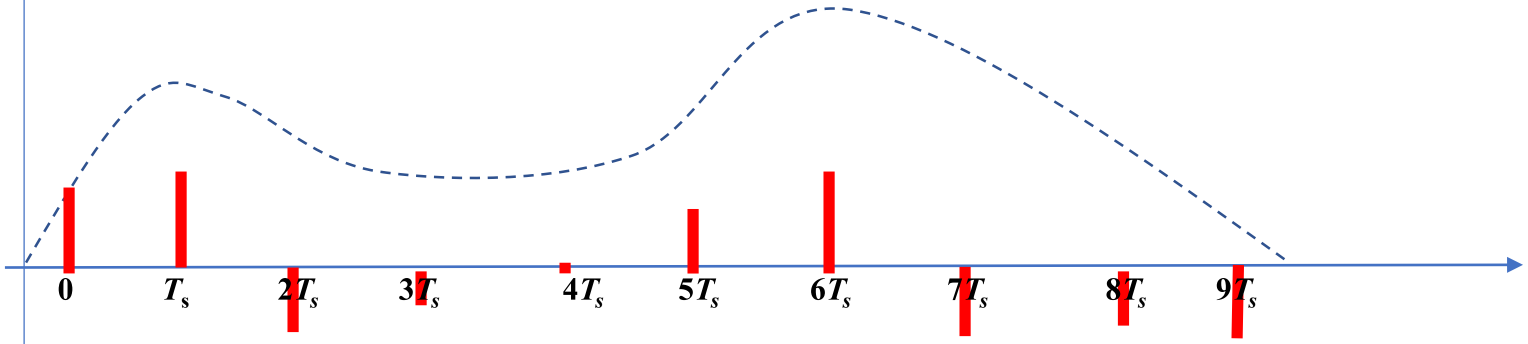
- ✓ It is found that average amplitude of sample to sample difference is less than that of original sampled wave of voice signal therefore less number bit is required for PCM, maintaining same SQR.

- ✓ If PCM is done on consecutive pulse difference instead of individual pulse known as ***Differential Pulse Code Modulation*** (DPCM). When sample to sample difference is expressed by a single bit ($+k$ or $-k$) then the modulation scheme is called ***delta modulation*** is considered as an special case of DPCM.

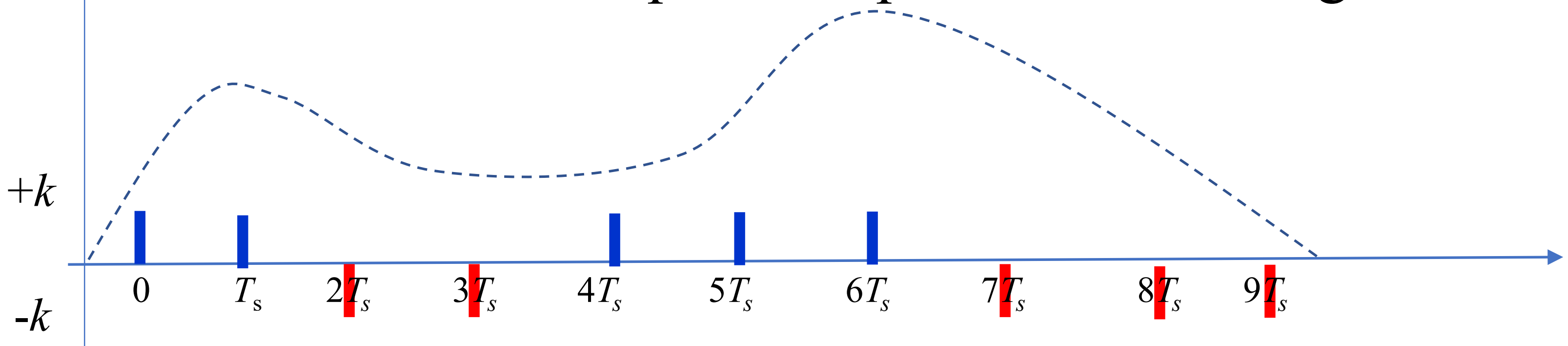
স্যাম্পলের Amplitude বা উচ্চতা যত বড় হয় তার জন্য কোয়ান্টাইজেশন লেভেলের সংখ্যা ও তত বেশি লাগে; একই সাথে প্রতিটি স্যাম্পলের জন্য বেশি সংখ্যক বিট লাগে । যেমন কোয়ান্টাইজেশন লেভেলের সংখ্যা ১৬ হলে প্রতি স্যাম্পলের জন্য চারটি করে বিট লাগে, কোয়ান্টাইজেশন লেভেলের সংখ্যা ৩২ হলে প্রতিটি স্যাম্পলের জন্য পাঁচটি করে বিট লাগে, কোয়ান্টাইজেশন লেভেলের সংখ্যা ৬৪ হলে প্রতিটি স্যাম্পলের জন্য ছয়টি করে বিট লাগে ইত্যাদি ।



Sampling of analog signal



PCM of above samples will provide DPCM signal



Delta Modulation of above samples

Line coding

Binary data (logic 0 or 1 of PCM) can be transmitted using a number of different types of serial pulses. **The choice of a particular pair of pulses to represent the symbols 1 and 0 is called Line Coding.** Line coding can be represented by the diagram of fig. below.

