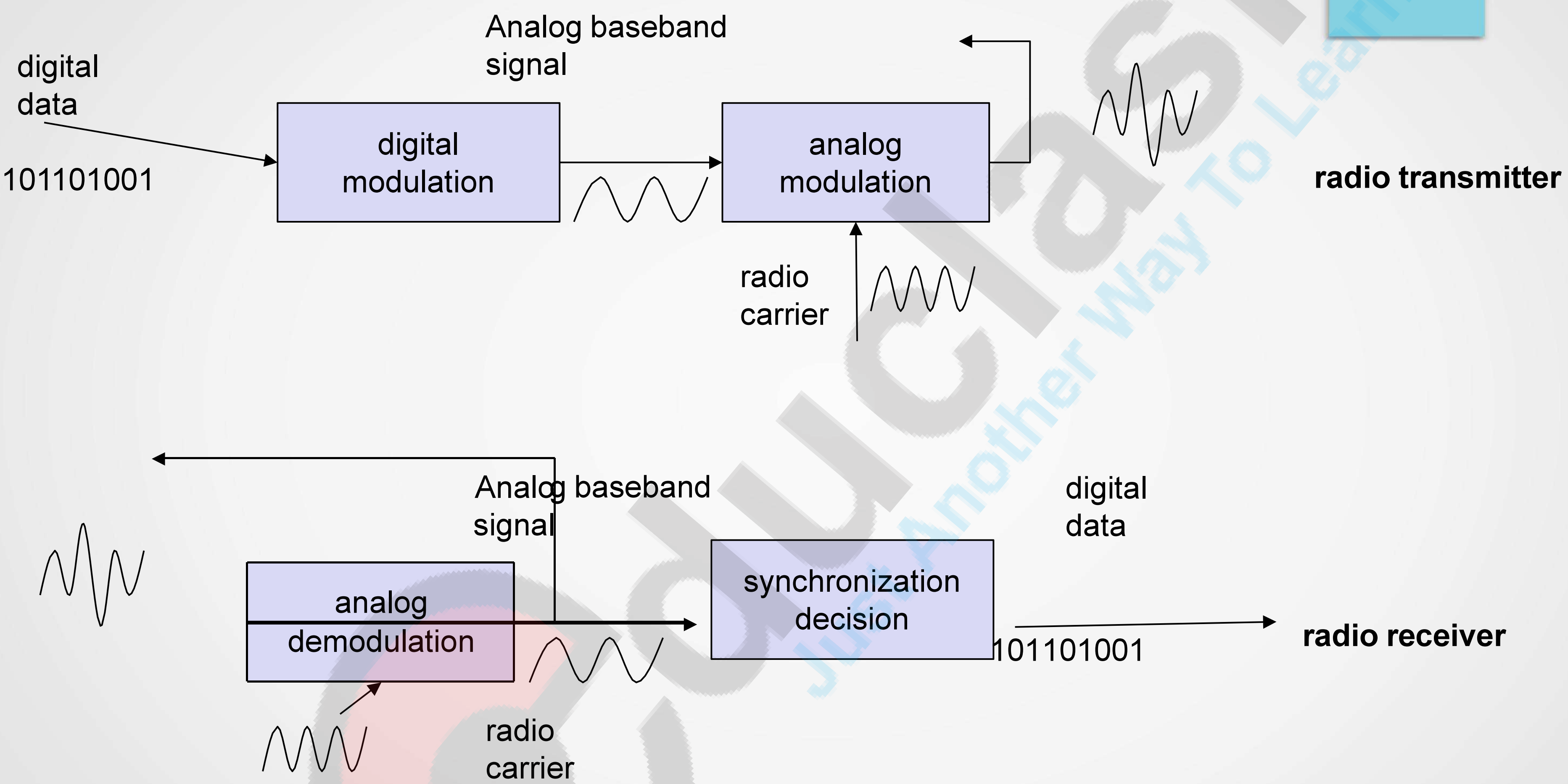
Signal Encoding Techniques

Modulation and demodulation



Modulation

- Modulation is defined as the process of combining an input signal and a carrier frequency to produce a signal whose bandwidth is centered around fc.

Reasons for Choosing Encoding Techniques

- Digital data, digital signal
  - Equipment less complex and expensive than digital-to-analog modulation equipment
- Analog data, digital signal
  - Permits use of modern digital transmission and switching equipment
- Digital data, analog signal
  - Some transmission media will only propagate analog signals
  - E.g., optical fiber and unguided media
- Analog data, analog signal
  - Analog data in electrical form can be transmitted easily and cheaply
  - Done with voice transmission over voice-grade lines

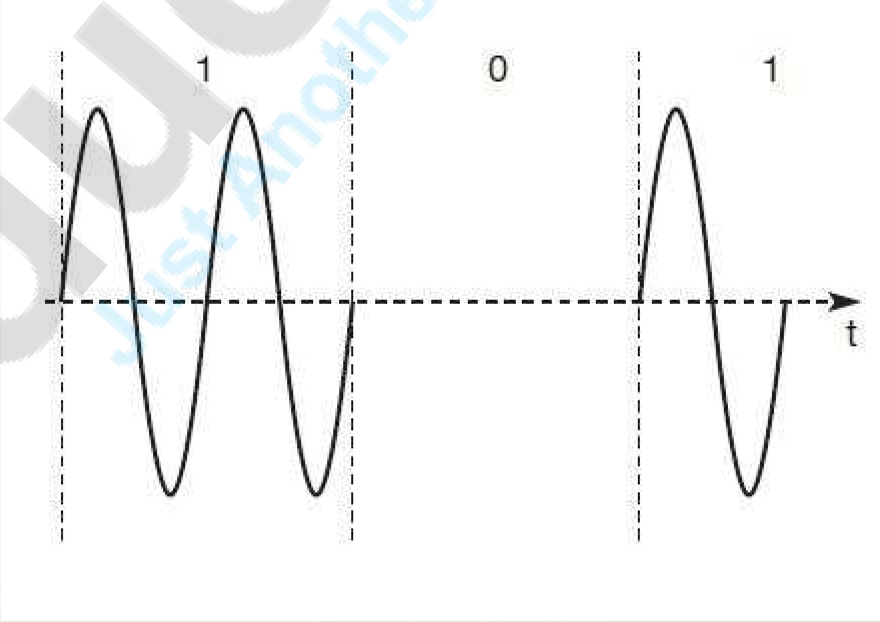
Encoding Techniques

- **Digital data to Analog signal**

- Amplitude-shift keying (ASK)
  - Amplitude difference of carrier frequency
- Frequency-shift keying (FSK)
  - Frequency difference near carrier frequency
- Phase-shift keying (PSK)
  - Phase of carrier signal shifted
- Advanced FSK
- Advanced PSK
- OFDM

Amplitude-Shift Keying

- One binary digit represented by presence of carrier, at constant amplitude
- Other binary digit represented by absence of carrier

