Physical layer
Modulation

Mobile Computing

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TYPES OF SIGNALS

(a) continuous time/discrete time

(b) continuous values/discrete values

- analog signal = continuous time, continuous values
- digital signal = discrete time, discrete values

Periodic signal - analog or digital signal that repeats over time

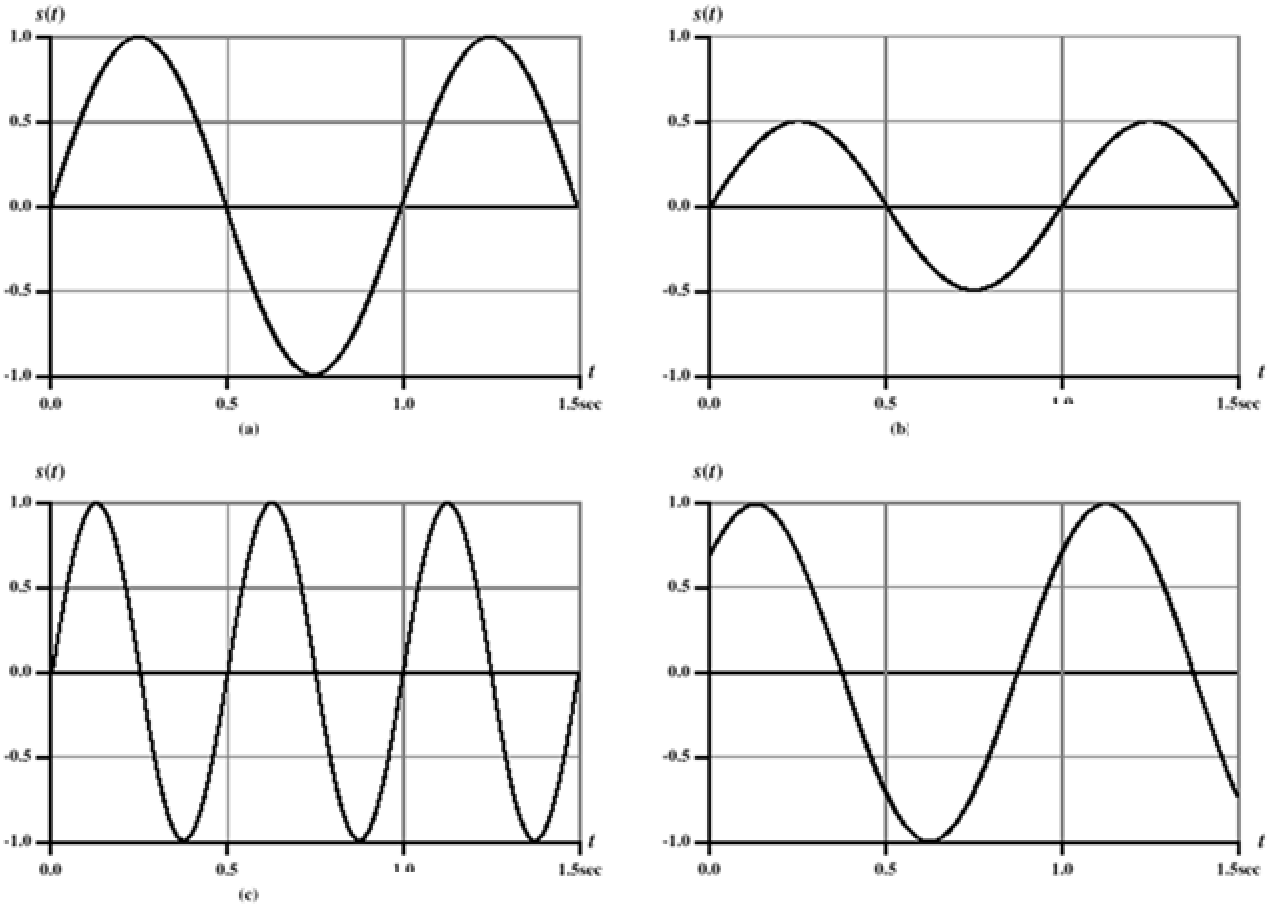
- $$s(t+T) = s(t) \quad -\infty < t < +\infty$$
  - where T is the period of the signal

signal parameters of periodic signals:
period T, frequency f=1/T, amplitude A, phase shift φ

- sine wave as special periodic signal for a carrier:

$$s(t) = A_t \sin(2\,\pi\, f_t\, t + \varphi_t)$$

SINE WAVE PARAMETERS



$$s(t) = A \sin (2 \; ft + \phi)$$

MODULATION

Digital modulation

- digital data is translated into an analog signal (baseband)
- ASK, FSK, PSK - main focus in this chapter
- differences in spectral efficiency, power efficiency, robustness

Analog modulation

- shifts center frequency of baseband signal up to the radio carrier

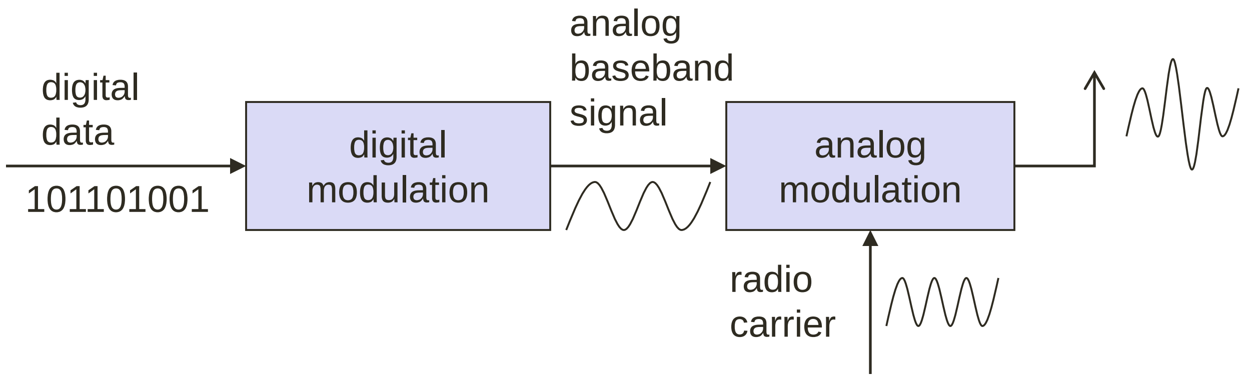
Motivation

- smaller antennas (e.g., $\lambda/4$)
- Frequency Division Multiplexing
- medium characteristics

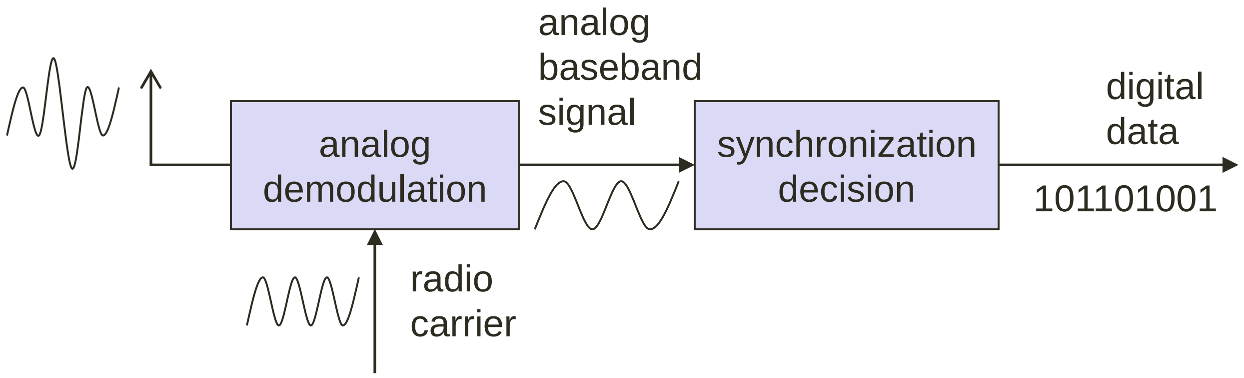
Basic schemes

- Amplitude Modulation (AM)
- Frequency Modulation (FM)
- Phase Modulation (PM)

MODULATION AND DEMODULATION



radio transmitter



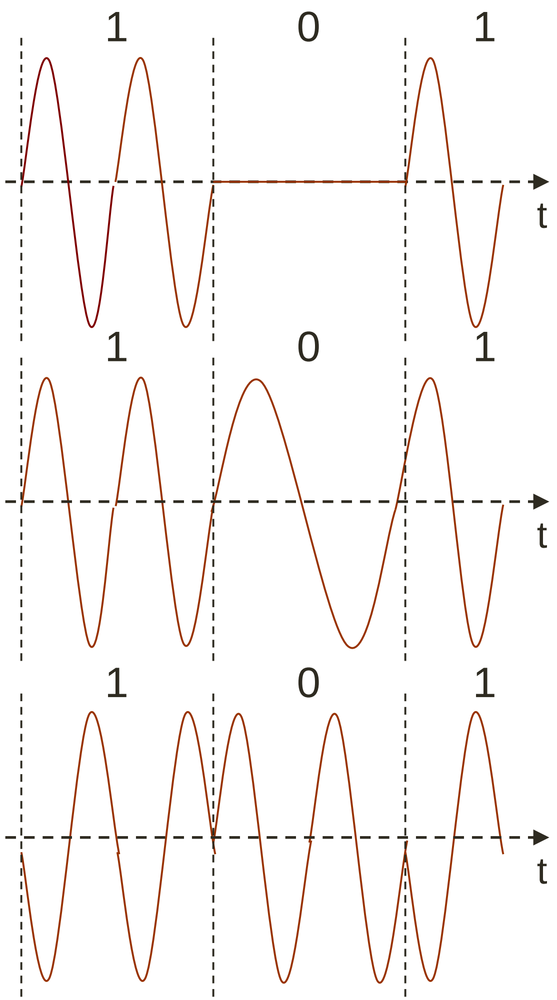
radio receiver

DIGITAL MODULATION

Modulation of digital signals known as Shift Keying

Amplitude Shift Keying (ASK):

- very simple
- low bandwidth requirements
- very susceptible to interference



Frequency Shift Keying (FSK):

- needs larger bandwidth

Phase Shift Keying (PSK):

- more complex
- robust against interference

EX.

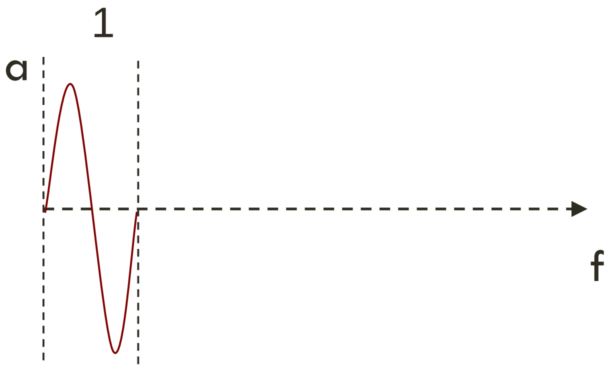
Draw the bit sequence “001101010” using the following types of digital modulation :

1. Amplitude Shift Keying (ASK)

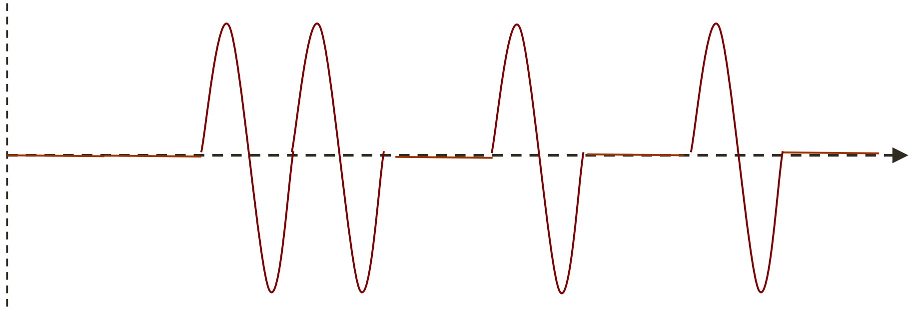
2. Frequency Shift Keying (FSK)