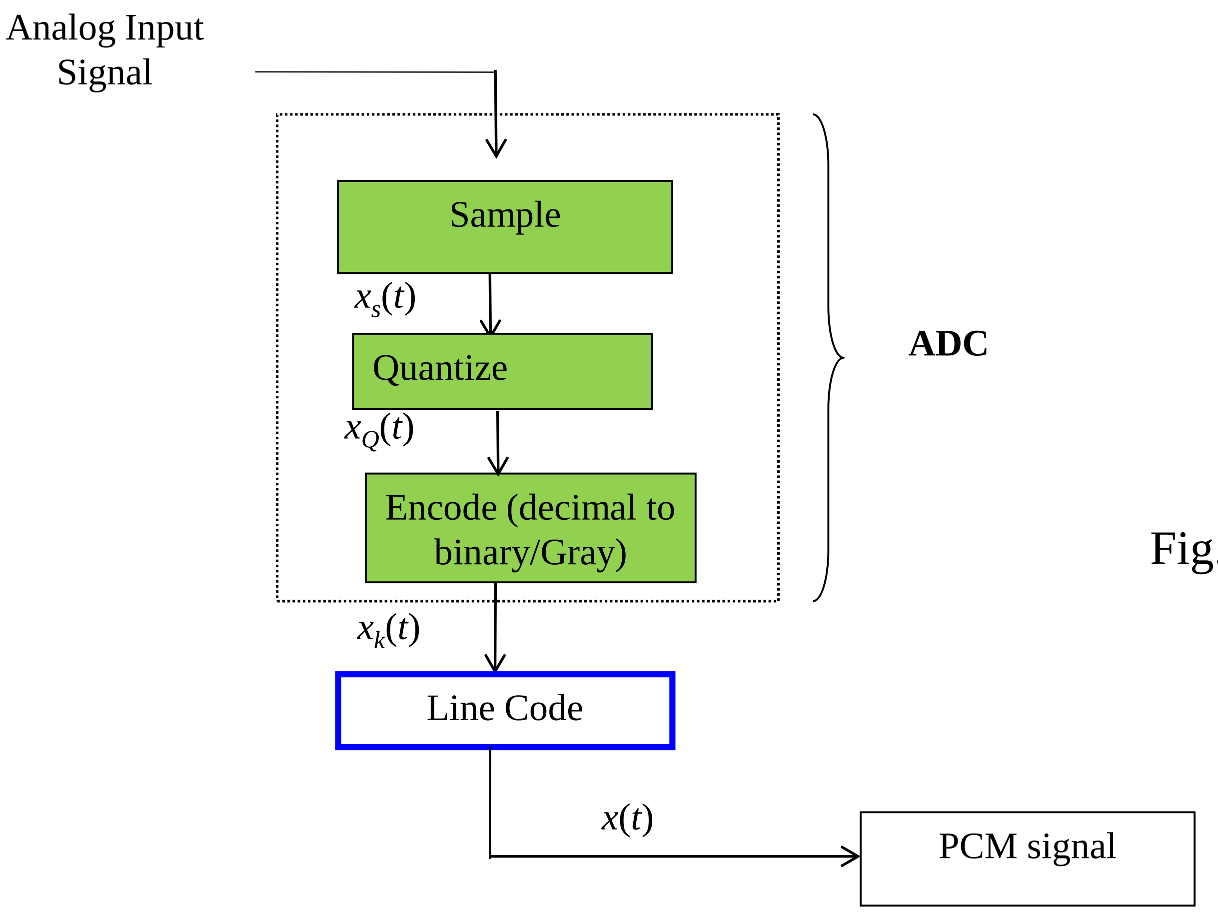
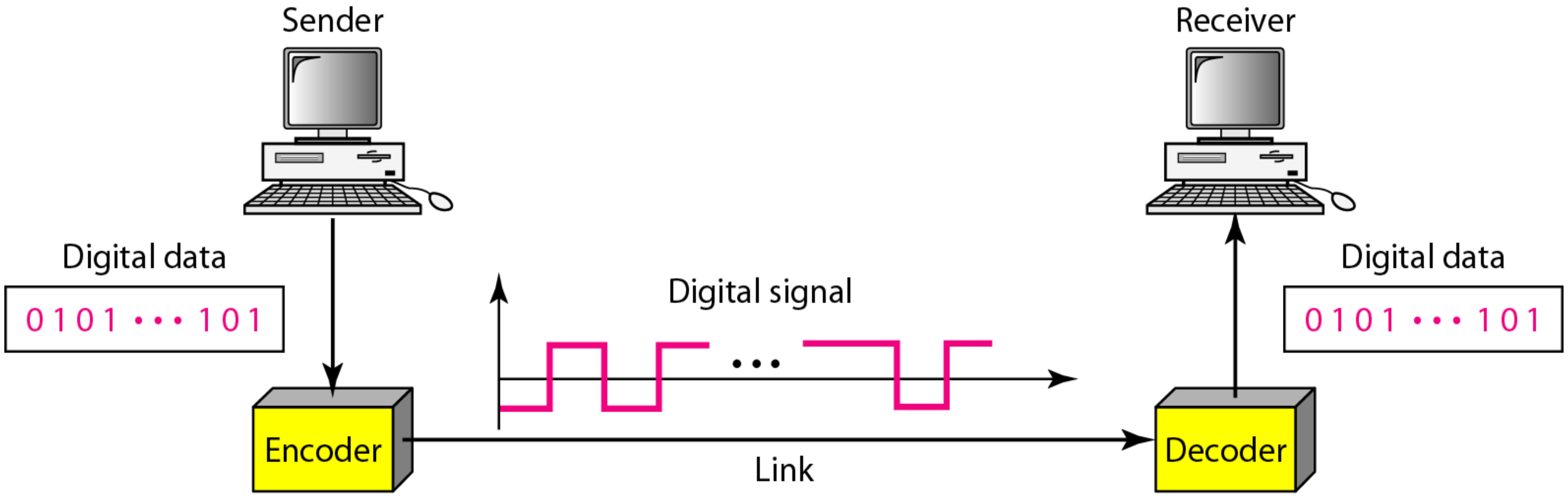


Fig. Line coding



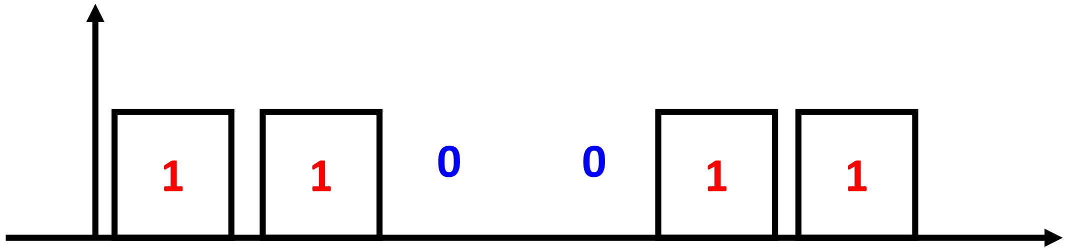
Line coding and decoding

Line code can be classified based on symbol mapping functions (a_k) like,

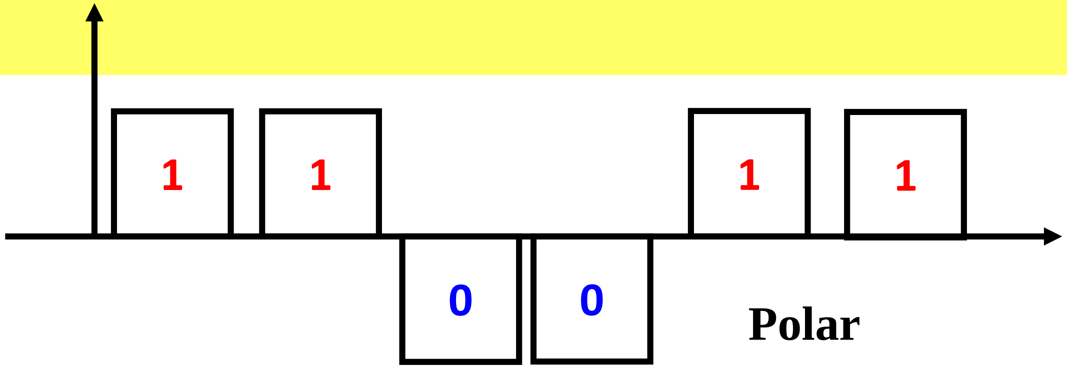
Unipolar: In unipolar signalling binary symbol 0 is represented by the absence of a pulse called space and the other binary symbol 1 is represented by the presence of a pulse called mark. It is also called on-off keying.

Polar: In polar signalling a binary 1 is represented by a pulse $p(t)$ and a binary 0 by the opposite (or antipodal) pulse $-p(t)$.

Bipolar: Bipolar Signalling is also called '**alternate mark inversion**' (AMI) which uses three voltage levels ($+V$, 0, $-V$) to represent binary symbols. Zeros, as in unipolar, are represented by the absence of a pulse and ones (or marks) are represented by alternating voltage levels of $+V$ and $-V$.



Unipolar

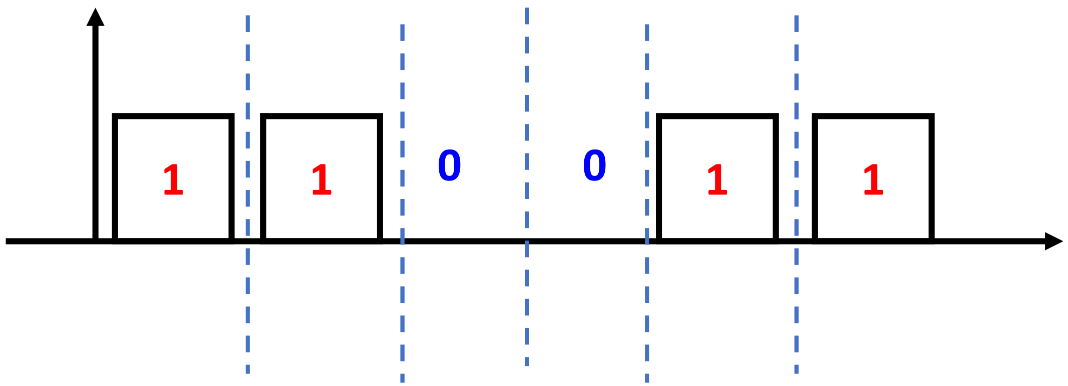


Line code can again be classified based on pulse shapes $p(t)$ like,

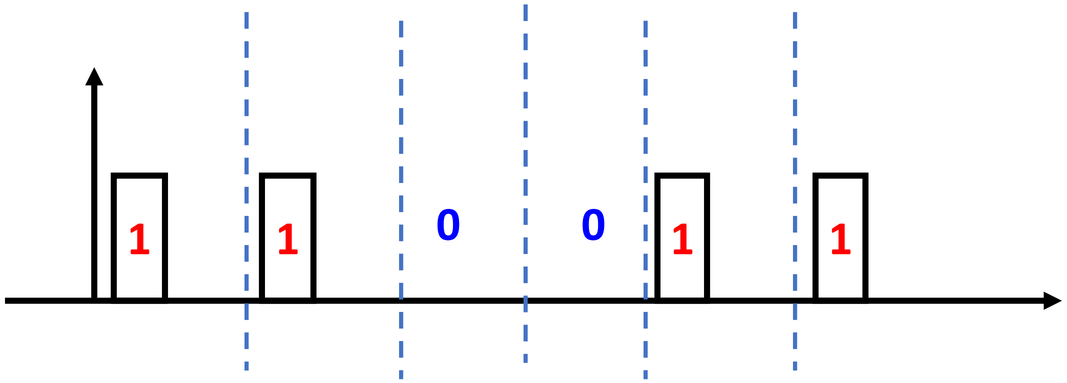
NRZ (Nonreturn-to-zero): The pulse occupies the full duration of a symbol.