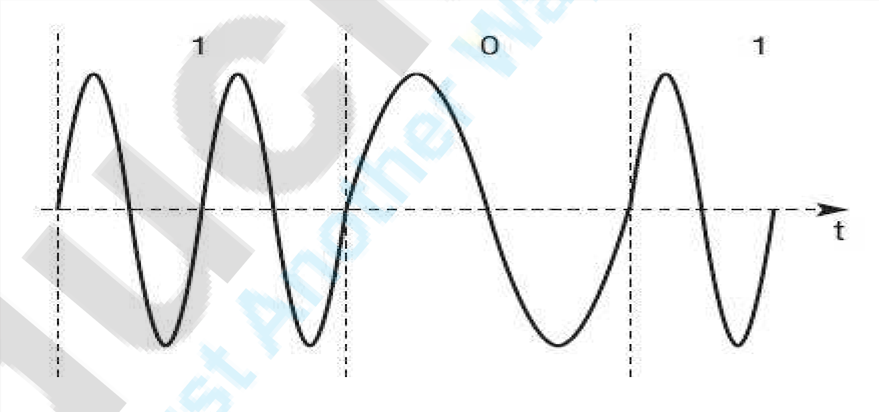


Amplitude-Shift Keying

- Susceptible to sudden gain changes
- Inefficient modulation technique
- On voice-grade lines, used up to 1200 bps
- Used to transmit digital data over optical fiber

Binary Frequency-Shift Keying (BFSK)

- Two binary digits represented by two different frequencies near the carrier frequency



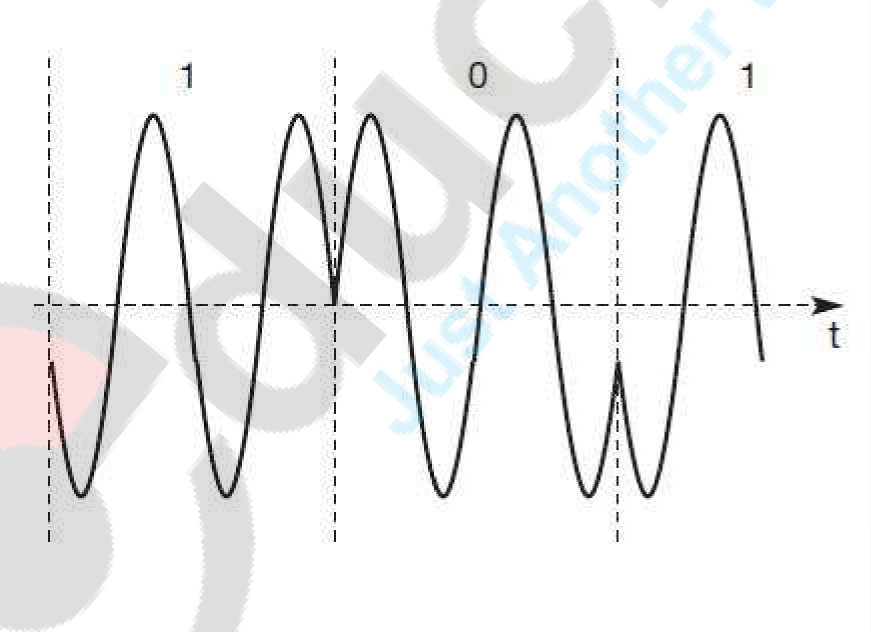
  - where *f*1 and *f*2 are offset from carrier frequency *fc* by equal but opposite amounts

Binary Frequency-Shift Keying (BFSK)

- Less susceptible to error than ASK
- On voice-grade lines, used up to 1200bps
- Used for high-frequency (3 to 30 MHz) radio transmission
- Can be used at higher frequencies on LANs that use coaxial cable

Phase-Shift Keying (PSK)

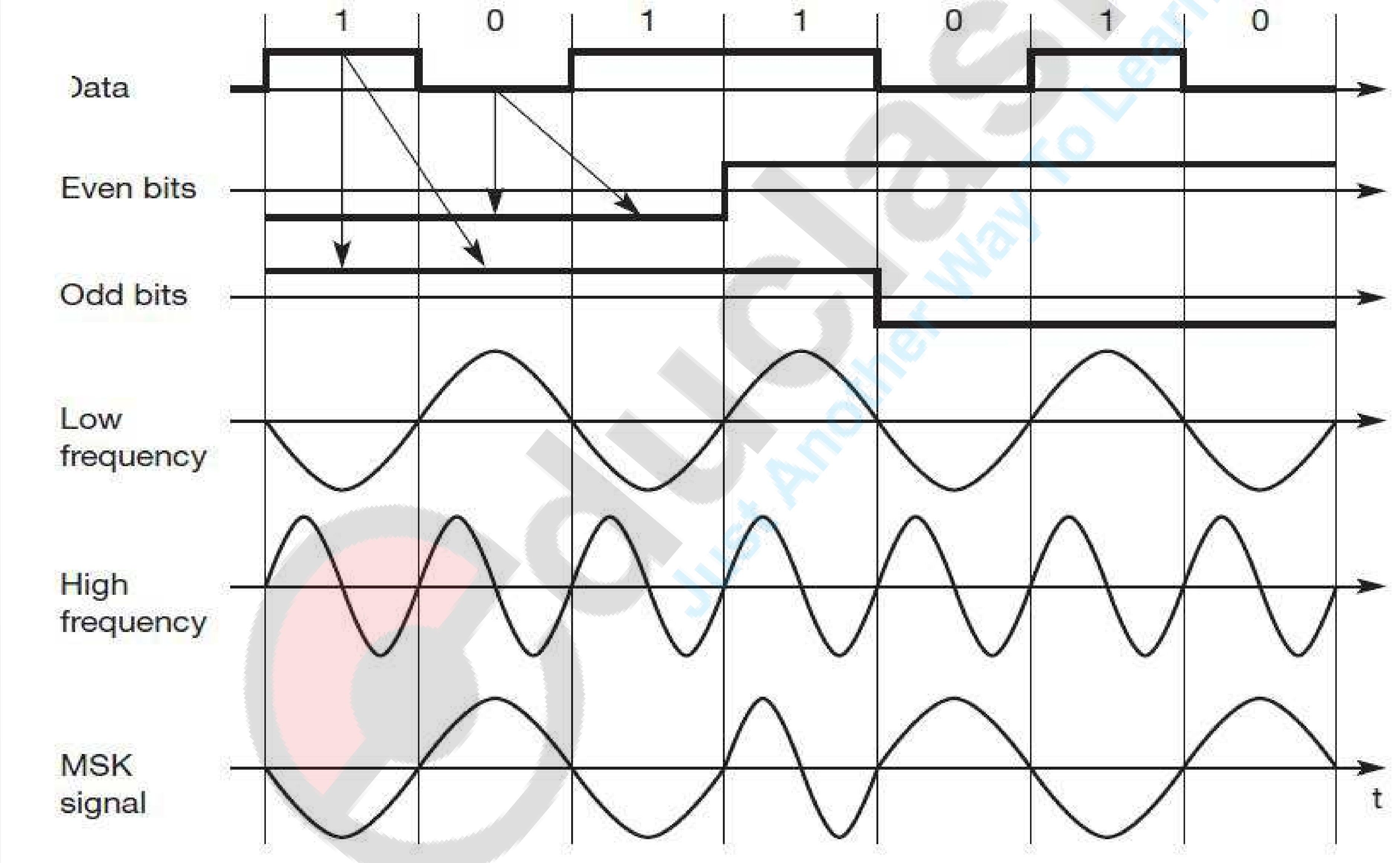
- Two-level PSK (BPSK)
  - Uses two phases to represent binary digits



Advanced frequency shift keying

- **Minimum shift keying (MSK)**
- without abrupt phase changes.
- data bits are separated into even and odd bits
- the duration of each bit being doubled.
- It uses two frequencies:
  - f1, the lower frequency,
  - f2, the higher frequency, with f2 = 2f1

Advanced frequency shift keying



Advanced frequency shift keying

- if the even and the odd bit are both 0, then the higher frequency f2 is inverted (i.e., f2 is used with a phase shift of 180°);

- if the even bit is 1, the odd bit 0, then the lower frequency f1 is inverted. This is the case, e.g., in the fifth to seventh columns.