3. Phase Shift Keying (PSK)

ASK

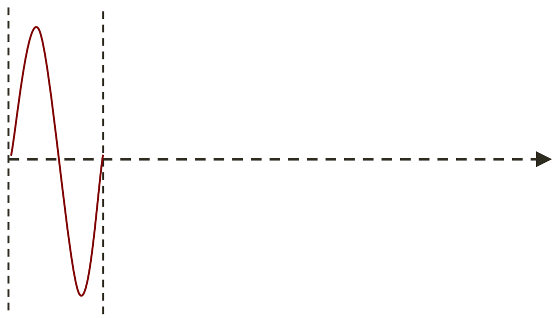


"001101010"

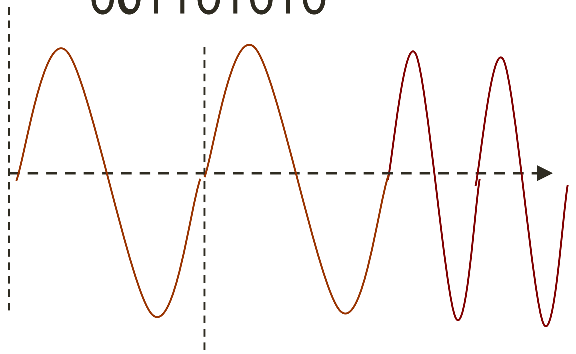


FSK

1

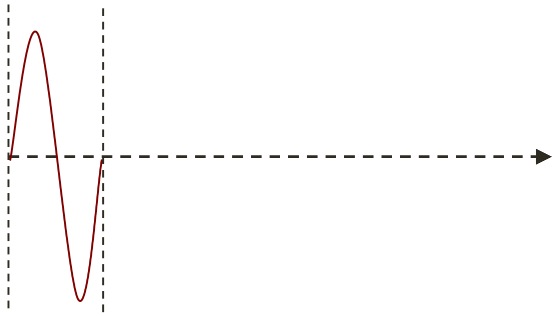


“001101010”

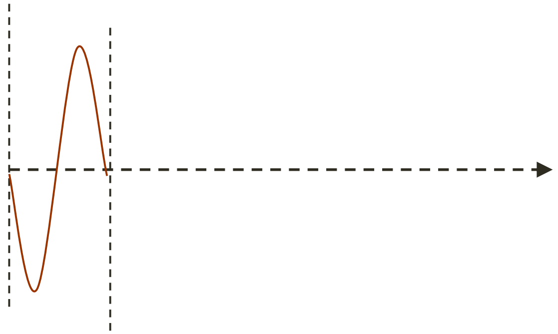


PSK

1



0



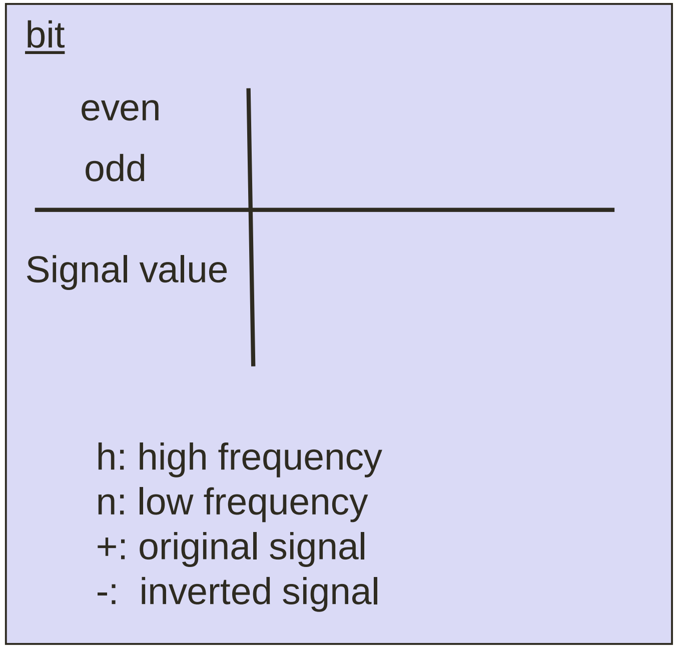
ADVANCED FREQUENCY SHIFT KEYING

- A famous FSK scheme used in many wireless systems is **minimum shift keying (MSK).**
- MSK is basically BFSK (Binary FSK) without abrupt phase changes,
  i.e., it belongs to CPM (Continuous Phase Modulation) schemes.
- In a first step, data bits are separated into even and odd bits, the duration of each bit being doubled.
- The scheme also uses two frequencies: $f1$, the lower frequency, and $f2$, the higher frequency, with $f2 = 2f1$.

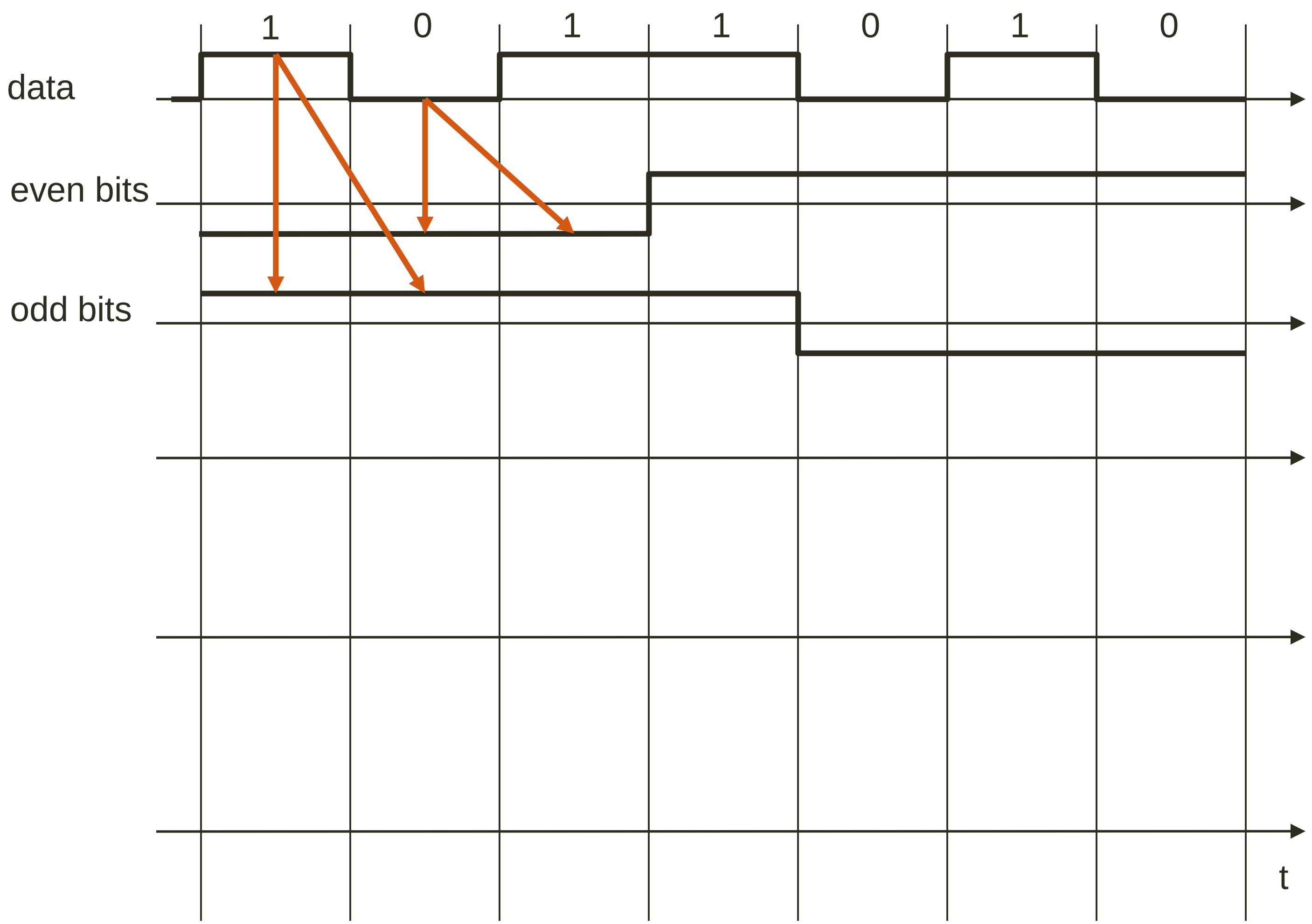
MSK

According to the following scheme, the lower or higher frequency is chosen (either inverted or non-inverted) to generate the MSK signal:

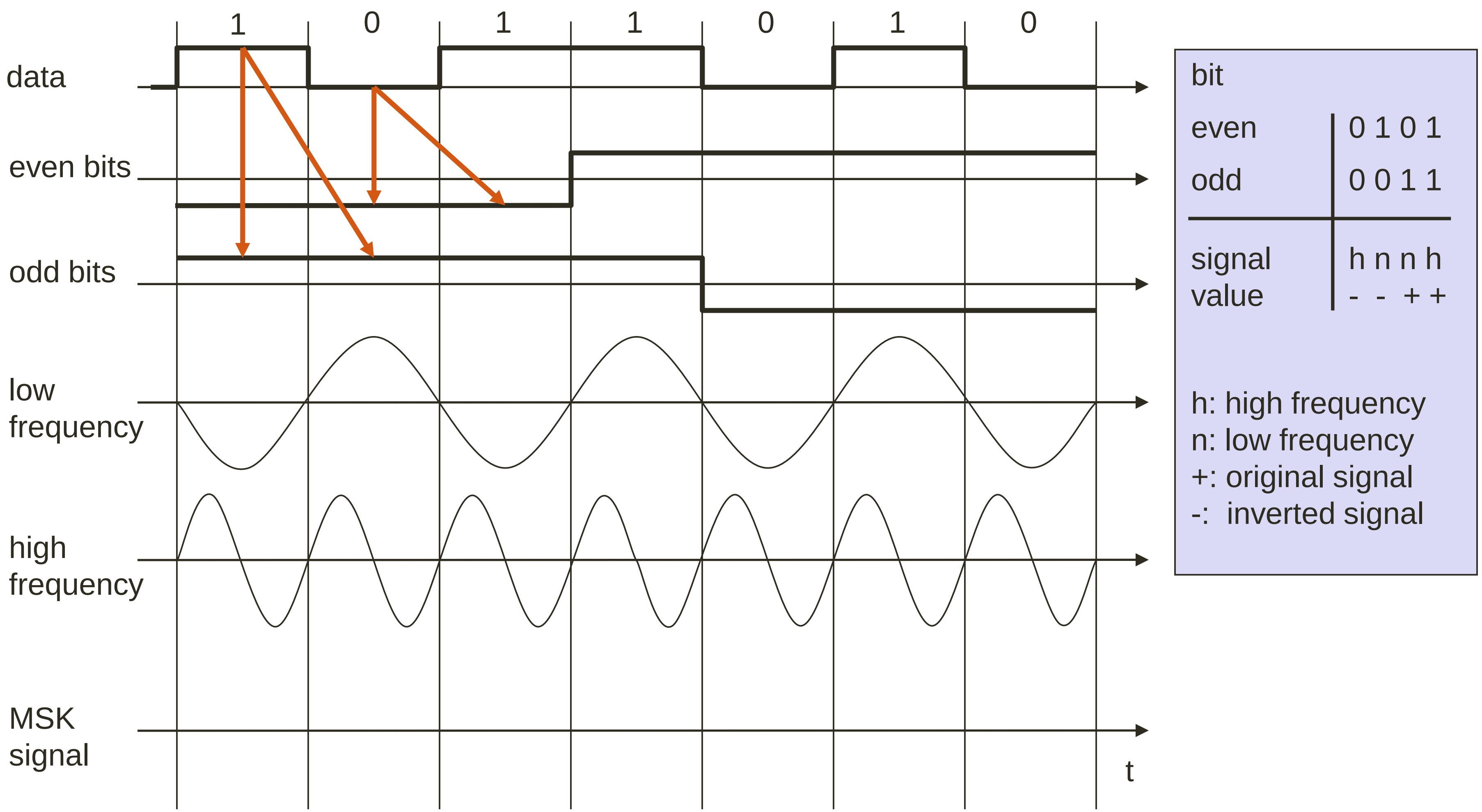
- if the even and the odd bit are both 0,
  then the higher frequency f2 is inverted
  (i.e., f2 is used with a phase shift of 180°);
- if the even bit is 1,
  the odd bit 0, then the lower frequency f1 is inverted.
  This is the case, e.g., in the fifth to seventh columns,
- if the even bit is 0 and the odd bit is 1,
  f1 is taken without changing the phase,
- if both bits are 1 then the original f2 is taken.