RZ (Return to Zero): The pulse occupies the half of duration of a symbol.

Manchester (split phase): In Manchester encoding, the duration of the bit is divided into two halves. The voltage remains at one level during the first half and moves to the other level during the second half. Binary logic 1 is +ve in 1st half and -ve in 2nd half. Binary logic 0 is -ve in 1st half and +ve in 2nd half.



NRZ



RZ

According to above classification different types of line coding is shown in fig. below.

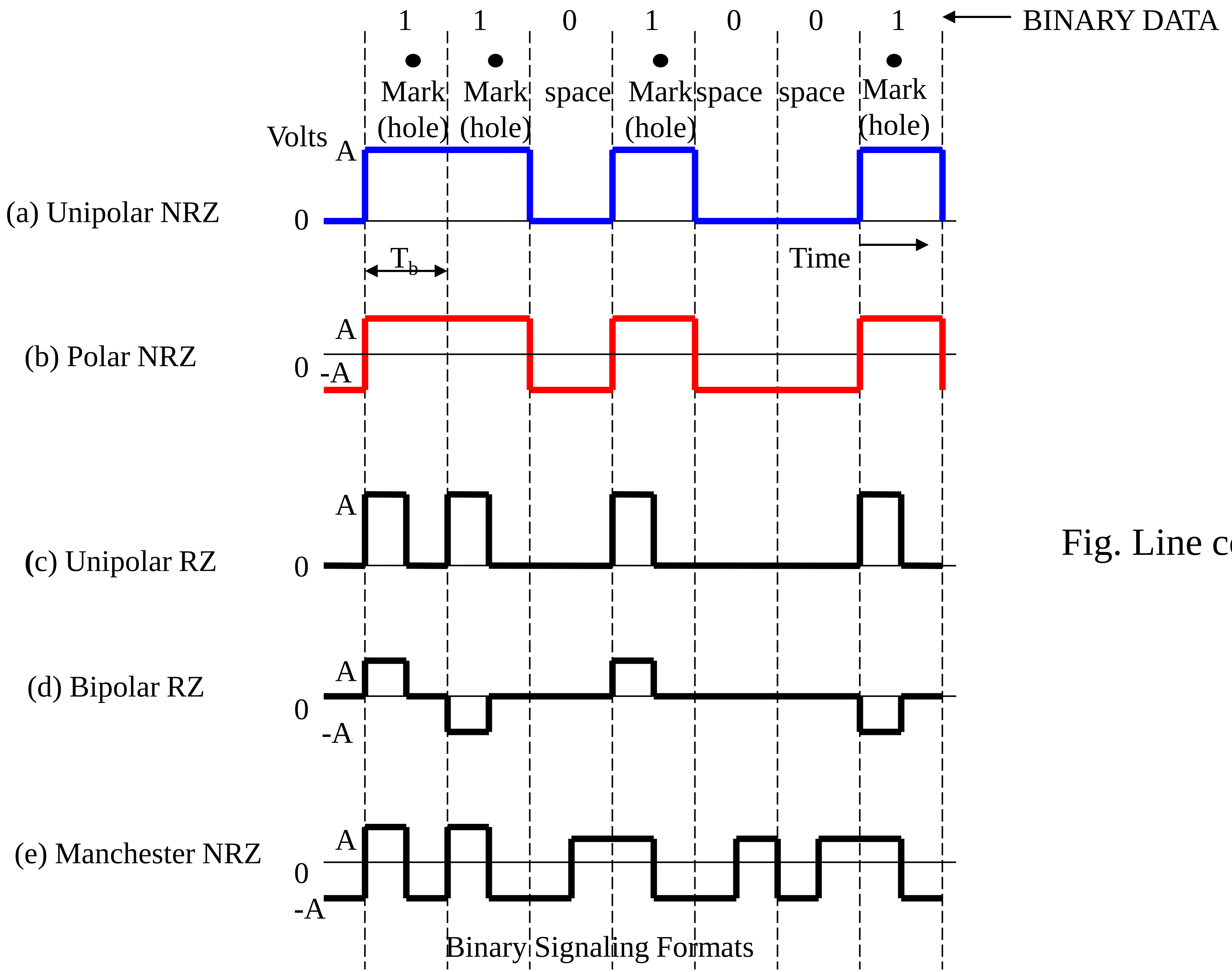


Fig. Line coding

Scrambling Technique

- In data communication long sequence of 0 is replaced by combination of other levels to provide synchronization called **Scrambling Technique**. It must satisfy:
  - Must be recognized by receiver and replace with original
  - Same length as original
  - Error detection capability

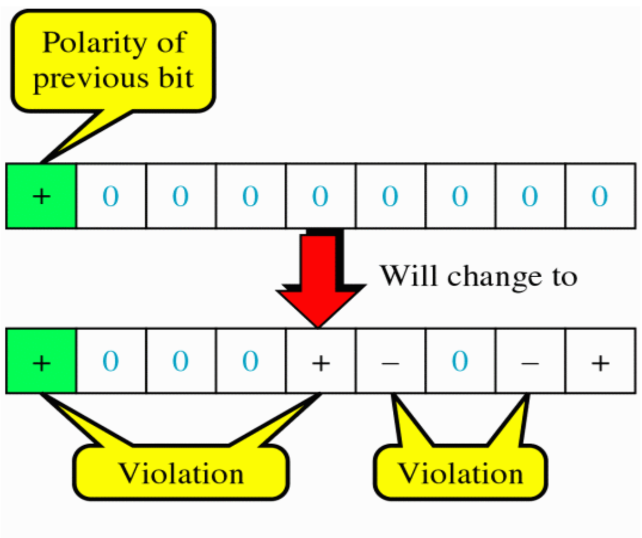
Two commonly used techniques are:

B8ZS (Bipolar With 8 Zeros Substitution), and **HDB3 (High Density Bipolar 3 Zeros)**

Used for long distance transmission (WAN)

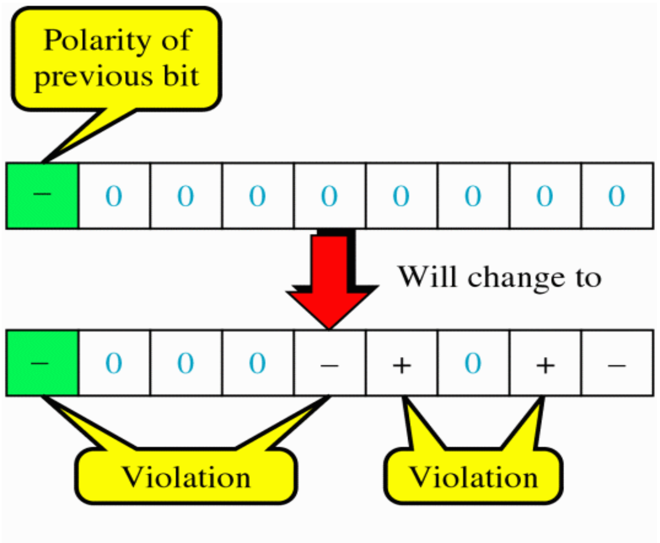
Bipolar With 8 Zeros Substitution (B8ZS)

- 8 consecutive bits of all zeros are replaced by **000VB0VB** where B is called **bipolar** pulse i.e. nonzero level voltage in accordance with AMI rule. The V in the sequence denotes **violation** i.e. nonzero voltage breaks the AMI rule.
- If the preceding is positive, encode as **000 + - 0 - +** again if the preceding was negative, encode as **000 - + 0 + -**
- Causes two violations of AMI code - intentional
  - Unlikely to occur as a result of noise
- Receiver detects and interprets as octet of all zeros