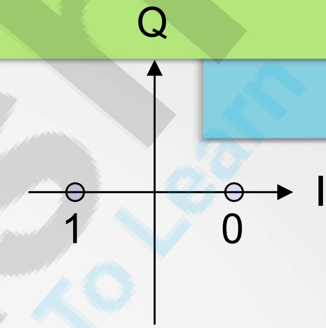
- if the even bit is 0 and the odd bit is 1, as in columns 1 to 3, f1 is taken without changing the phase

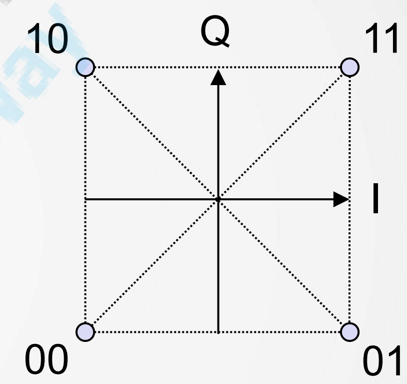
- if both bits are 1 then the original f2 is taken.

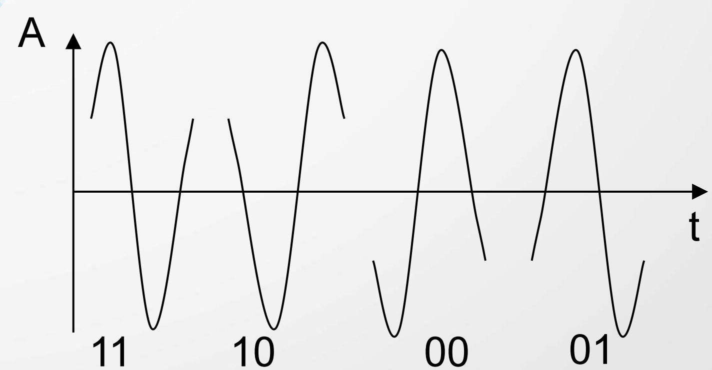
Advanced Phase Shift Keying

QPSK (Quadrature Phase Shift Keying):

- 2 bits coded as one symbol
- The phase shift can always be relative to reference signal (with the same frequency).
- If this scheme is used, a phase shift of 0 means that the signal is in phase with the reference signal.
- A QPSK signal will then exhibit a phase shift of 45° for the data 11, 135° for 10, 225° for 00, and 315° for 01 – with all phase shifts being relative to the referencesignal.





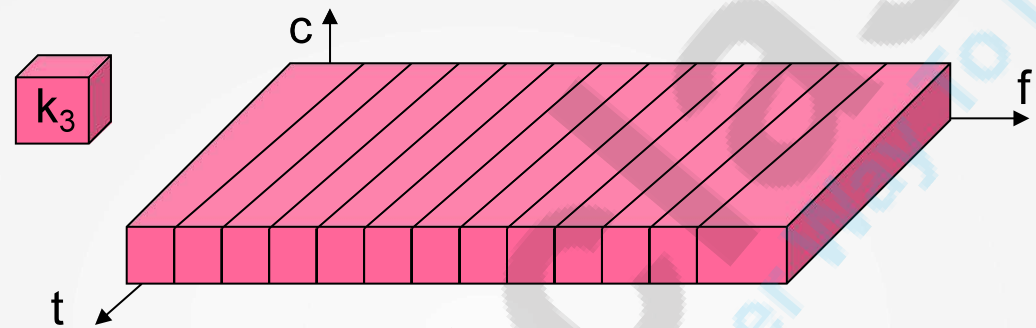


QPSK (Quadrature Phase Shift Keying):

- The transmitter 'selects' parts of the signal and concatenates them.
- To reconstruct data, the receiver has to compare the incoming signal with the reference signal.
- One problem of this scheme involves producing a reference signal at the receiver.
- Transmitter and receiver have to be synchronized very often, e.g., by using special synchronization patterns before user data arrives or via a pilot frequency as reference
- DQPSK - Differential QPSK (IS-136, PACS, PHS)-the phase shift is not relative to a reference signal but to the phase of the previous two bits.

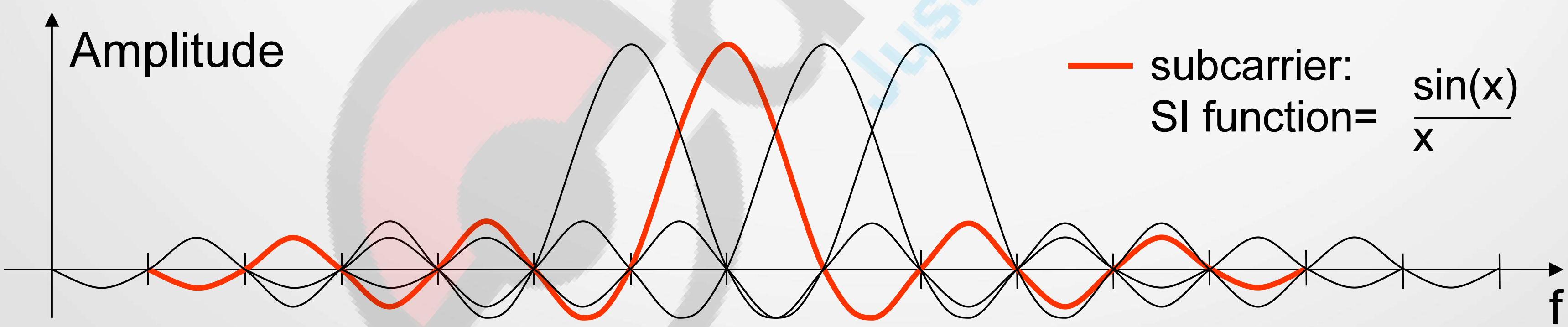
OFDM (Orthogonal Frequency Division)

Parallel data transmission on several orthogonal subcarriers with lower rate



Maximum of one subcarrier frequency appears exactly at a frequency where all other subcarriers equal zero

- superposition of frequencies in the same frequency range



OFDM

Properties

- Lower data rate on each subcarrier ➔ less ISI interference on one frequency results in interference of one subcarrier only
- no guard space necessary
- orthogonality allows for signal separation via inverse FFT on receiver side
- precise synchronization necessary (sender/receiver)