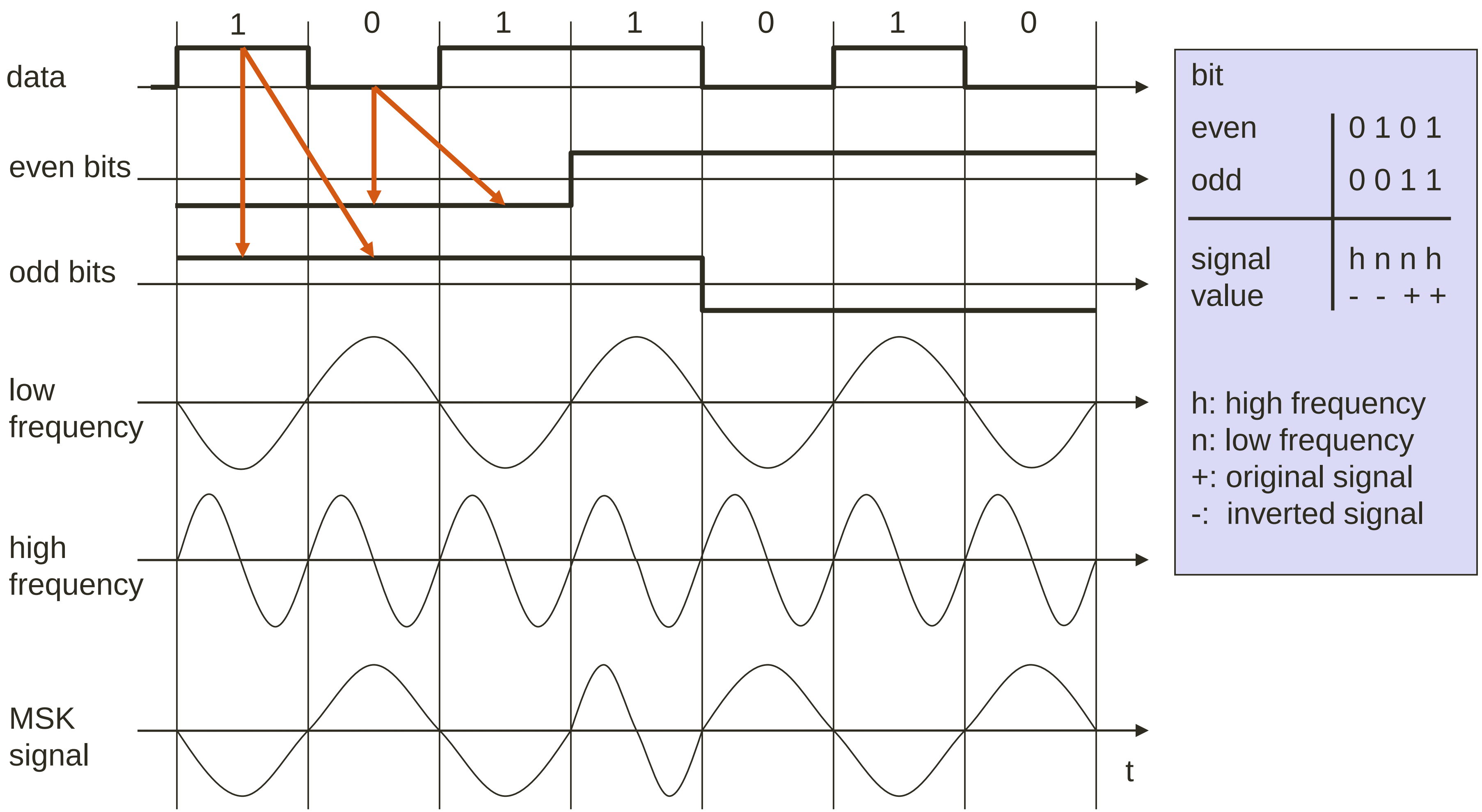
EXAMPLE OF MSK



EXAMPLE OF MSK



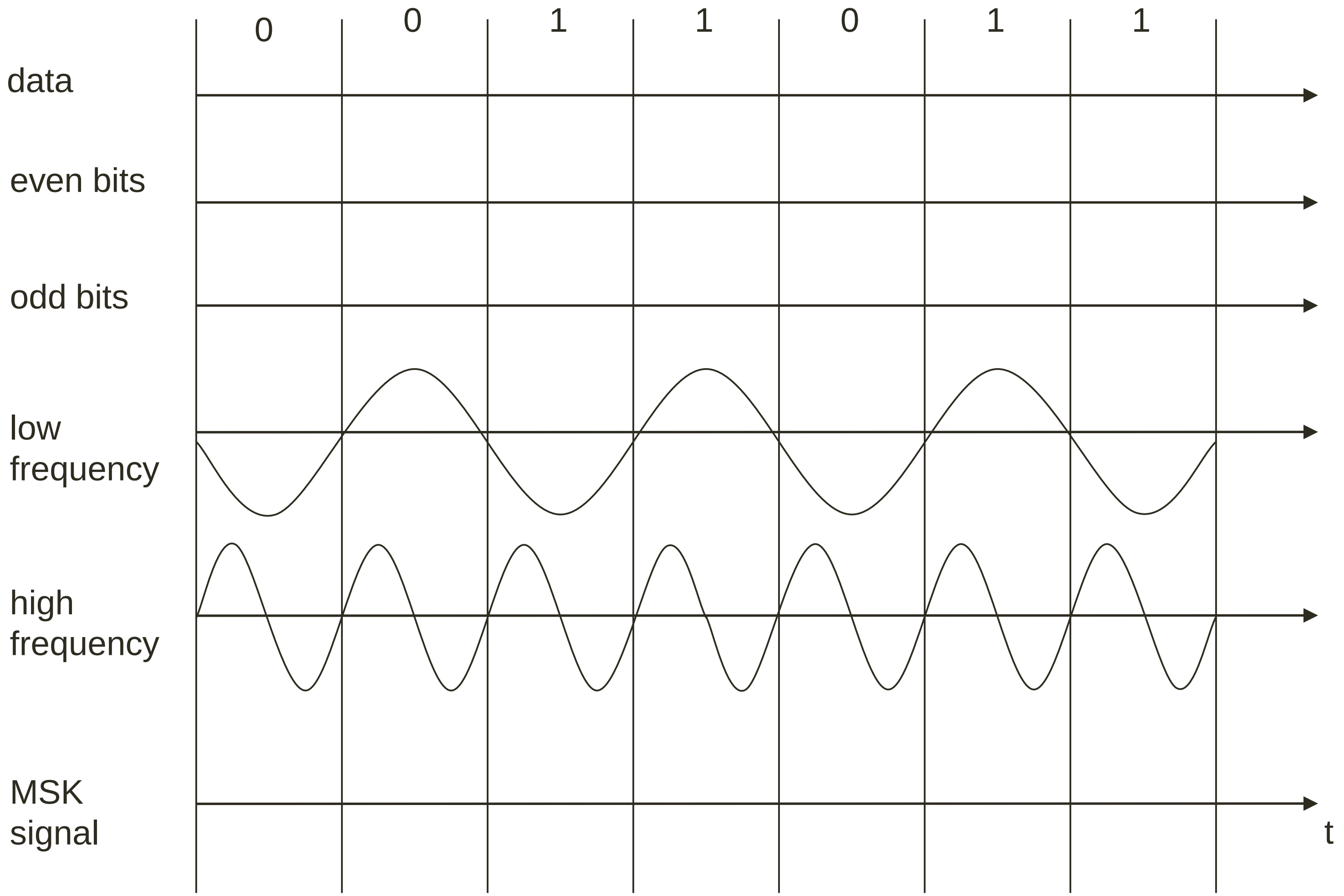
EXAMPLE OF MSK



EX:

Draw the resultant signal for the given bit sequence “00110110” using MSK scheme?

EX: **Draw the resultant signal for the given bit sequence “00110110” using MSK scheme?**



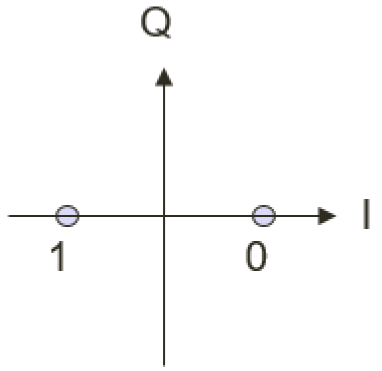
bit	
even	0 1 0 1
odd	0 0 1 1
signal	h n n h
value	- - + +

h: high frequency
n: low frequency
+: original signal
-: inverted signal

ADVANCED PHASE SHIFT KEYING

BPSK (Binary Phase Shift Keying):

- bit value 0: sine wave
- bit value 1: inverted sine wave
- very simple PSK
- low spectral efficiency
- robust, used e.g. in satellite systems

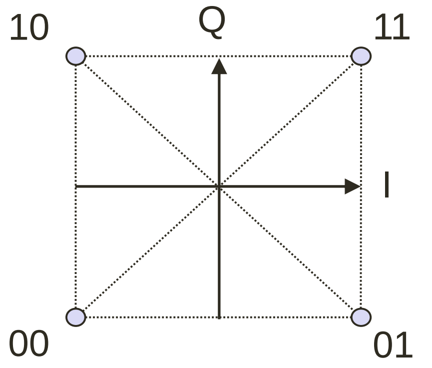


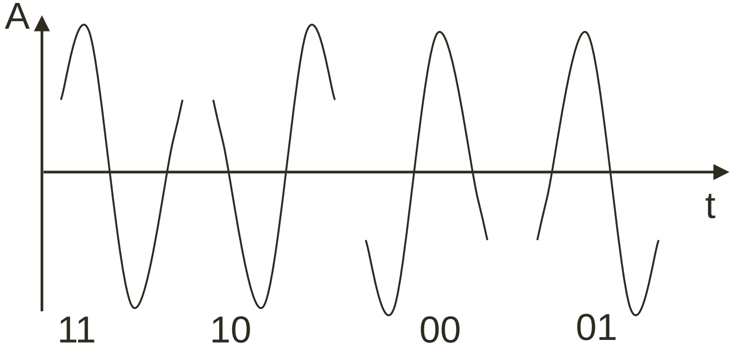
ADVANCED PHASE SHIFT KEYING

QPSK (Quadrature Phase Shift Keying):

- 2 bits coded as one symbol
- symbol determines shift of sine wave
- needs less bandwidth compared to BPSK
- more complex

Often also transmission of relative, not absolute phase shift: DQPSK - Differential QPSK (IS-136, PHS)





EX.

Draw the bit sequence “00110110” using QPSK (Quadrature Phase Shift Keying).