(a)

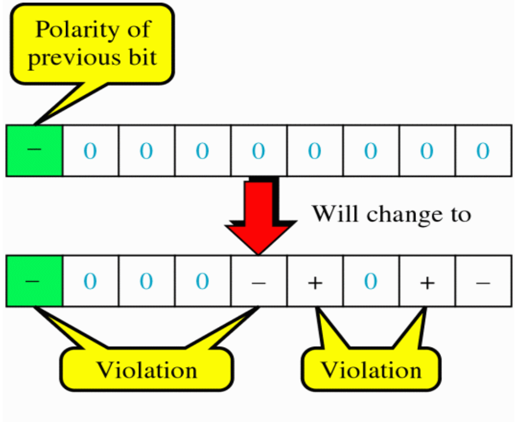
000VB0VB



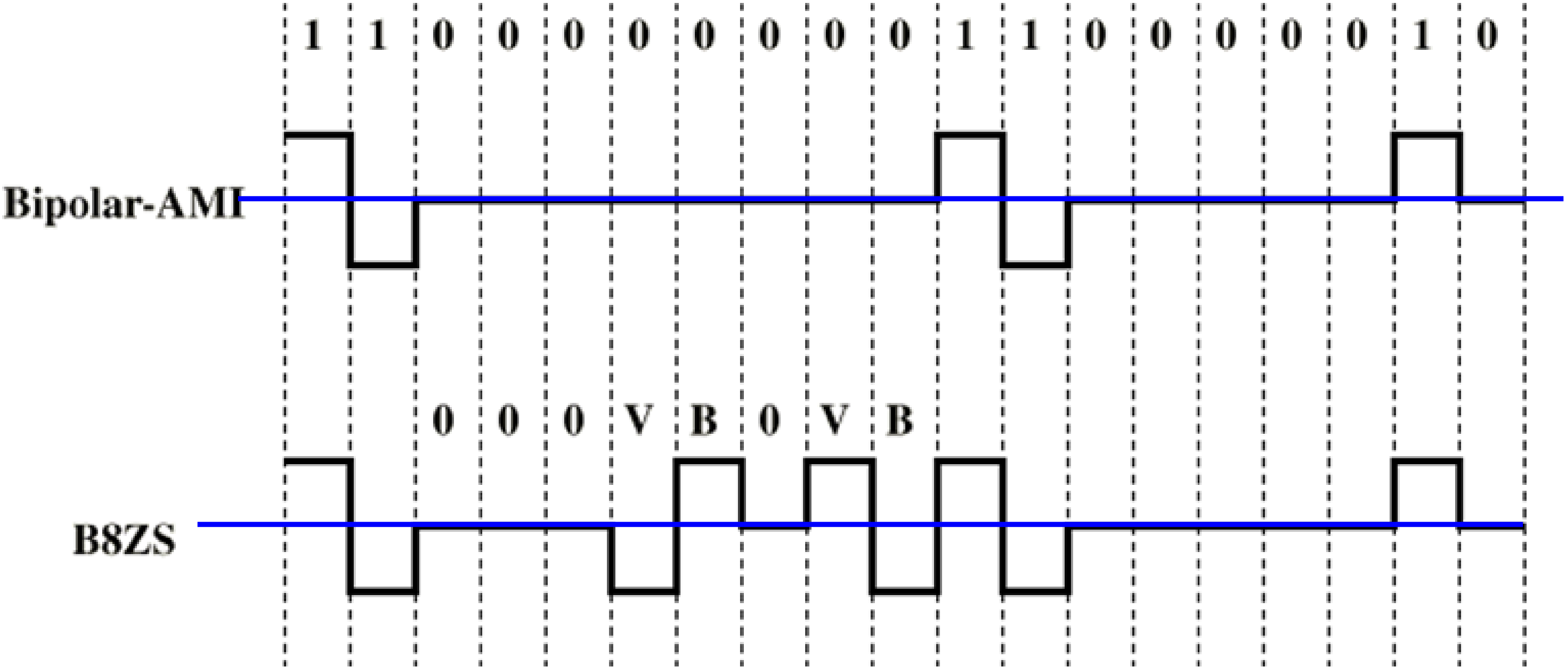
(b)

Example-1

0 0 0 V B 0 V B



(b)



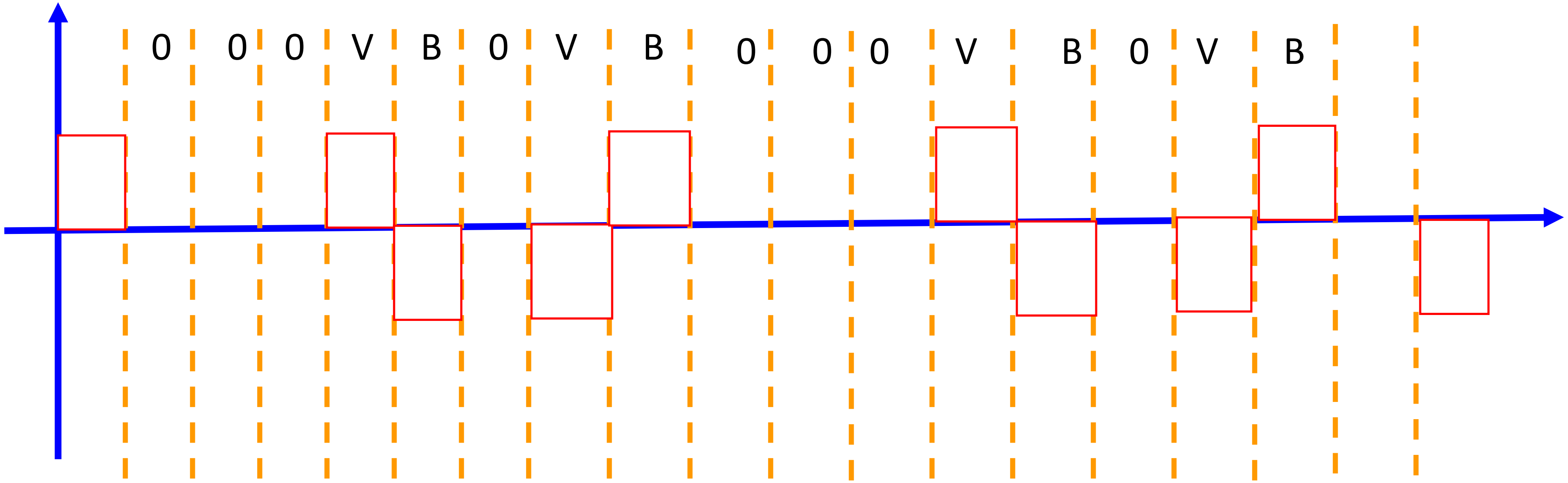
0 0 0 V B 0 V B

+ve

0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 1 0 1 0

0 0 0 V B 0 V B 0 0 0 V B 0 V B

0 0 0 + - 0 - + 0 0 0 + - 0 - +



HDB3 (High Density Bipolar 3 Zeros)

There are four rules for HDB3 coding.

I. More than three consecutive zeros are not allowed to be present in the waveform. For the fourth ‘0’ introduce a Violation bit.

II. Violation bit has to be of the same polarity as the previous mark.

III. Two consecutive violation bits has to be of opposite polarity.

IV. If the number of marks after last substitution is **even** the format should be **B00V** (**+00+ or −00−**) where B is called **bipolar** pulse i.e. nonzero level voltage in accordance with AMI rule. The V in the sequence denotes **violation** i.e. nonzero voltage breaks the AMI rule. It is opposite polarity to the previous mark. If the number of marks is an **odd** number the format should be **000V** (**000+ or 000−** **).**

Example-1

HDB 3 coding of 0000_2

Number of marks after last substitution	Pattern	Previous pulse	Coded
Odd	000V	+	000+
		−	000−
Even	B00V	+	−00−
		−	+00+

The pattern of bits (initially consider odd 1s after last substitution) and the first 1 is +ve:

101 **0000** 1**0000** 1 1**0000**1 1 1**0000**1 1 1 1**0000** 10 1**0000**$_2$

Encoded in HDB3 considering odd parity at the starting is:

1 0 1000V1000V1 1B00V1 1 1000V1 1 1 1B00V101 B00V

+ 0− 000 -+000 +−+- 00 - +−+ 000+−+−+ - 00- + 0 − + 0 0+

Corresponding encoding using AMI is

+0−0000+0000−+0000− + − 0000+ − + −0000+0−0000

Even→B00V

Odd→000V

Example-2

0 1 1 0 0 0 0 0 1 1 0 1 0 0 0 0 0 0 0 0 0 1 0

Provided number of 1s after last substitution is even and the first 1 is +ve pulse.