Advantages

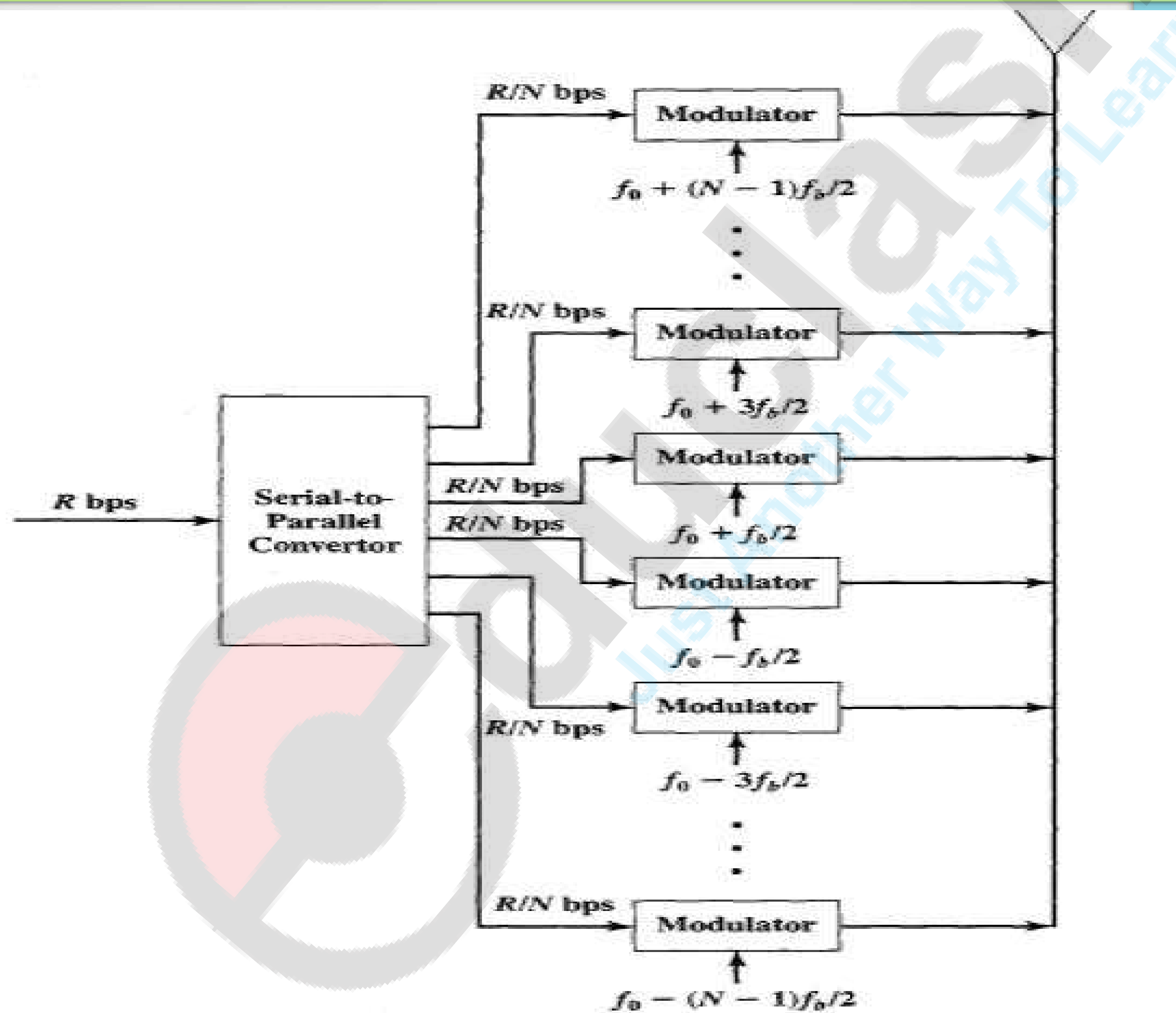
- Frequency selective fading only affects some subchannels and not the whole signal.

- OFDM overcome intersymbol interference (ISI) in a multipath environment.

Application

802.11a, HiperLAN2, ADSL

OFDM



R bps
Serial-to-Parallel Convertor
R/N bps
R/N bps
R/N bps
R/N bps
R/N bps
R/N bps
Modulator
Modulator
Modulator
Modulator
Modulator
Modulator
$f_0 + (N-1)f_b/2$
$f_0 + 3f_b/2$
$f_0 + f_b/2$
$f_0 - f_b/2$
$f_0 - 3f_b/2$
$f_0 - (N-1)f_b/2$

OFDM

- Suppose we have a data stream operating at R bps and an available bandwidth of Nf_b, centered at f_a.
- The entire bandwidth could beused to send the data stream, in which case each bit duration would be 1/R.
- The alternativeis to split the data stream into N substreams, using a serial-to-parallel converter.
- Each substream has a data rate of R/N bps and is transmitted on a separate subcarrier, with a spacing between adjacent subcarriers of f_b
- Now the bit duration is N/R.

Spread spectrum

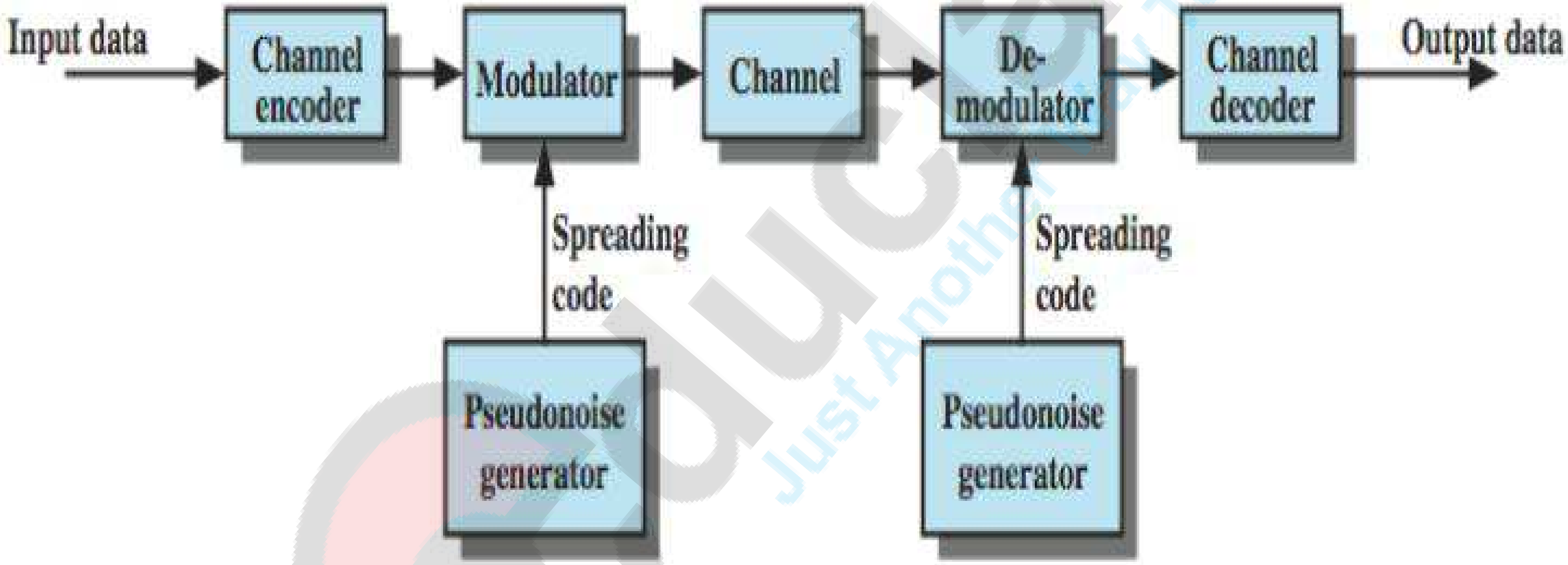
Definition of Spread Spectrum :

Spread spectrum is a modulation method applied to digitally modulated signals that increases the transmit signal bandwidth to a value much larger than is needed to transmit the underlying information bits.