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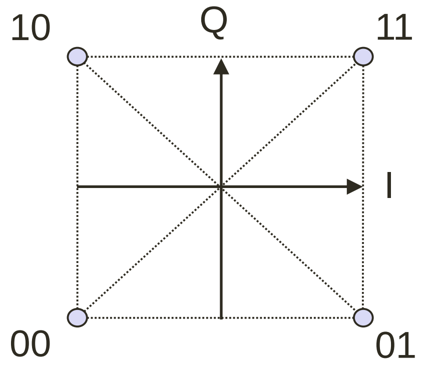
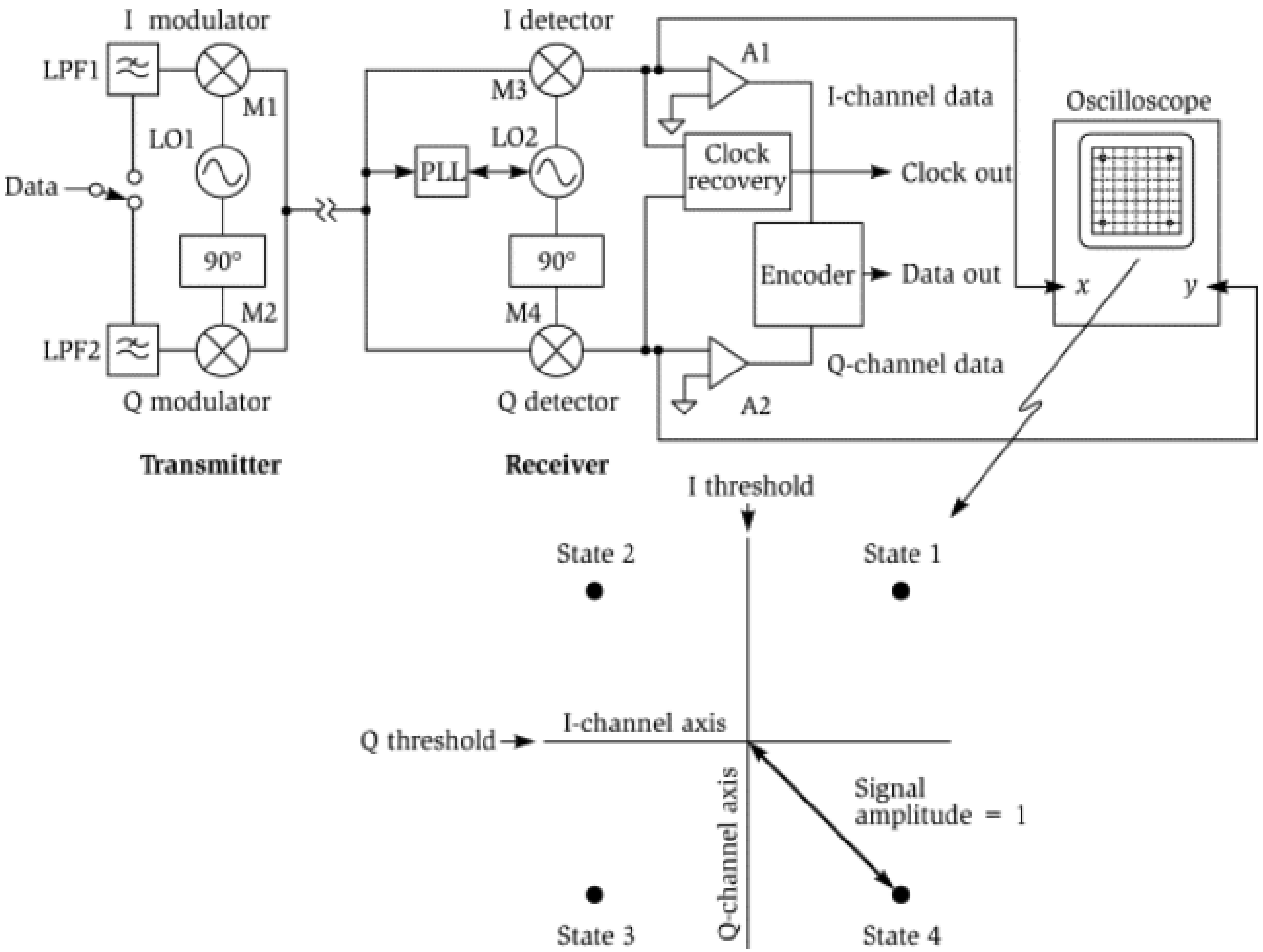


Basic QPSK Modulator and Demodulator



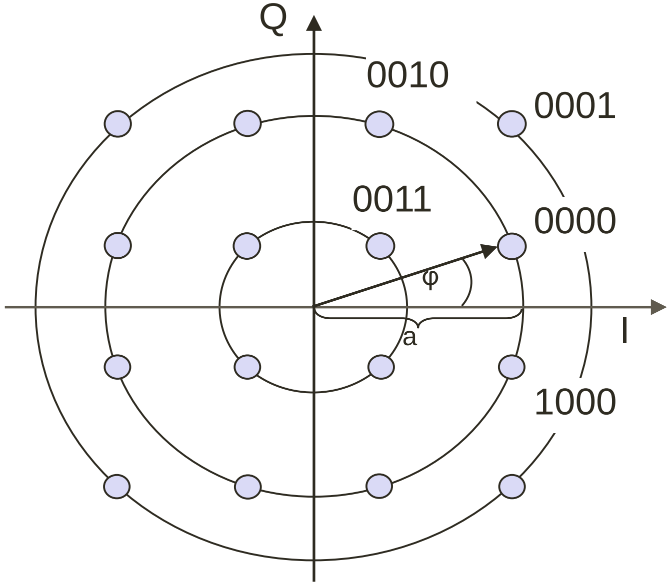
QUADRATURE AMPLITUDE MODULATION

. Quadrature Amplitude Modulation (QAM)

- combines amplitude and phase modulation
- it is possible to code n bits using one symbol
- 2^n discrete levels, n=2 identical to QPSK

Bit error rate increases with n, but less errors compared to comparable PSK schemes

- Example: 16-QAM (4 bits = 1 symbol)
- Symbols 0011 and 0001 have the same phase ϕ, but different amplitude a.
- 0000 and 1000 have different phase, but same amplitude



HIERARCHICAL MODULATION

DVB-T modulates two separate data streams onto a single DVB-T stream

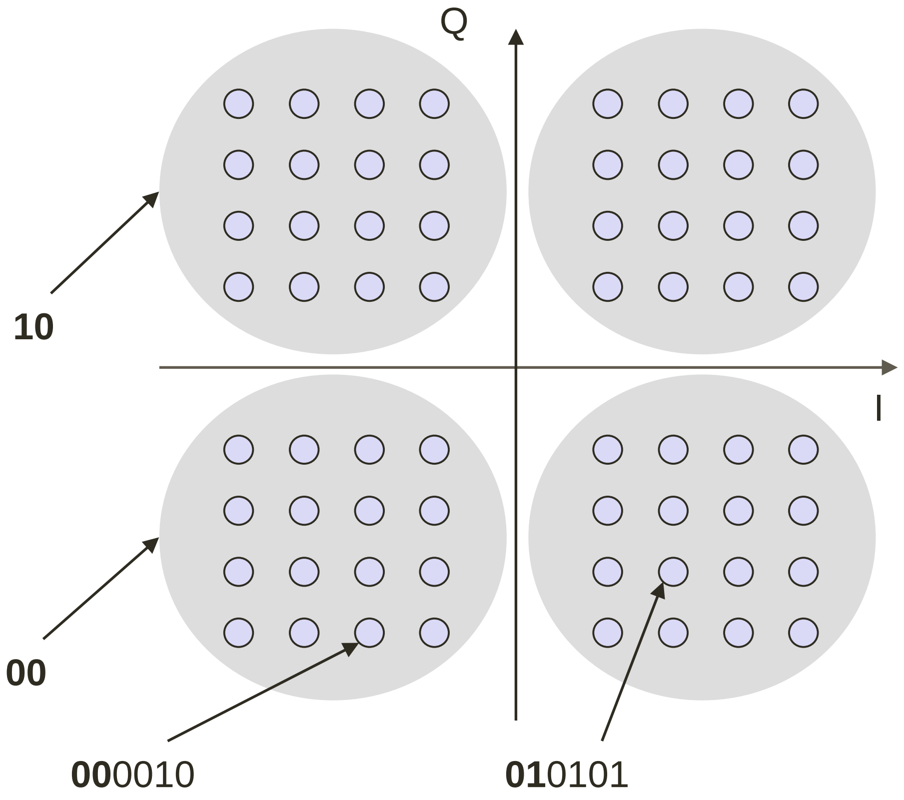
High Priority (HP) embedded within a Low Priority (LP) stream

Multi carrier system, about 2000 or 8000 carriers

QPSK, 16 QAM, 64QAM

Example: 64QAM

- good reception: resolve the entire 64QAM constellation
- poor reception, mobile reception: resolve only QPSK portion
- 6 bit per QAM symbol, 2 most significant determine QPSK
- HP service coded in QPSK (2 bit), LP uses remaining 4 bit



FREQUENCY DOMAIN

Fundamental frequency - when all frequency components of a signal are integer multiples of one frequency, it's referred to as the fundamental frequency

Spectrum - range of frequencies that a signal contains

Absolute bandwidth - width of the spectrum of a signal

Effective bandwidth (or just bandwidth) - narrow band of frequencies that most of the signal's energy is contained in

BIT RATES, CHANNEL CAPACITY

Impairments, such as noise, limit data rate that can be achieved

For digital data, to what extent do impairments limit data rate?

Channel Capacity – the maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions

SIGNAL-TO-NOISE RATIO

Ratio of the power in a signal to the power contained in the noise that's present at a particular point in the transmission

Typically measured at a receiver

Signal-to-noise ratio (SNR, or S/N)

$$(SNR)_{\text{dB}} = 10 \log_{10} \frac{\text{signal power}}{\text{noise power}}$$

A high SNR means a high-quality signal, low number of required intermediate repeaters

SNR sets upper bound on achievable data rate

SHANNON CAPACITY FORMULA

Equation: $$C = B\log_2(1+\mathrm{SNR})$$

Represents theoretical maximum that can be achieved

In practice, only much lower rates achieved

- Formula assumes white noise (thermal noise)
- Impulse noise is not accounted for
- Attenuation distortion or delay distortion not accounted for

EXAMPLE OF NYQUIST AND SHANNON FORMULATIONS

Spectrum of a channel between 3 MHz and 4 MHz ; SNR_{dB} = 24 dB

$$B = 4\ \mathrm{MHz} - 3\ \mathrm{MHz} = 1\ \mathrm{MHz}$$

$$\mathrm{SNR}_{\mathrm{dB}} = 24\ \mathrm{dB} = 10\log_{10}(\mathrm{SNR})$$

$$\mathrm{SNR} = 251$$

Using Shannon's formula $C = B\log_2(1 + \mathrm{SNR})$

$$C = 10^6 \times \log_2(1 + 251) \approx 10^6 \times 8 = 8\mathrm{Mbps}$$

SHANNON CAPACITY FORMULA – EXAMPLE 1

Binary data is transmitted through an additive white Gaussian noise (AWGN) channel with SNR = 3.5 dB and bandwidth B. Channel coding is used to ensure reliable communications. Then:

i. What is the maximum bit rate that can be transmitted?

ii. If the bit rate is increased to 3B, how much must the channel SNR be increased to ensure reliable transmission?

SHANNON CAPACITY FORMULA – EXAMPLE 1

SNR = 3.5 dB (=2.24 in ratio)

i. Channel capacity is given by Shannon equation (3.1):

$$C = B \cdot \log_2(1 + 2.24) = B \cdot \log_2(3.24)$$
$$= B \cdot \frac{\log_{10}(3.24)}{\log_2(2)} = 1.7B$$

Note the maximum bit rate for binary transmission that can be achieved with no errors in an ideal channel (no noise) is 2B. In this example the bit rate is about 1.7B.

ii. $C = 3B = B\log_2(1 + SNR)$ where SNR represents the channel's new signal-to-noise ratio.

Thus $(1 + SNR) = 2^3 = 8$, therefore, $SNR = 7 = 8.45$ dB

The increase in the channel $SNR = 8.45 - 3.5 = 4.95$ dB.

Note in this case, the bit rate is greater than 2B and the transmission of the data over the channel is multi-level but the symbol rate is still 2B.