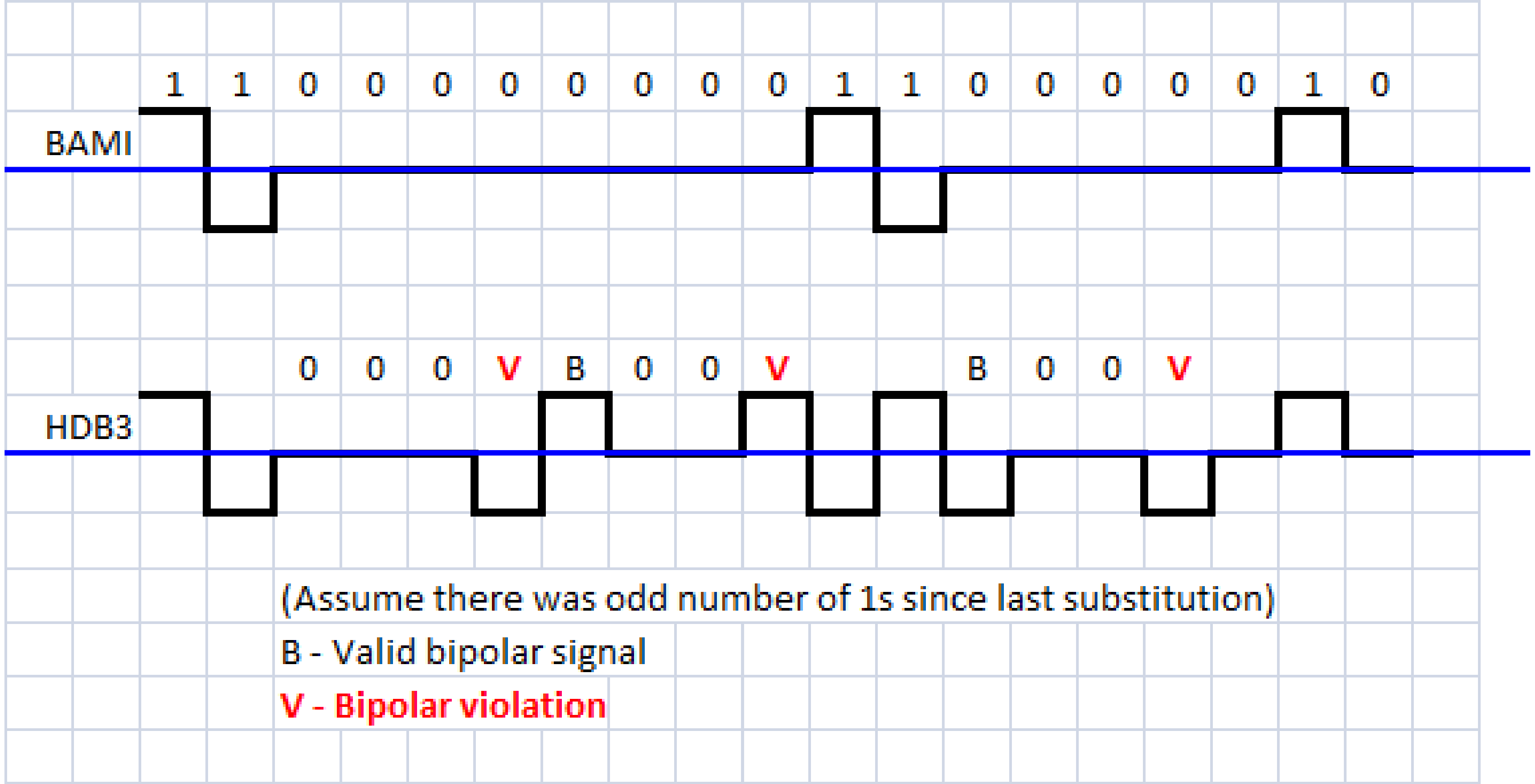
0 1 1 0 0 0 0 0 1 1 0 1 0 0 0 0 0 0 0 0 0 1 0

0 1 1 B 0 0 V 0 1 1 0 1 0 0 0 V B 0 0 V 0 1 0

0 + - + 0 0 + 0 - + 0 - 0 0 0 - + 0 0 + 0 - 0

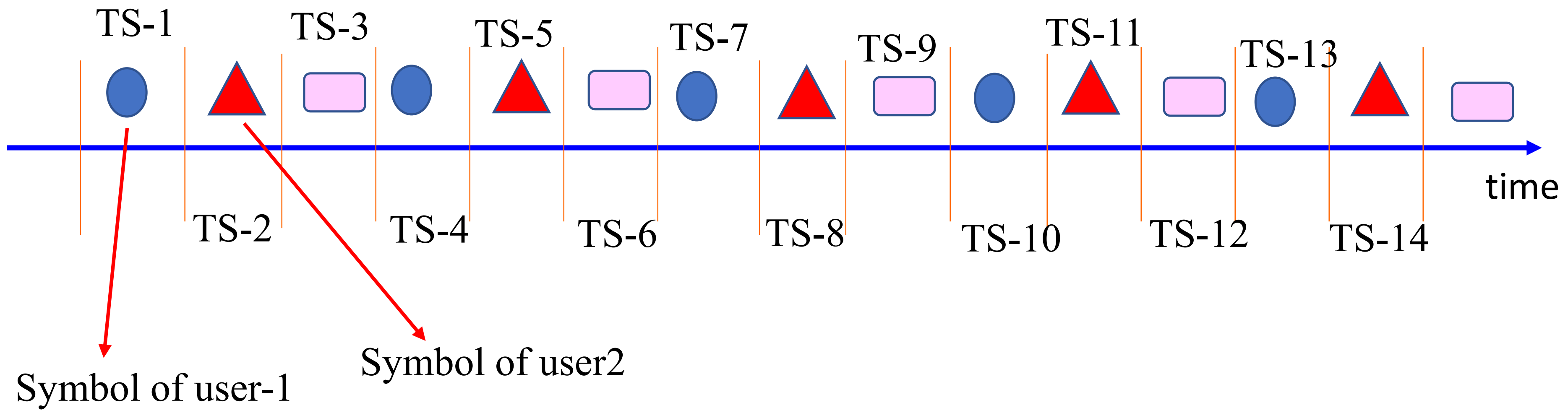
Example-3

Odd → 000V **Even → B00V**

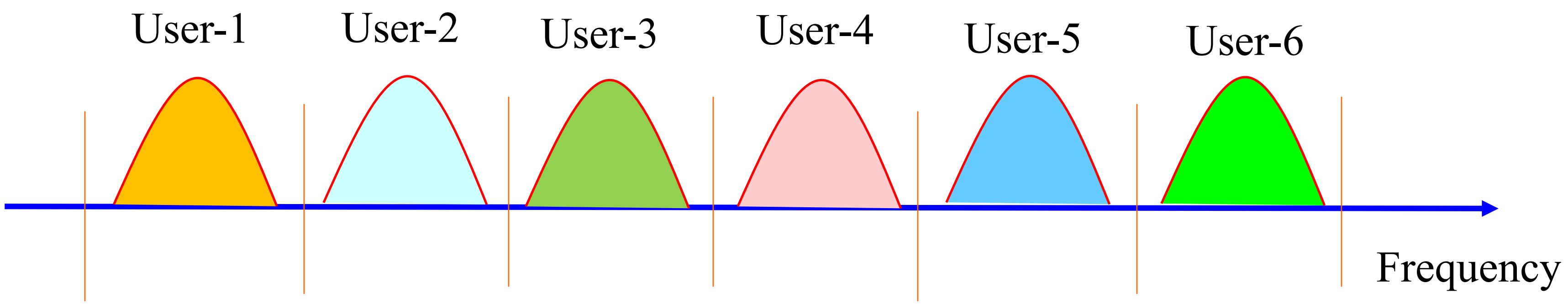


Multiplexing Techniques

In multiplexing several physical channel (**small time-slot** or **bandwidth)** are combined to form a channel of high bit /symbol rate or wide bandwidth. It allows simultaneous transmission of multiple signal across a single data link.