Spread Spectrum

- Important encoding method for wireless communications
- Spreads data over wide bandwidth
- Makes jamming and interception harder
- Two approaches, both in use:
  - Frequency hopping
  - Direct sequence

General Model of Spread Spectrum System



Spread Spectrum Advantages

- Immunity from noise and multipath distortion
- Can hide / encrypt signals
- Several users can share same higher bandwidth with little interference
    - CDM/CDMA mobile telephones

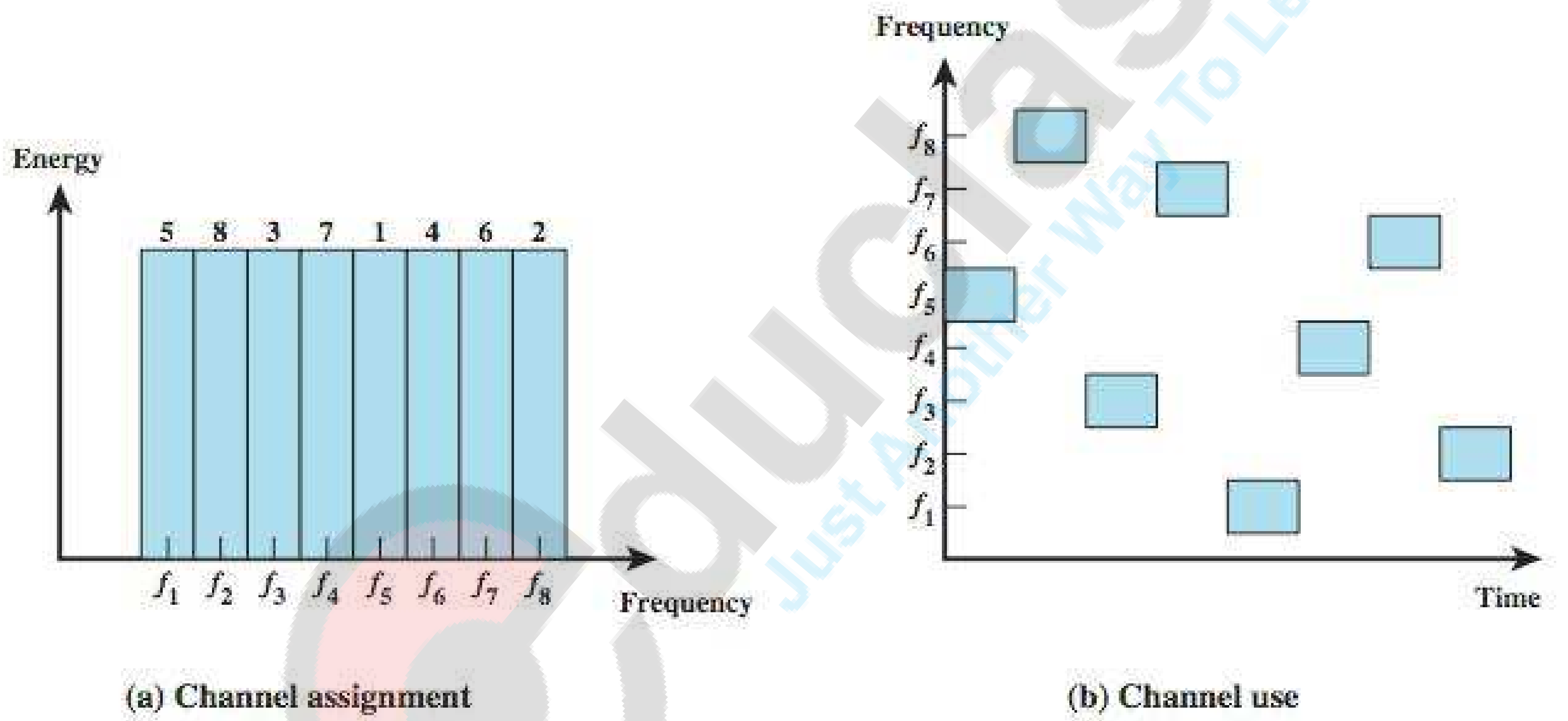
Pseudorandom Numbers

- Generated by a deterministic algorithm
  - Not actually random
  - But if algorithm good, results pass reasonable tests of randomness
- Starting from an initial seed
- Need to know algorithm and seed to predict sequence
- Hence only receiver can decode signal

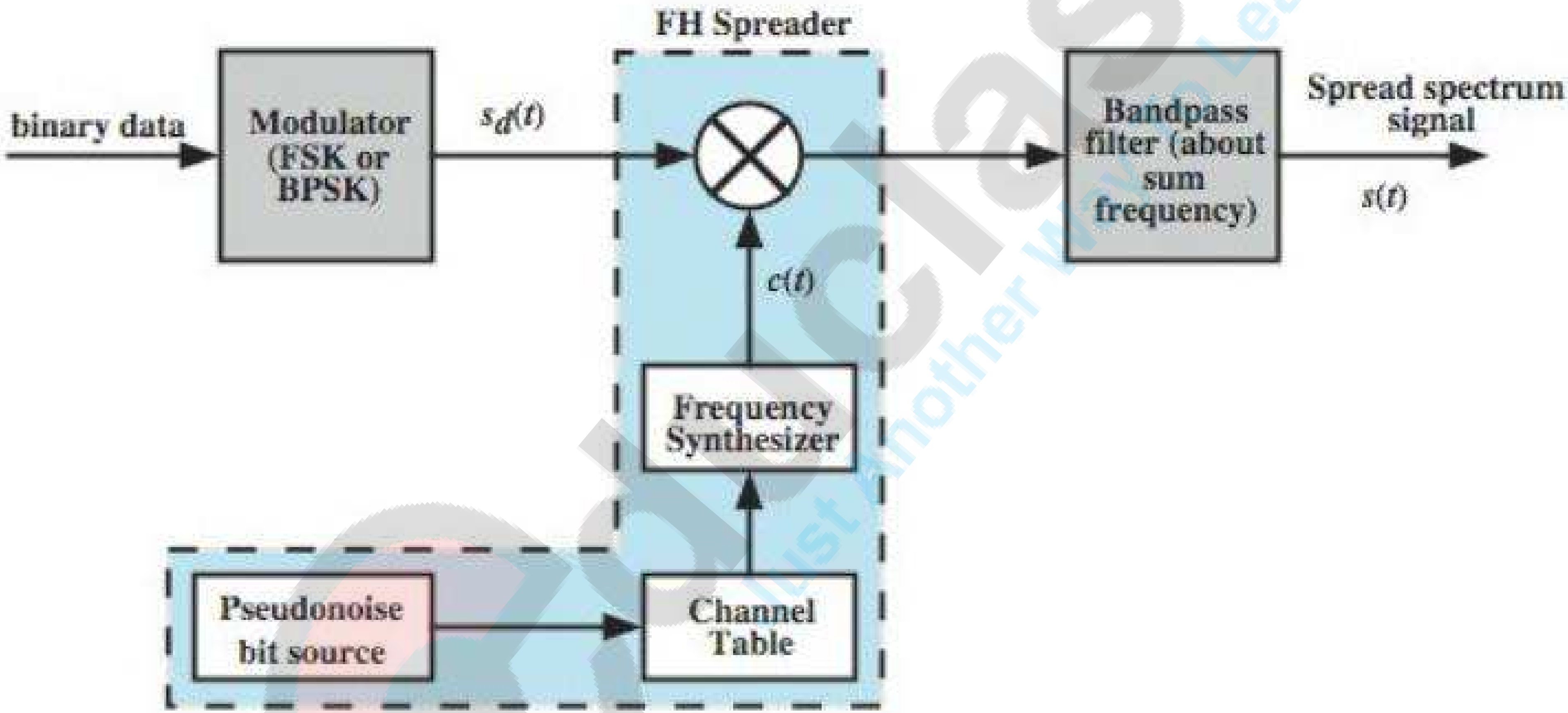
Frequency Hopping Spread Spectrum (FHSS)