EXAMPLE OF NYQUIST AND SHANNON FORMULATIONS

How many signaling levels are required?

$$C = 2B\log_2 M$$

$$8\times10^6 = 2\times\left(10^6\right)\times\log_2 M$$

$$4 = \log_2 M$$

$$M = 16$$

FREQUENCIES FOR WIRELESS COMMUNICATION

VLF = Very Low Frequency

LF = Low Frequency

MF = Medium Frequency

HF = High Frequency

VHF = Very High Frequency

UHF = Ultra High Frequency

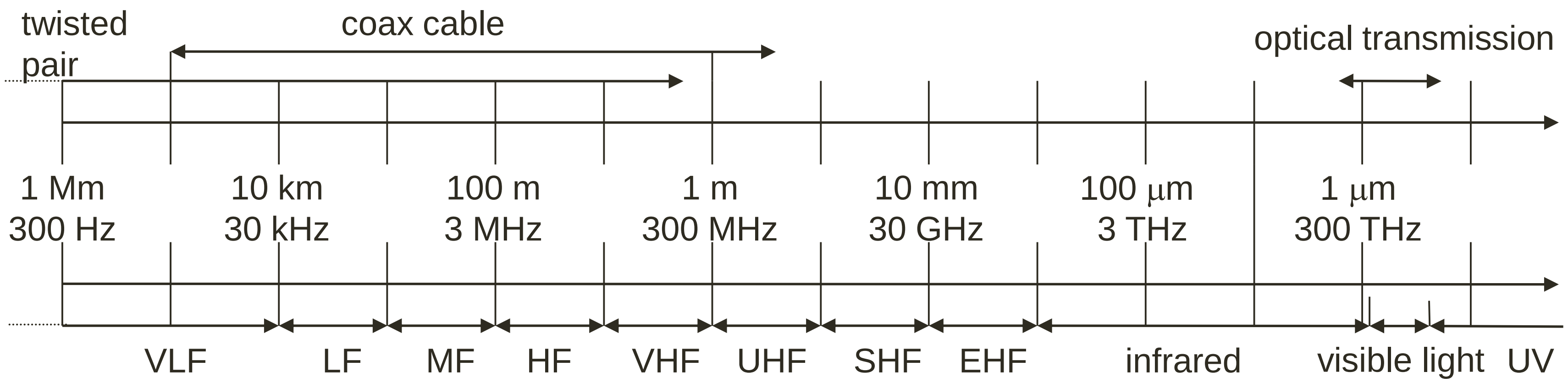
SHF = Super High Frequency

EHF = Extra High Frequency

UV = Ultraviolet Light

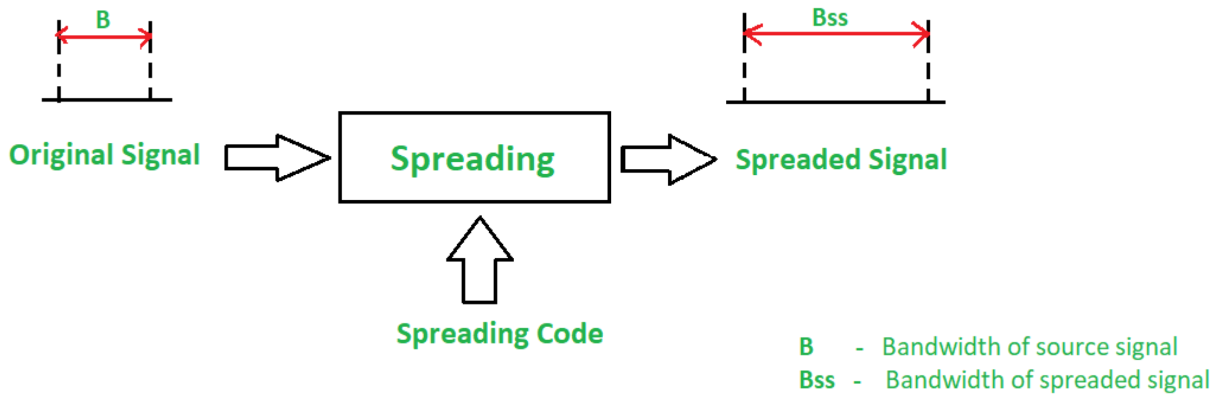
Frequency and wave length

- $\lambda = c/f$
- wave length λ, speed of light $c \cong 3 \times 10^8$ m/s, frequency f



Spread Spectrum

- A spread-spectrum system is one in which the transmitted signal is spread over a wide frequency band, much wider than the bandwidth required to transmit the message.
- Such a system would take a baseband voice signal with a bandwidth of a few kilohertz and spread it to a band of many megahertz.



Spread Spectrum Concept

Input fed into channel encoder

- Produces narrow bandwidth analog signal around central frequency

Signal modulated using sequence of digits

- Spreading code/sequence
- Typically generated by pseudonoise/pseudorandom number generator

Increases bandwidth significantly

- Spreads spectrum

Receiver uses same sequence to demodulate signal

Demodulated signal fed into channel decoder

Spread Spectrum

Two types of spread-spectrum systems are:

- Direct-sequence system: A digital code sequence with a bit rate higher than the message is used to obtain the modulated signal.
- Frequency-hopping system: The carrier frequency is shifted in discrete increments in a pattern dictated by a code sequence. We will not consider this here.

DIRECT SEQUENCE SPREAD SPECTRUM (DSSS)

Each bit represented by multiple bits using spreading code

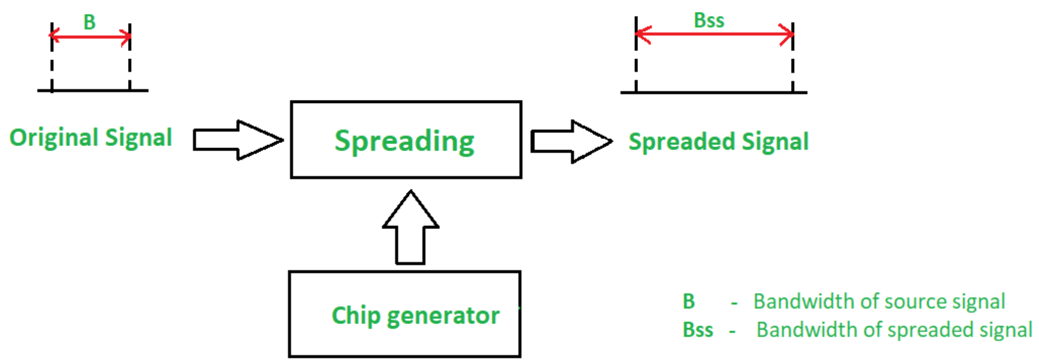
Spreading code spreads signal across wider frequency band

- In proportion to number of bits used
- 10 bit spreading code spreads signal across 10 times bandwidth of 1 bit code

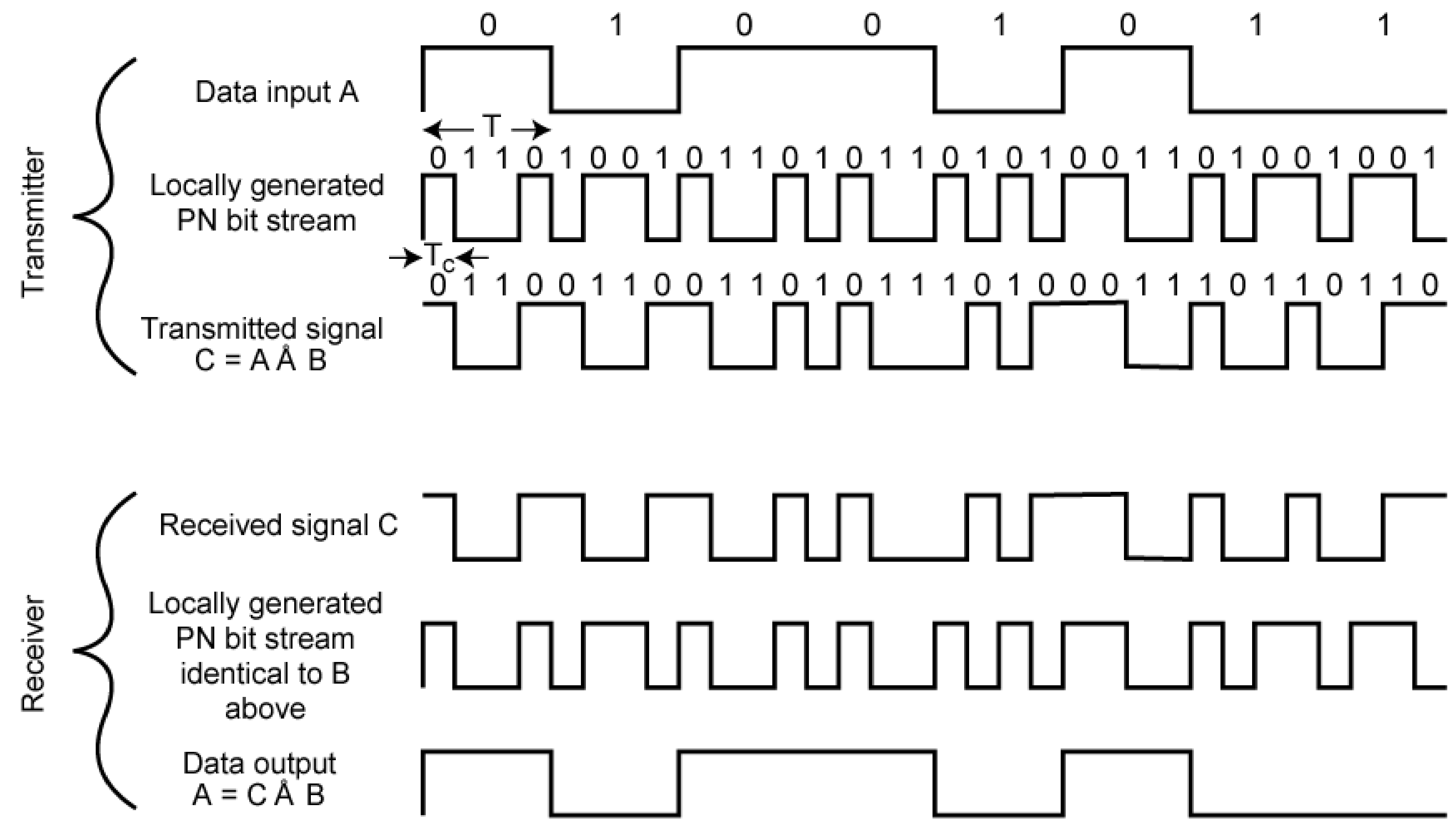
One method:

- Combine input with spreading code using XOR
- Input bit 1 inverts spreading code bit
- Input zero bit doesn't alter spreading code bit
- Data rate equal to original spreading code