Each TS is a physical channel can accommodate a symbol from a user



Each BW is a physical channel can accommodate a signal from a user

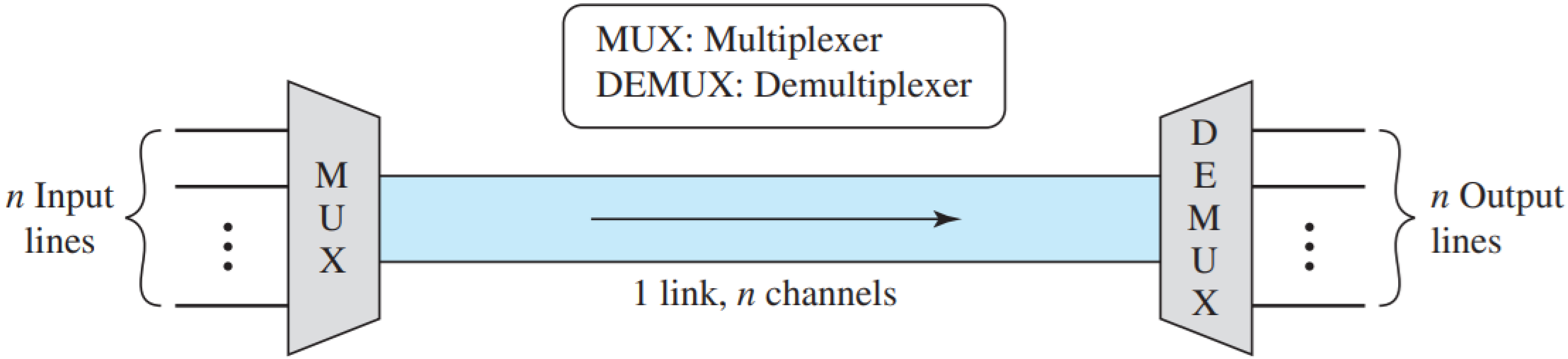
Multiplexing is process to combine **multiple** signal to transmit through a single channel or media.

Multiple access means many (several terminals) can **access** at on the same transmission medium, where each user/node/terminal shares the medium in the form of physical channel (TS, BW, code etc.). **Multiple access is the application of multiplexing**.

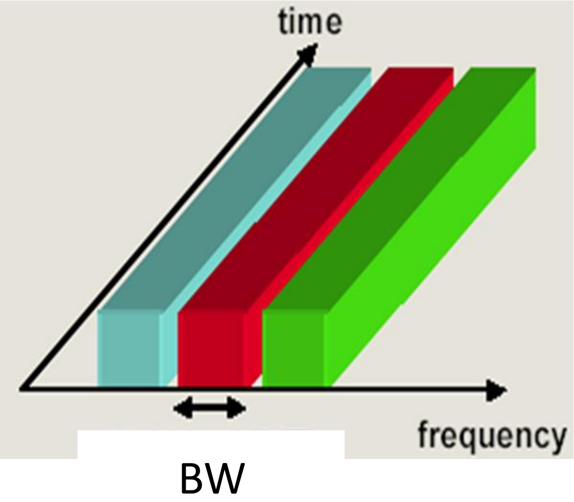
Most widely used multiple access are:

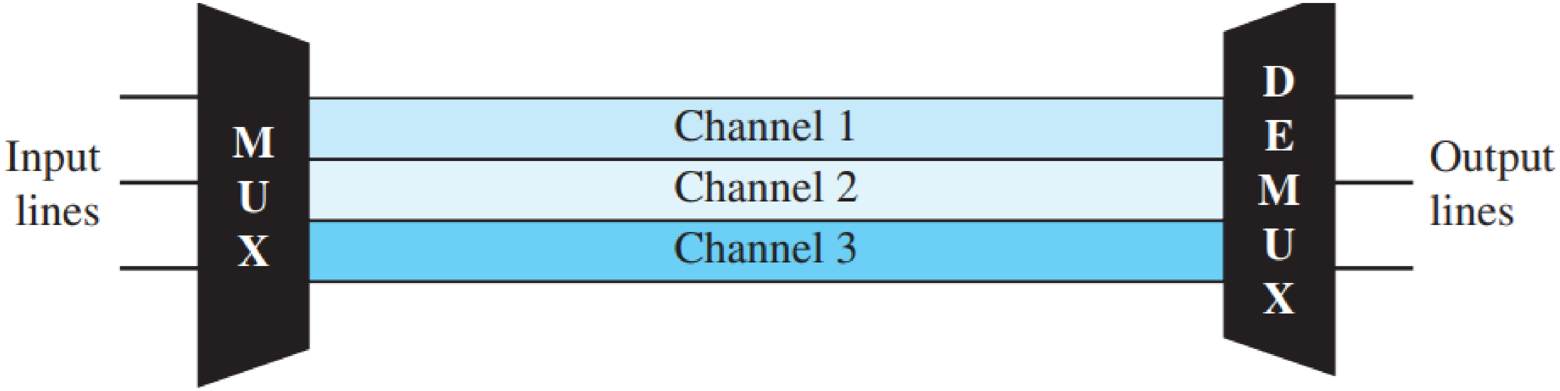
Frequency Division Multiple Access (FDMA)
Time Division Multiplexing (TDM)
Code Division Multiple Access (CDMA)
Orthogonal Frequency Division Multiple Access (OFDMA)
Wavelength Division Multiplexing (WDM)

At receiving end signals are separated by a technique called De-multiplexing.



Frequency Division Multiplexing (FDM)

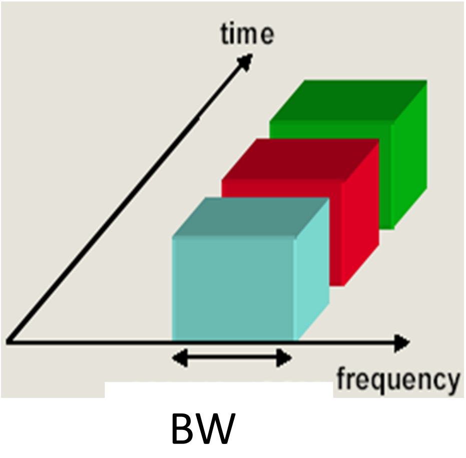


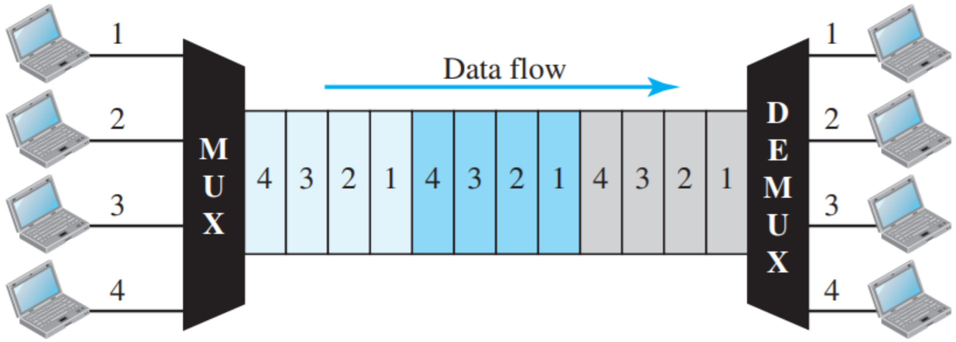


- ✓ In frequency-division multiple access (FDMA), the available bandwidth is divided into frequency bands. Each station is allocated a band to send its data. In other words, each band is reserved for a specific station, and it belongs to the station all the time.
- ✓ Each station also uses a bandpass filter to confine the transmitter frequencies. To prevent station interferences, the allocated bands are separated from one another by small guard bands.