- Signal is broadcast over seemingly random series of frequencies
- Receiver hops between frequencies in sync with transmitter
- Eavesdroppers hear unintelligible blips
- Jamming on one frequency affects only a few bits

Frequency Hopping Example

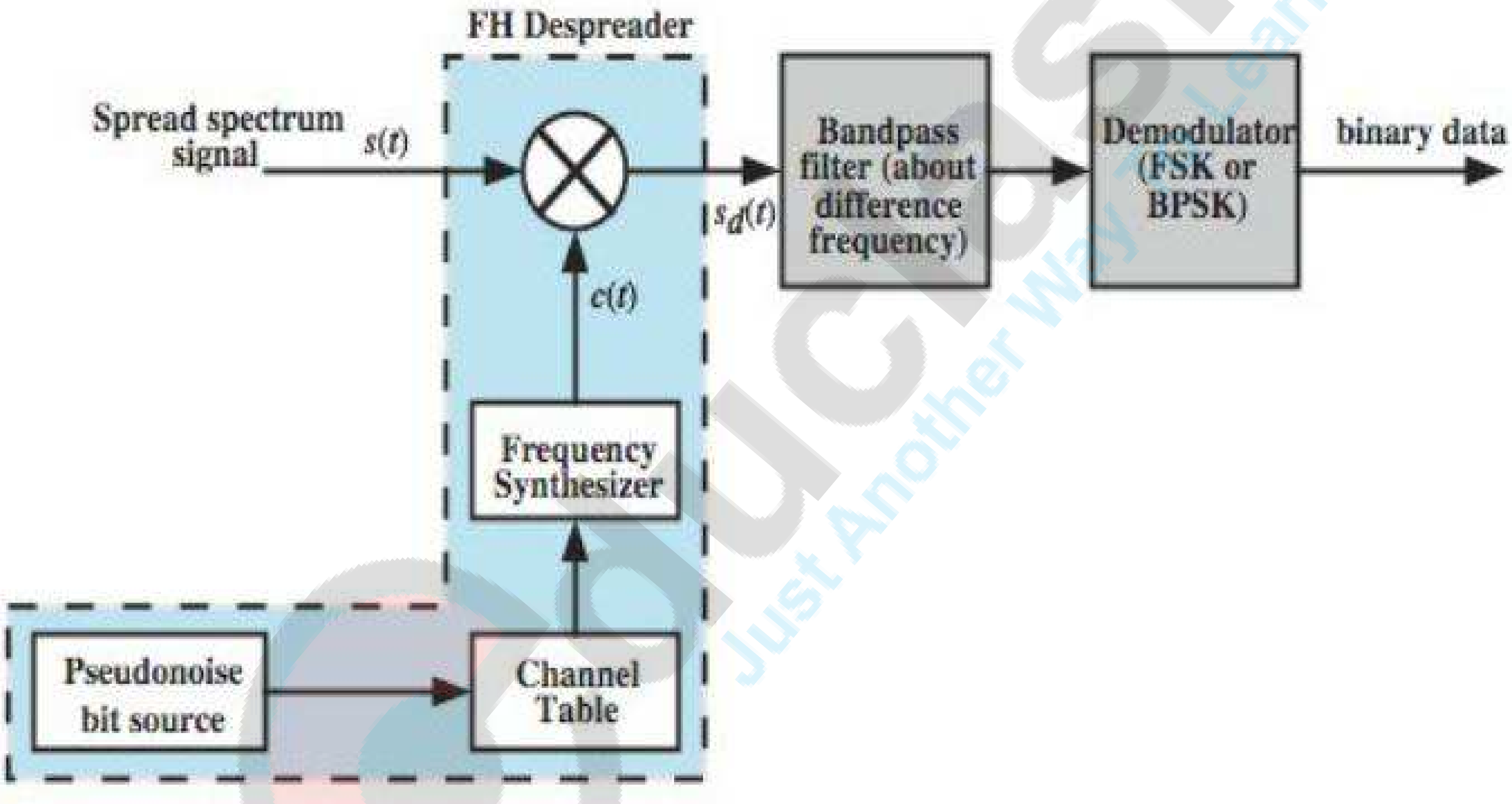


FHSS (Transmitter)



(a) Transmitter

FHSS (Receiver)



(b) Receiver

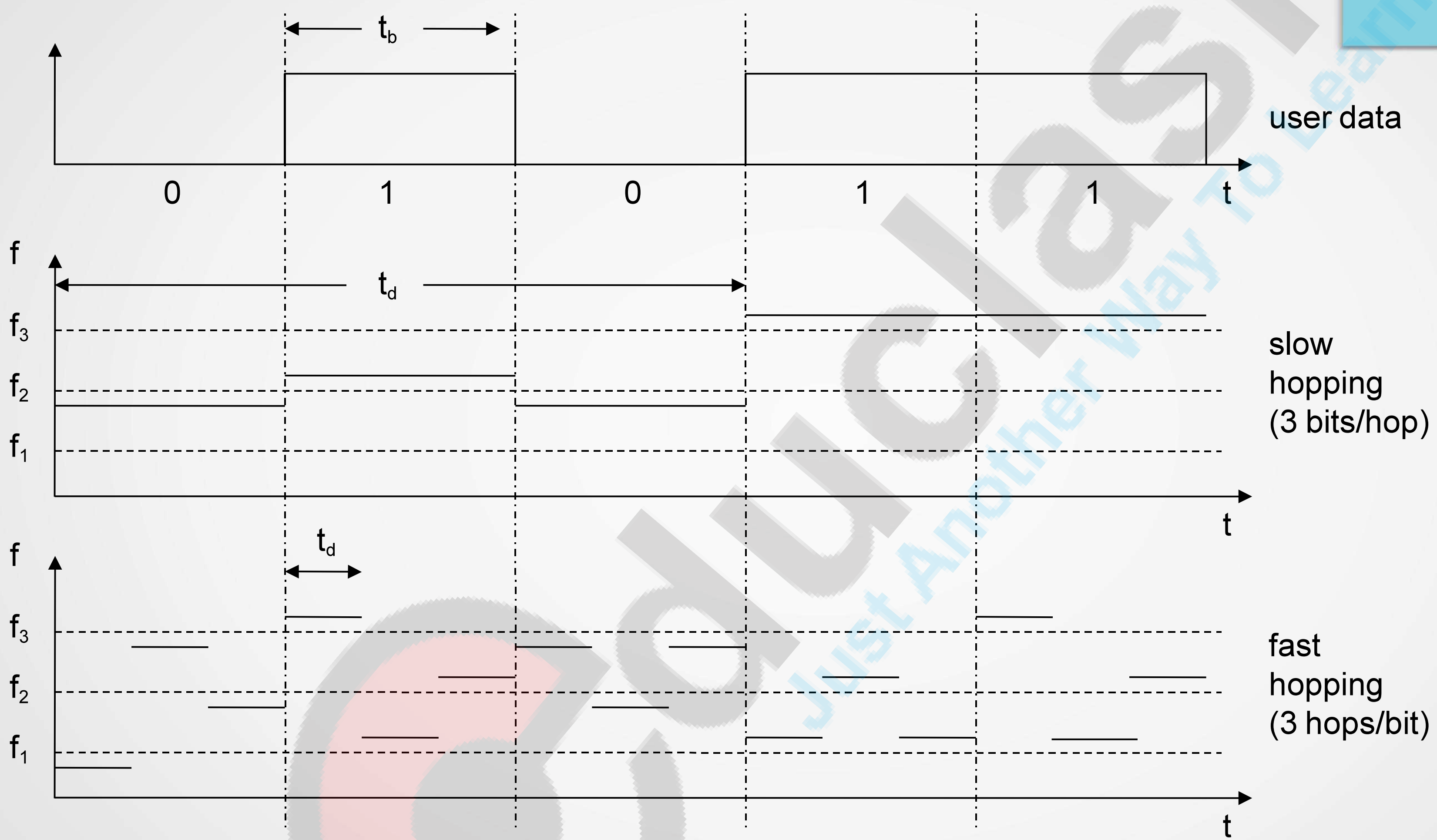
FHSS (Frequency Hopping Spread Spectrum)