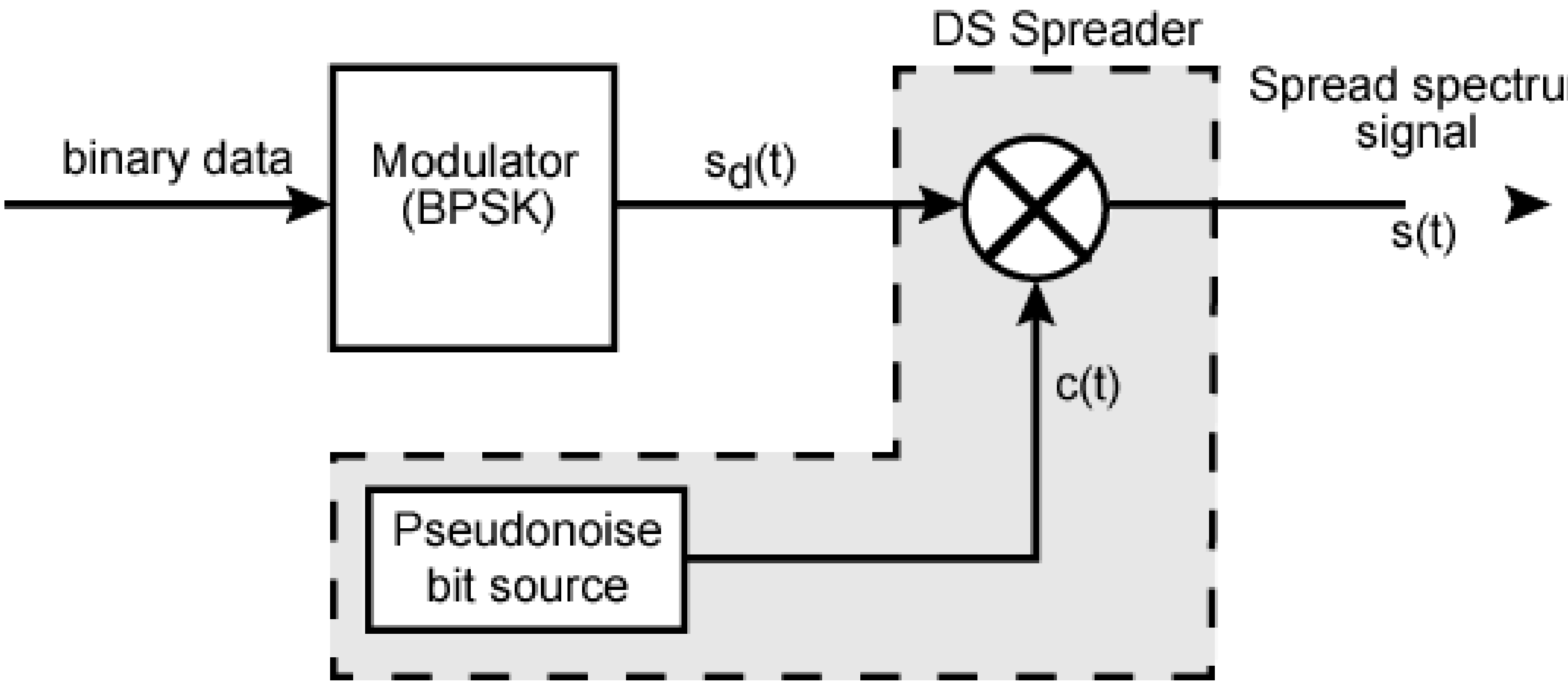
Performance similar to FHSS



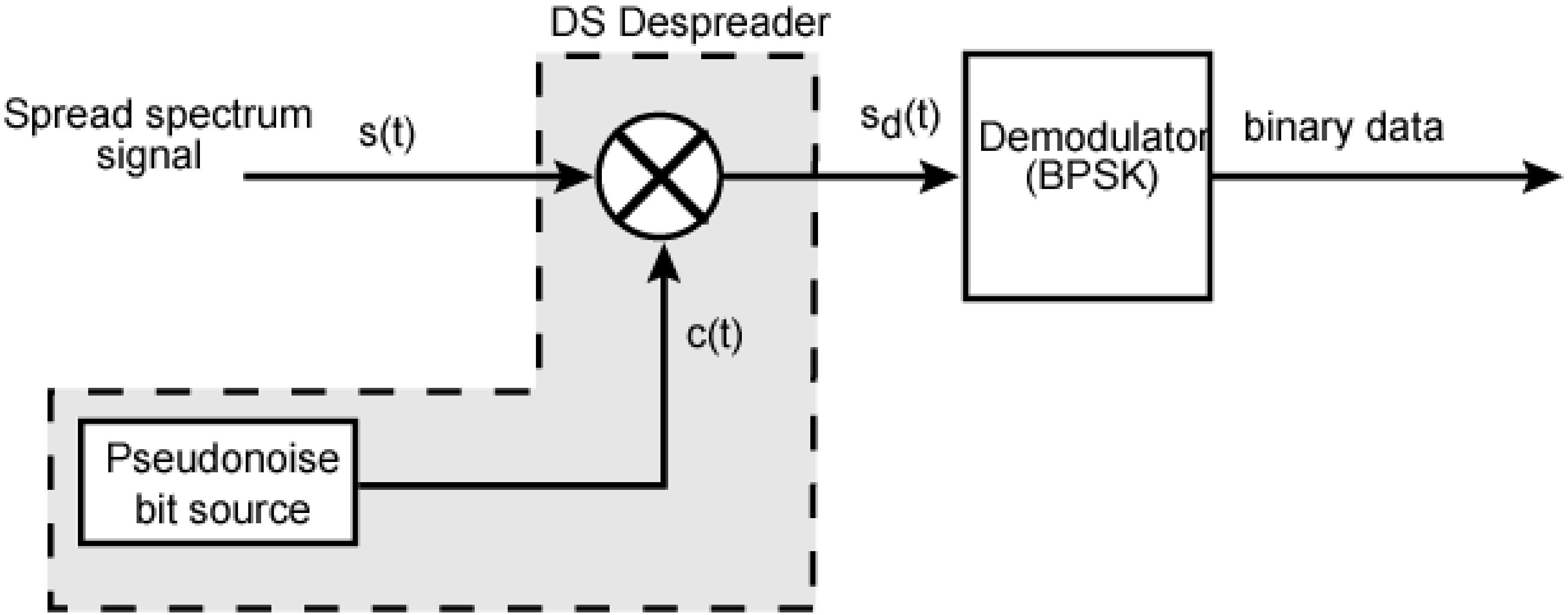
DIRECT SEQUENCE SPREAD SPECTRUM EXAMPLE



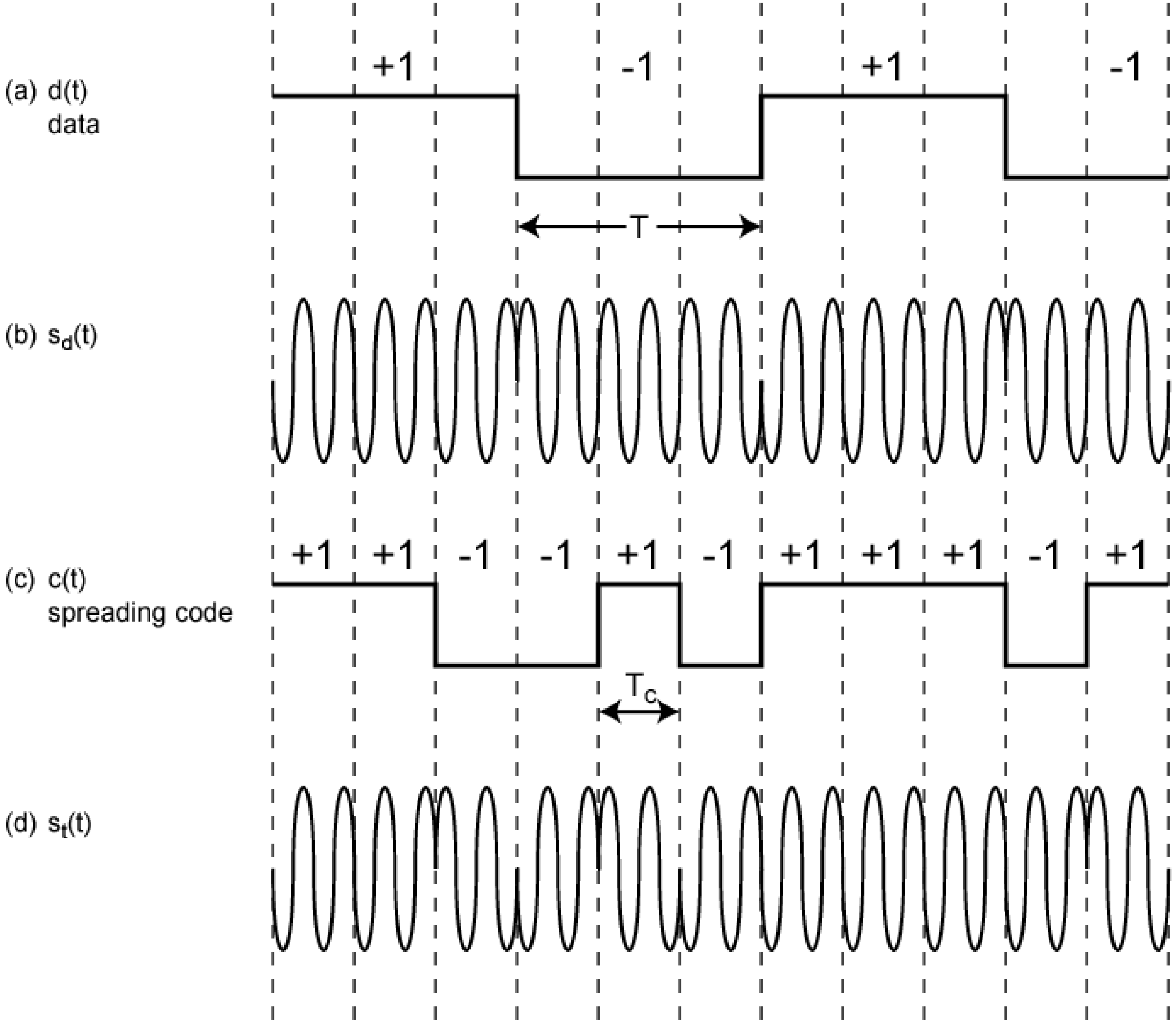
DIRECT SEQUENCE SPREAD SPECTRUM TRANSMITTER



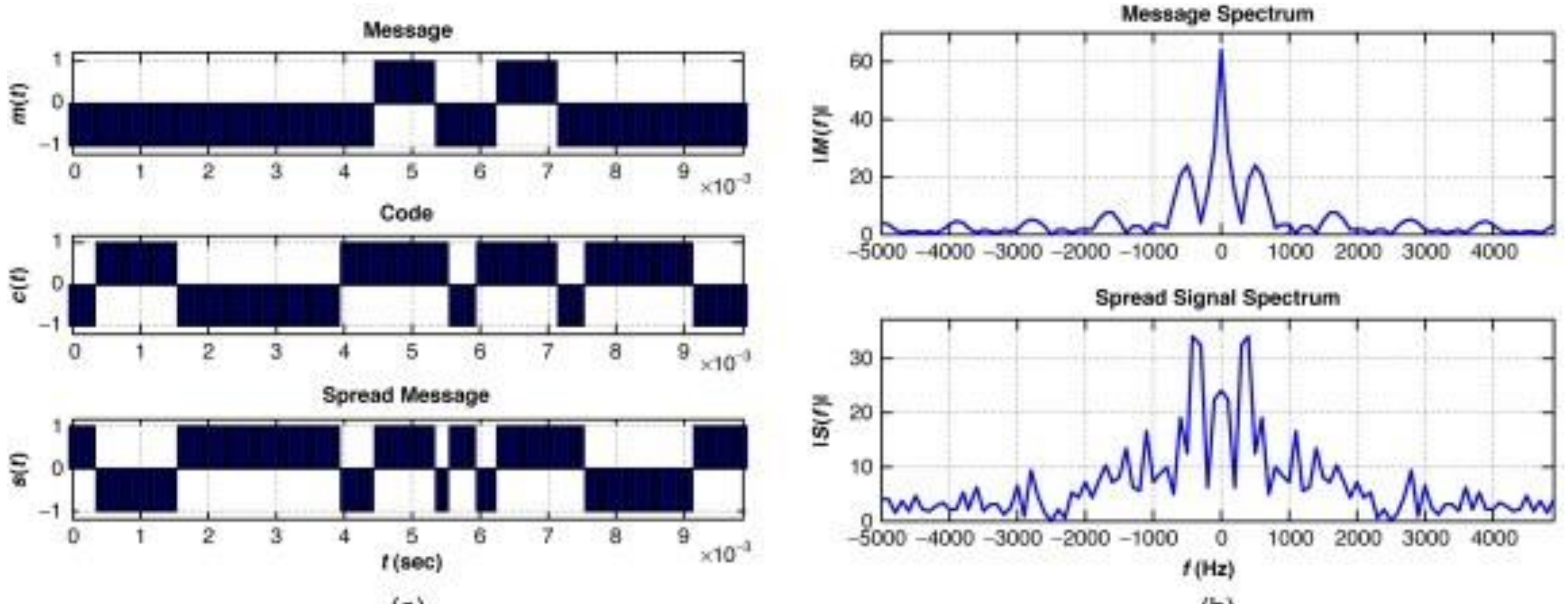
DIRECT SEQUENCE SPREAD SPECTRUM TRANSMITTER