Time Division Multiplexing (TDM)

In time-division multiple access (TDMA), the stations share the bandwidth of the channel in time. Each station is allocated a time slot during which it can send data.

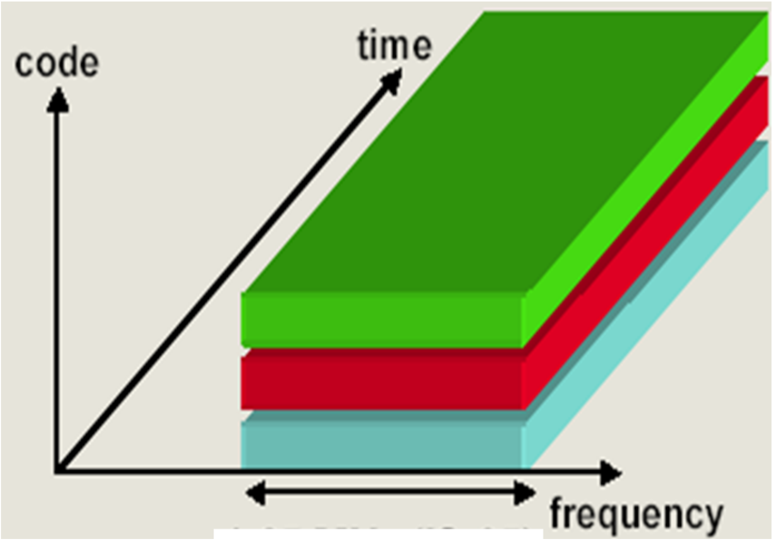




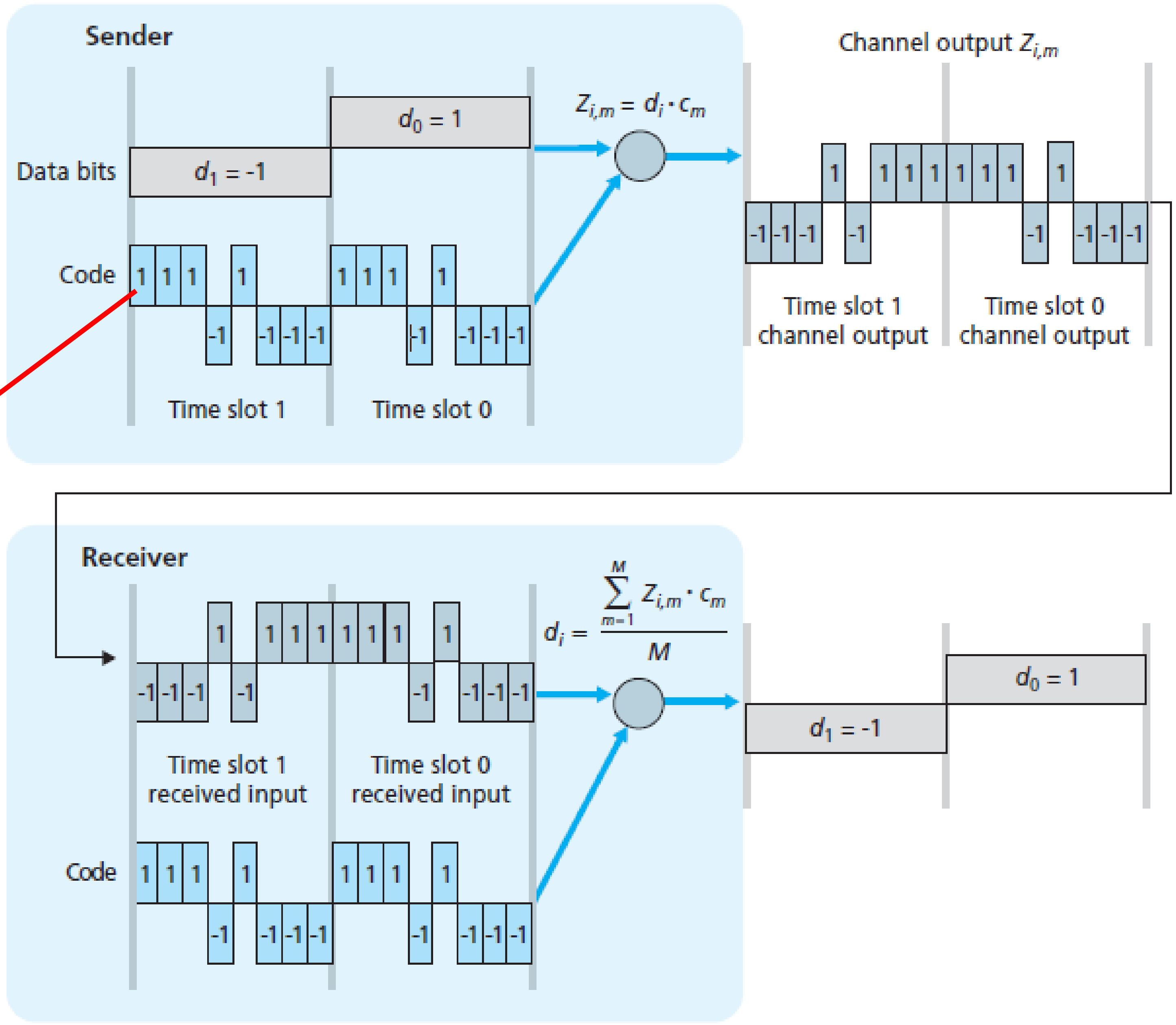
- ✓ The main problem with TDMA lies in achieving synchronization between the different stations. Each station needs to know the beginning of its slot and the location of its slot. This may be difficult because of propagation delays introduced in the system if the stations are spread over a large area.
- ✓ To compensate for the delays, we can insert guard times. Synchronization is normally accomplished by having some synchronization bits at the beginning of each slot.

Code-Division Multiple Access (CDMA)

CDMA differs from FDMA because only one channel occupies the entire bandwidth of the link. It differs from TDMA because all stations can send data simultaneously; there is no timesharing.



CDMA is based on coding theory. Each station is assigned a code, which is a sequence of numbers called chips,



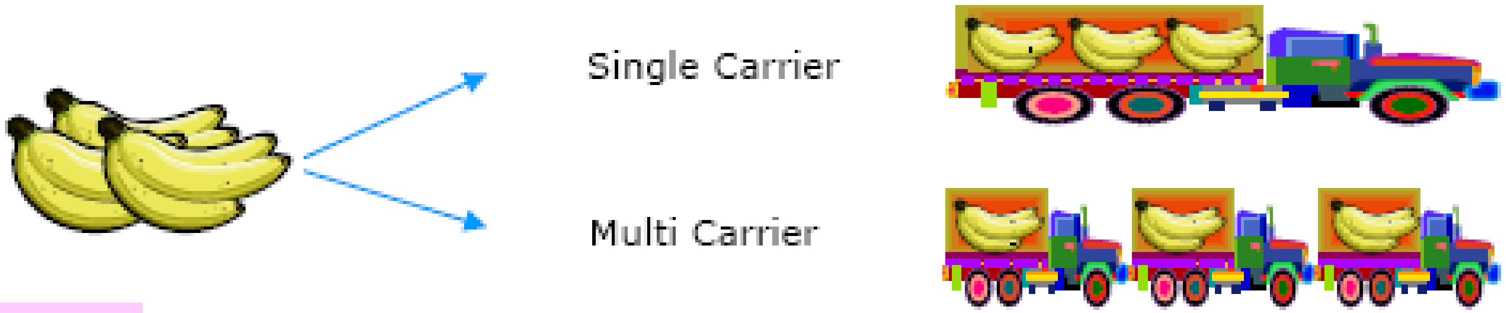
Chips

A simple CDMA example: sender encoding, receiver decoding

Orthogonal Frequency Division Multiplexing

❖***Orthogonal Frequency Division Multiplexing*** (OFDM) is a multi-carrier modulation scheme that transmits data over a number of **orthogonal subcarriers**. A conventional transmission uses only a single carrier modulated with all the data to be sent.