Two versions

- Fast Hopping:
  several frequencies per user bit
- Slow Hopping:
  several user bits per frequency

- **Advantages**
- frequency selective fading and interference limited to short period
- simple implementation
- uses only small portion of spectrum at any time
- **Disadvantages**
  - not as robust as DSSS
  - simpler to detect

FHSS (Frequency Hopping Spread Spectrum)

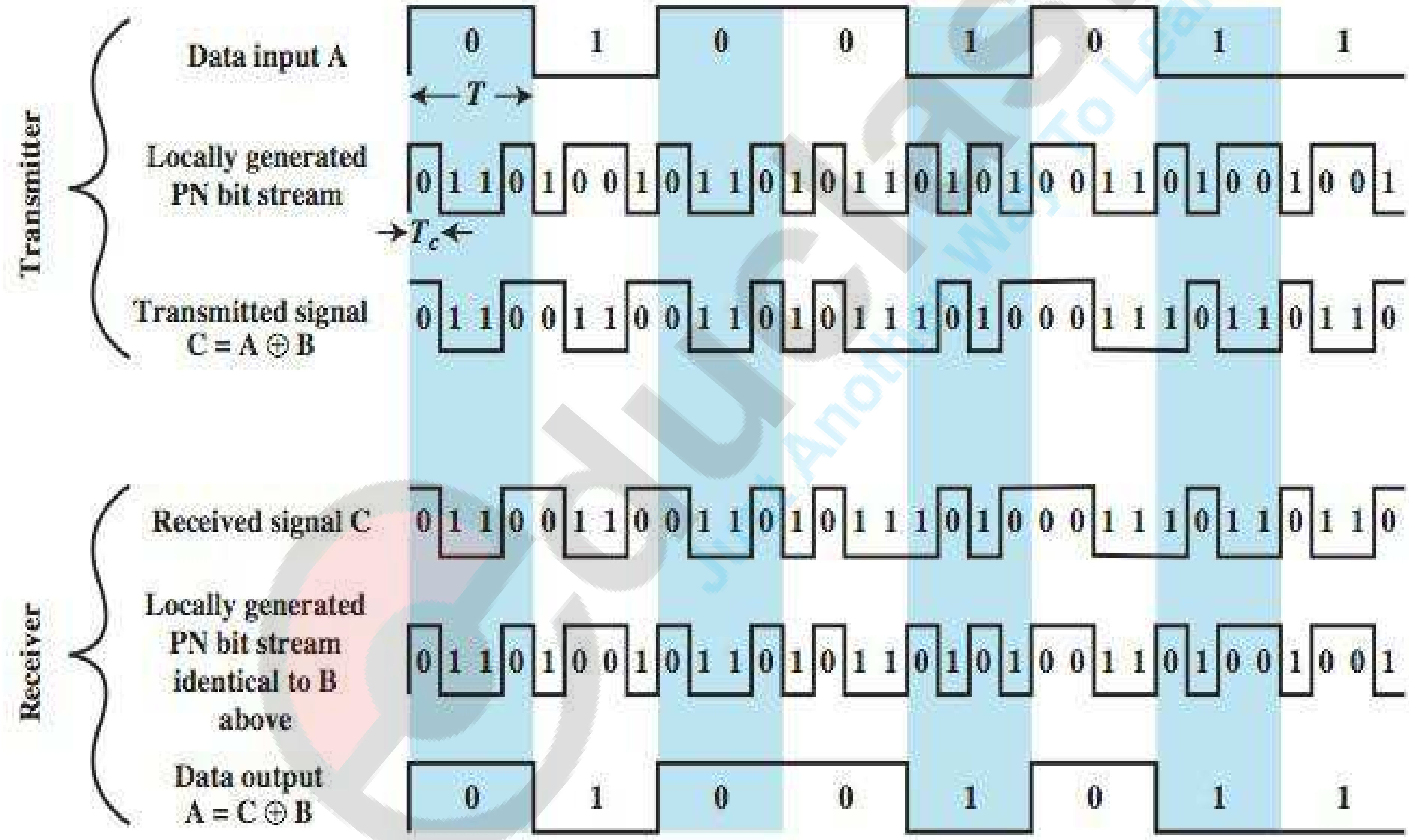


t_b: bit period t_d: dwell time

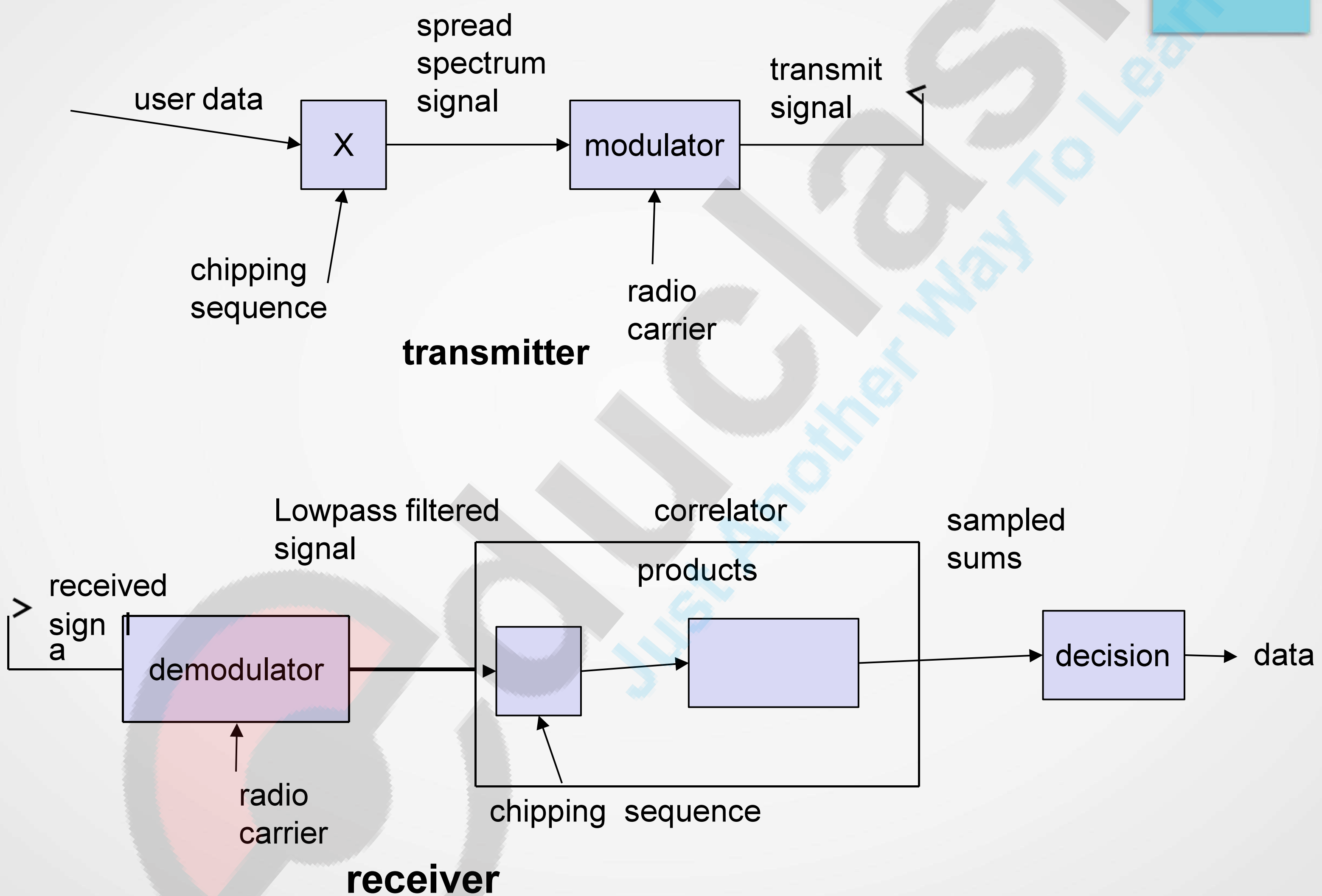
Direct Sequence Spread Spectrum (DSSS)

- Each bit is represented by multiple bits using a spreading code
- This spreads signal across a wider frequency band
- Has performance similar to FHSS

Direct Sequence Spread Spectrum Example



DSSS (Direct Sequence Spread Spectrum)



DSSS (Direct Sequence Spread Spectrum)