DIRECT SEQUENCE SPREAD SPECTRUM USING BPSK EXAMPLE

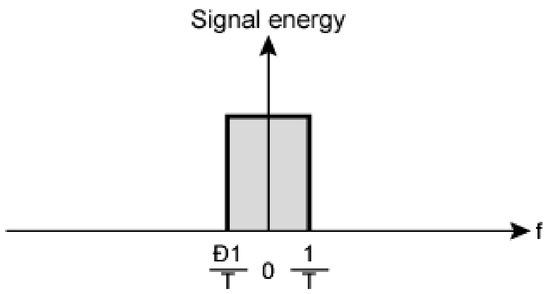


DIRECT SEQUENCE SPREAD SPECTRUM USING BPSK EXAMPLE

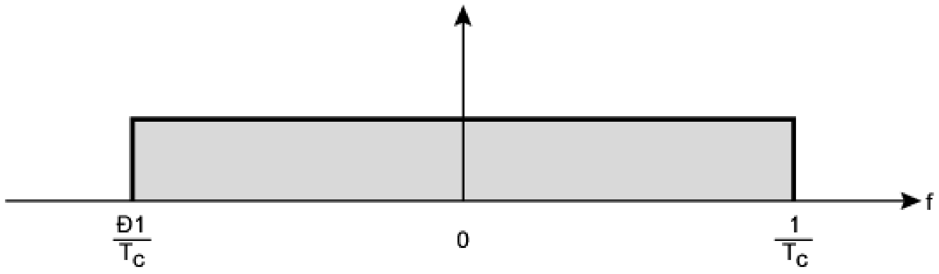


(a)
(b)

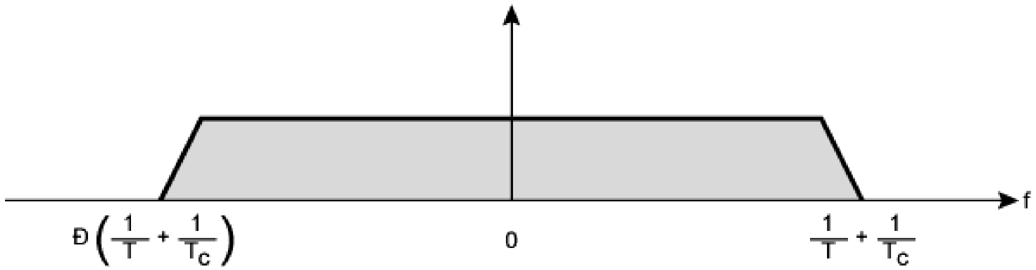
APPROXIMATE SPECTRUM OF DSSS SIGNAL



(a) Spectrum of data signal

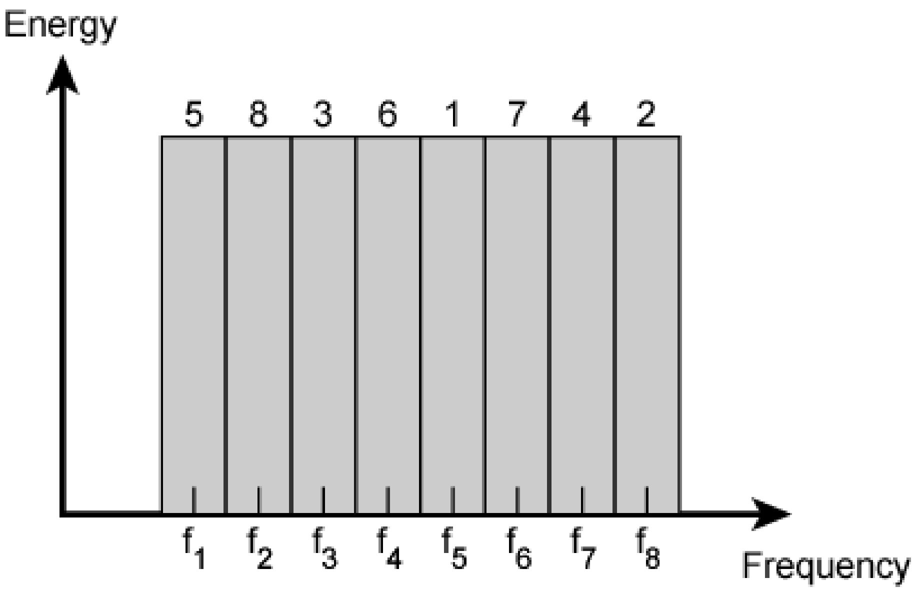


(b) Spectrum of pseudonoise signal

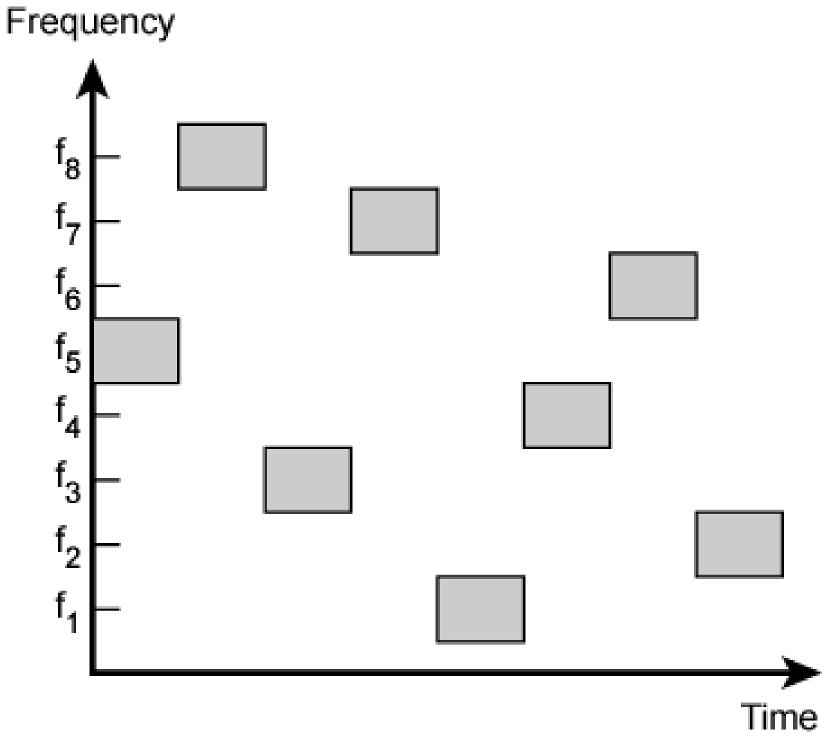


(c) Spectrum of combined signal

FREQUENCY HOPPING EXAMPLE

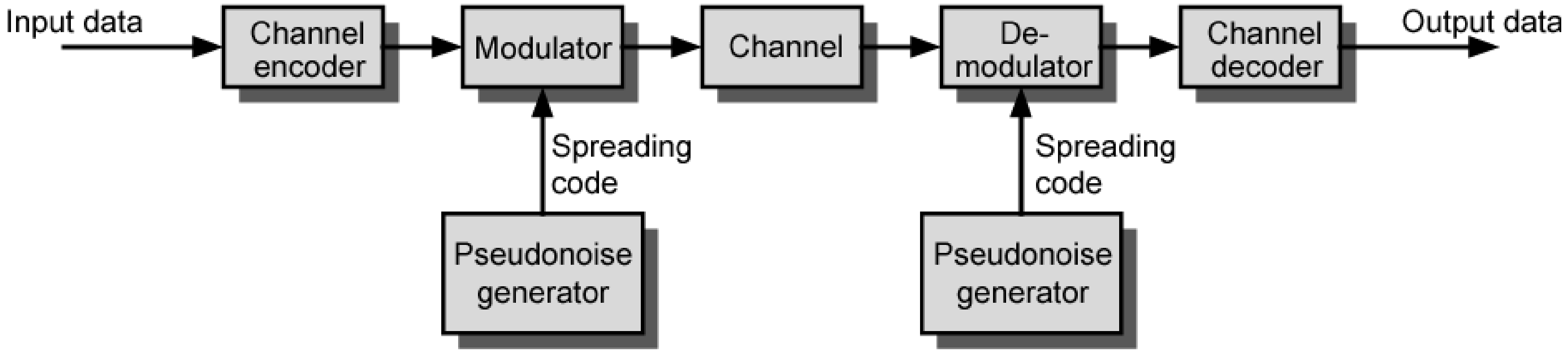


(a) Channel assignment



(b) Channel use

GENERAL MODEL OF SPREAD SPECTRUM SYSTEM



GAINS

Immunity from various noise and multipath distortion

- Including jamming

Can hide/encrypt signals

- Only receiver who knows spreading code can retrieve signal

Several users can share same higher bandwidth with little interference

- Cellular telephones
- Code division multiplexing (CDM)
- Code division multiple access (CDMA)

PSEUDORANDOM NUMBERS

Generated by algorithm using initial seed

Deterministic algorithm

- Not actually random
- If algorithm good, results pass reasonable tests of randomness

Need to know algorithm and seed to predict sequence

FREQUENCY HOPPING SPREAD SPECTRUM (FHSS)

- FHSS is a wireless technology that spreads its signal over rapidly hopping radio frequencies, it is highly resistant to interference and is difficult to intercept.
- Interference at a specific frequency only affects the transmission during that extremely short interval, making FHSS inherently cybersecure.

  - Signal 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

BASIC OPERATION

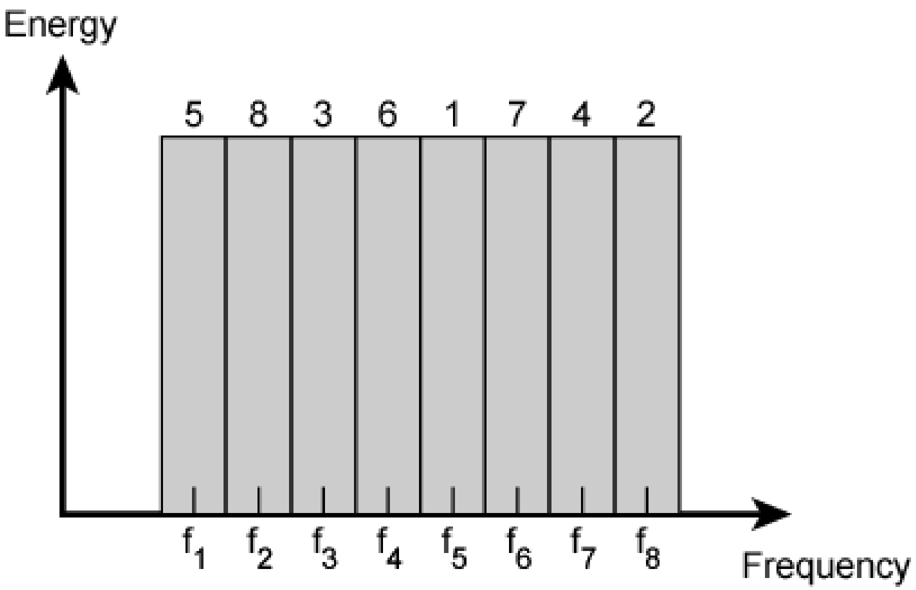
Typically 2^k carriers frequencies forming 2^k channels

Channel spacing corresponds with bandwidth of input

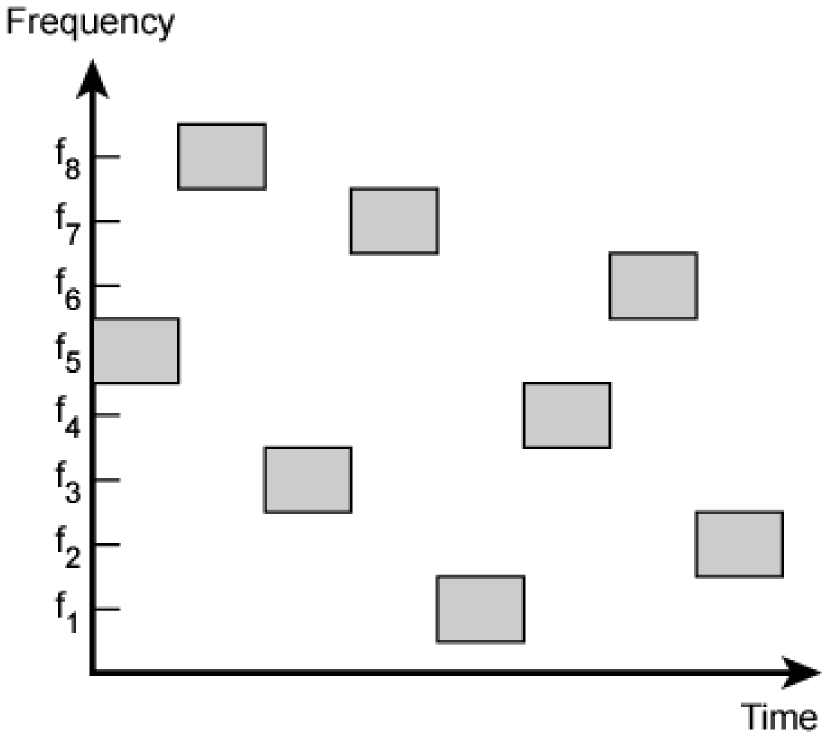
Each channel used for fixed interval

- 300 ms in IEEE 802.11
- Some number of bits transmitted using some encoding scheme
  - May be fractions of bit
- Sequence dictated by spreading code