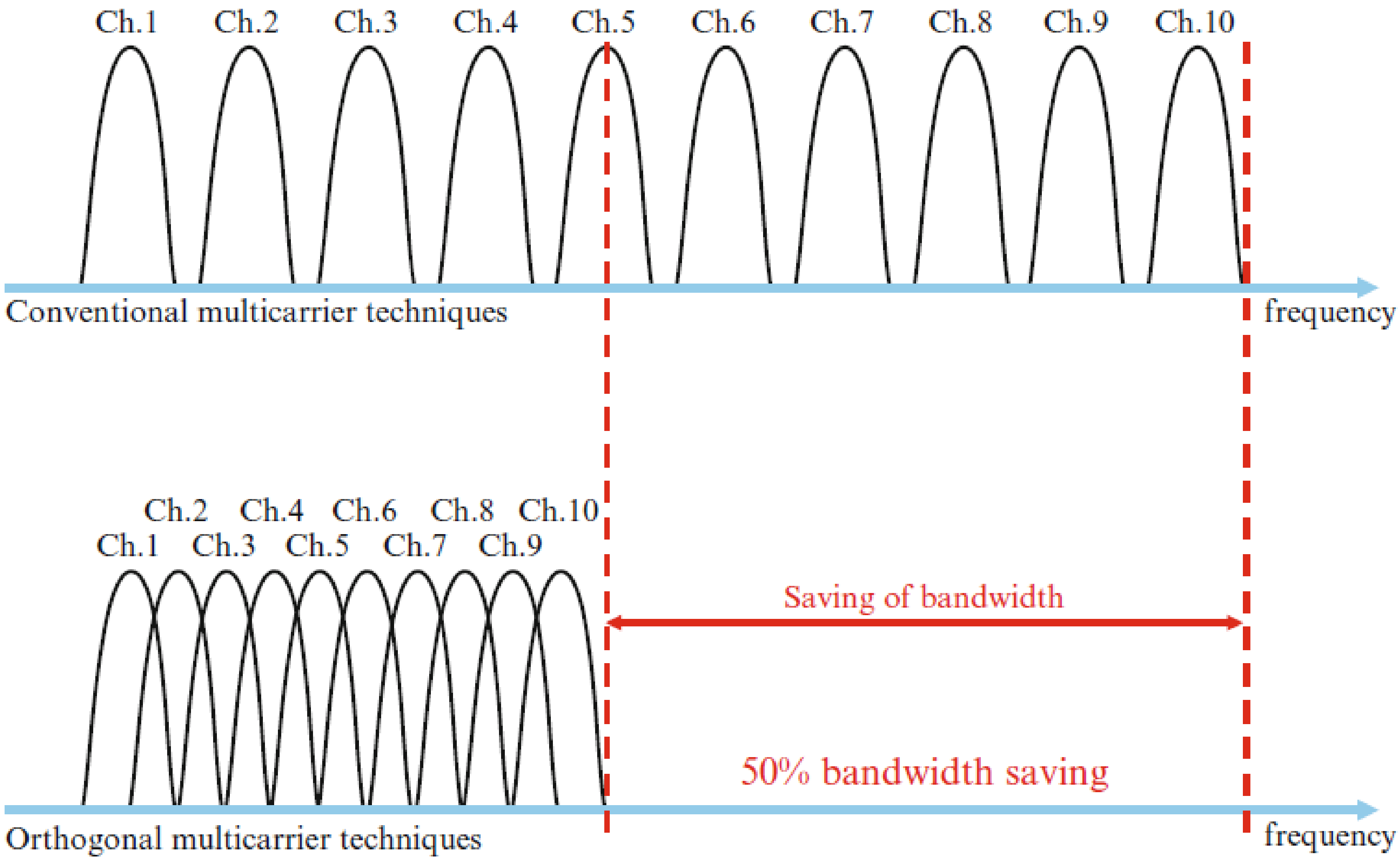
❖OFDM breaks the data to be sent into small chunks, allocating each sub-data stream to a sub-carrier and the data is sent in parallel orthogonal sub-carriers. As illustrated in Figure 1, this can be compared with a transport company utilizing several smaller trucks (multi-carrier) instead of one large truck (single carrier).

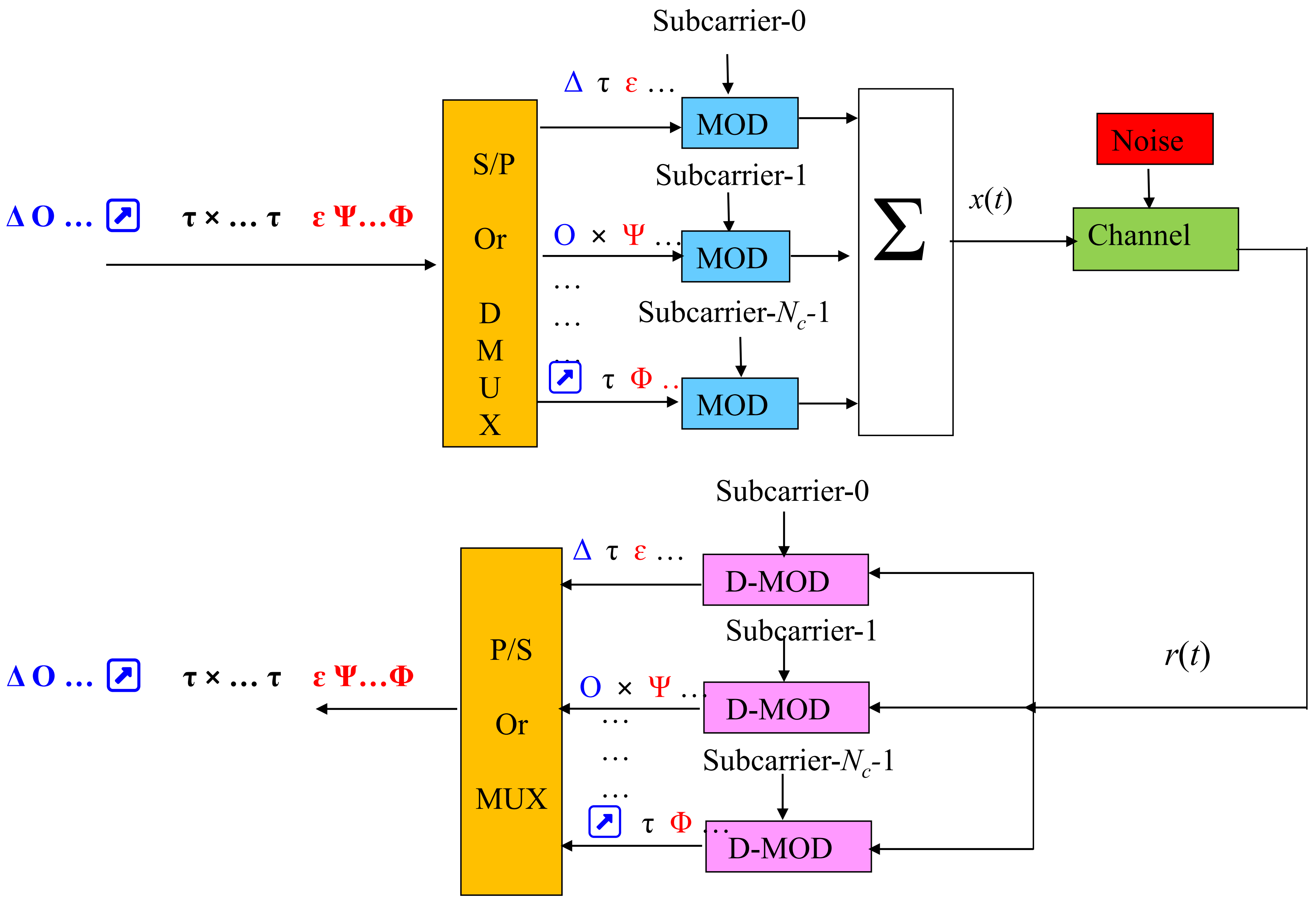


$$\hat{i}.\hat{j} = 0$$
$$\hat{i}.\hat{i} = 1$$

Fig.1 Single carrier vs. multi-carrier transmission

OFDM Versus FDM





OFDMA Communication System

OFDM offers many advantages over single-carrier modulations:

1. It elongates the symbol period so that the signal is more robust against intersymbol interference of wireless communication system.

2. It divides the entire frequency band into narrow bands so that it is less sensitive to wide-band impulse noise and supported by narrowband wireless channel.