- **Advantages**
  - reduces frequency selective fading
  - in cellular networks
    - base stations can use the same frequency range
    - several base stations can detect and recover the signal
    - soft handover
- **Disadvantages**
  - precise power control necessary

Convolutional Codes

- Generates redundant bits continuously

- Error checking and correcting carried out continuously

  - (n, k, K) code
    - Input processes k bits at a time
    - Output produces n bits for every k input bits
    - K = constraint factor/ number of memory blocks
    - k and n generally very small

  - n-bit output of (n, k, K) code depends on:
    - Current block of k input bits
    - Previous K-1 blocks of k input bits

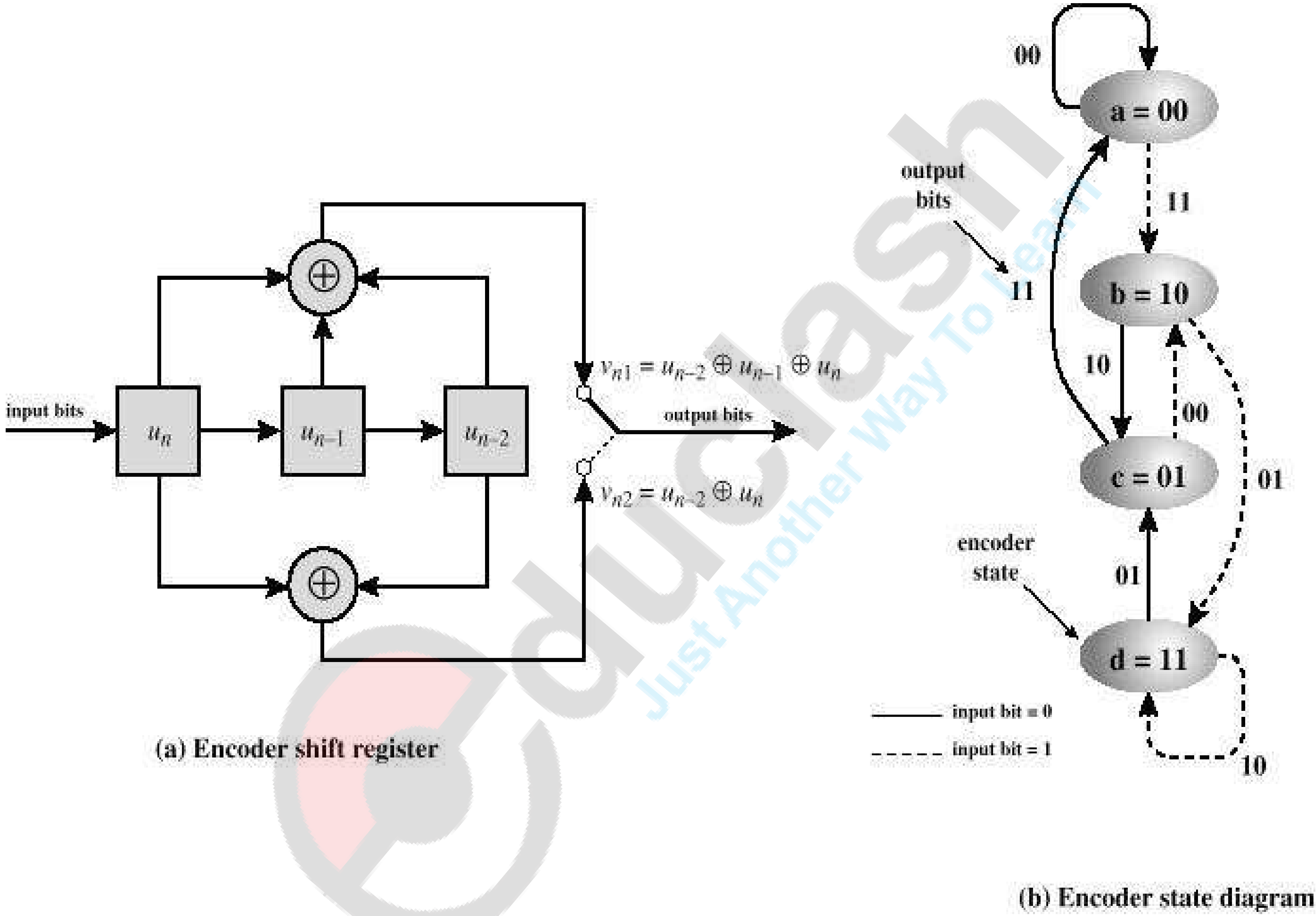


Figure 8.9 Convolutional Encoder with $(n, k, K) = (2, 1, 3)$