FREQUENCY HOPPING EXAMPLE

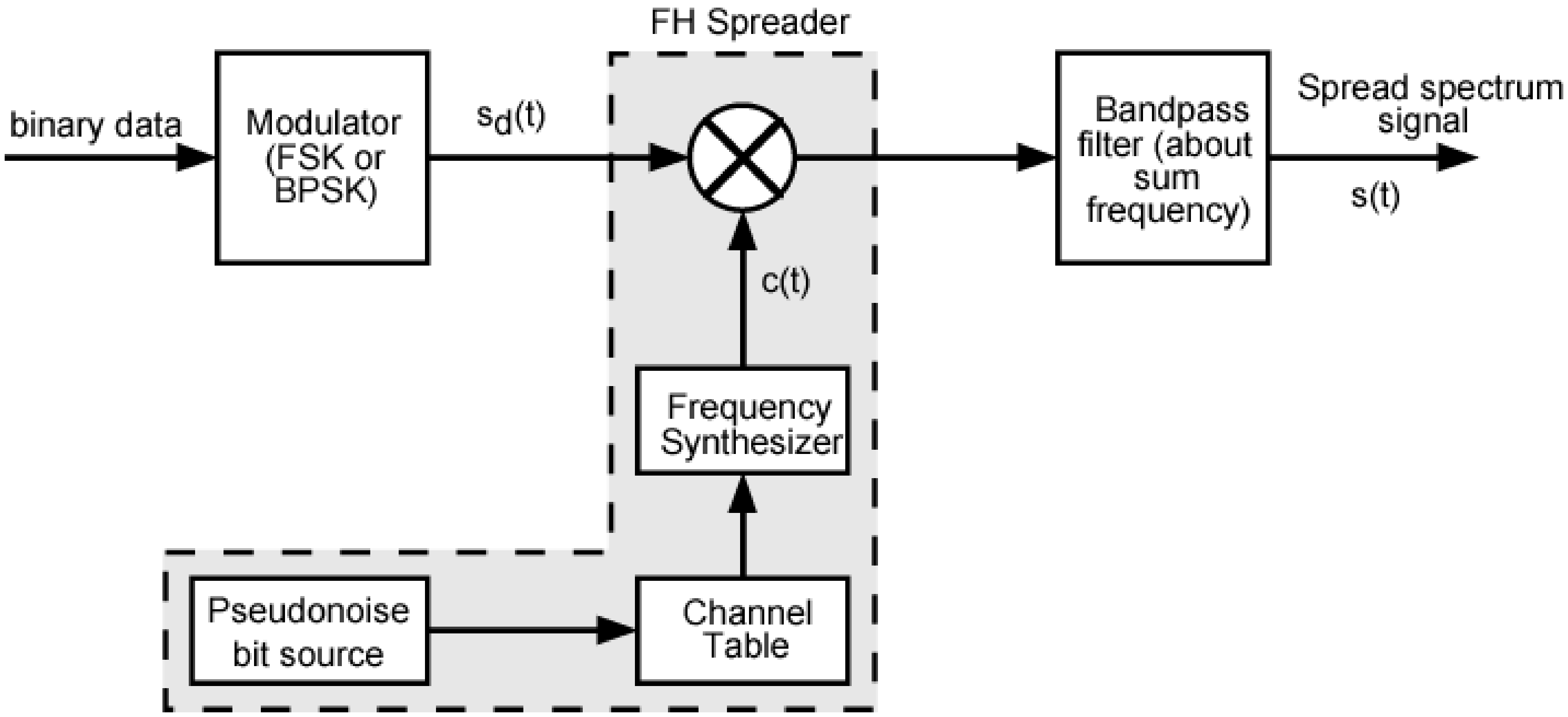


(a) Channel assignment

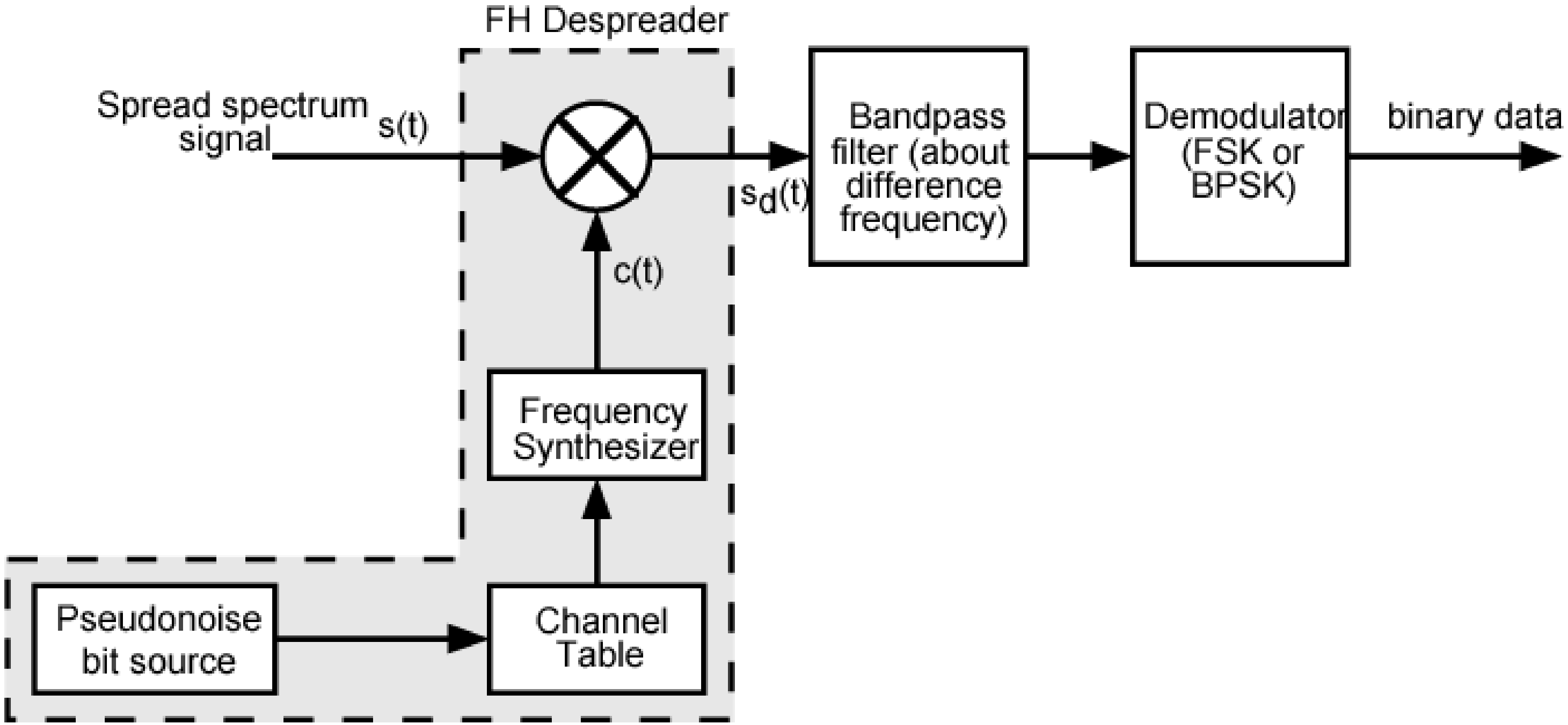


(b) Channel use

FREQUENCY HOPPING SPREAD SPECTRUM SYSTEM (TRANSMITTER)



FREQUENCY HOPPING SPREAD SPECTRUM SYSTEM (RECEIVER)



SLOW AND FAST FHSS

Frequency shifted every T_c seconds

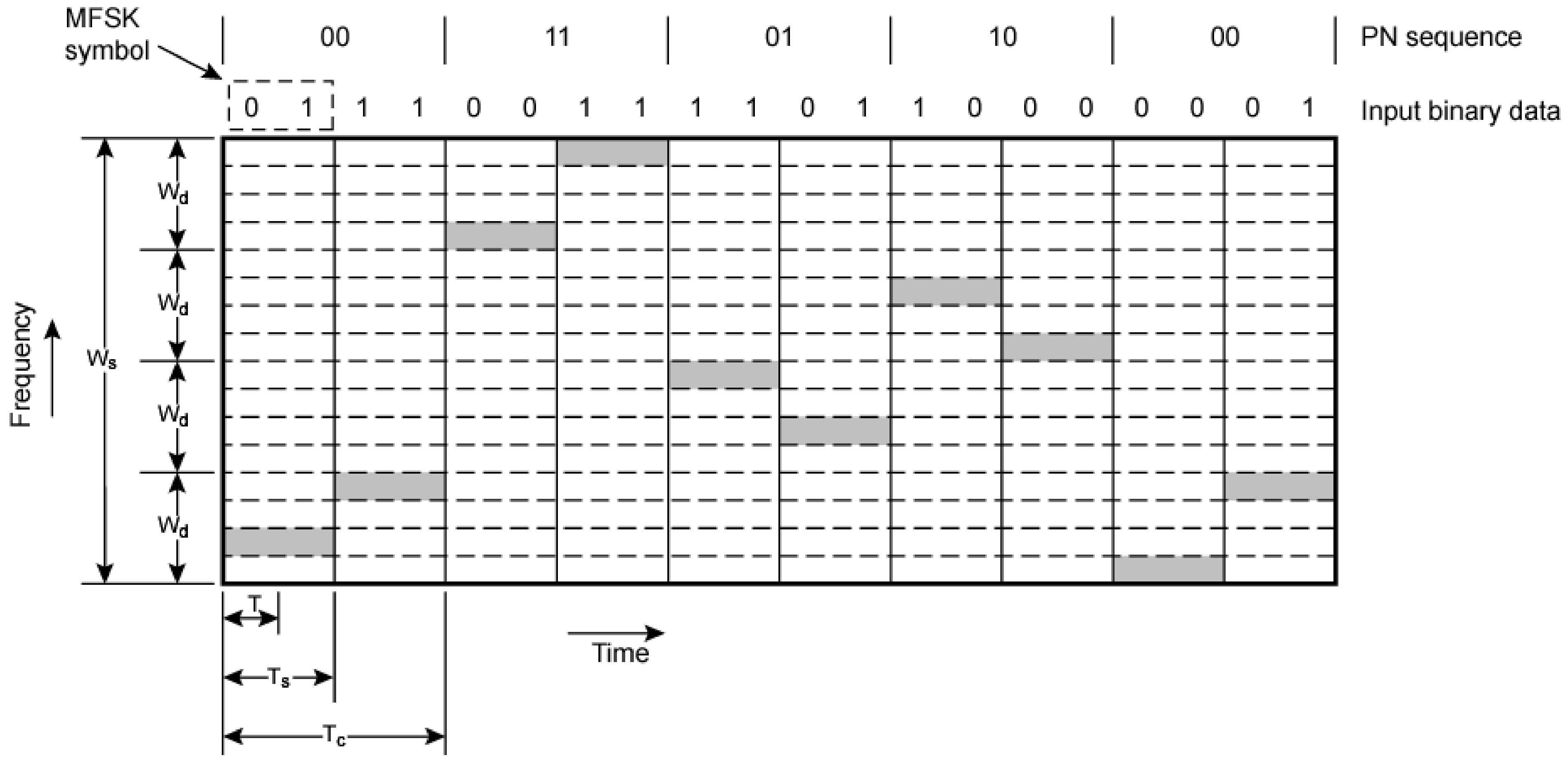
Duration of signal element is T_s seconds

Slow FHSS has $T_c \geq T_s$

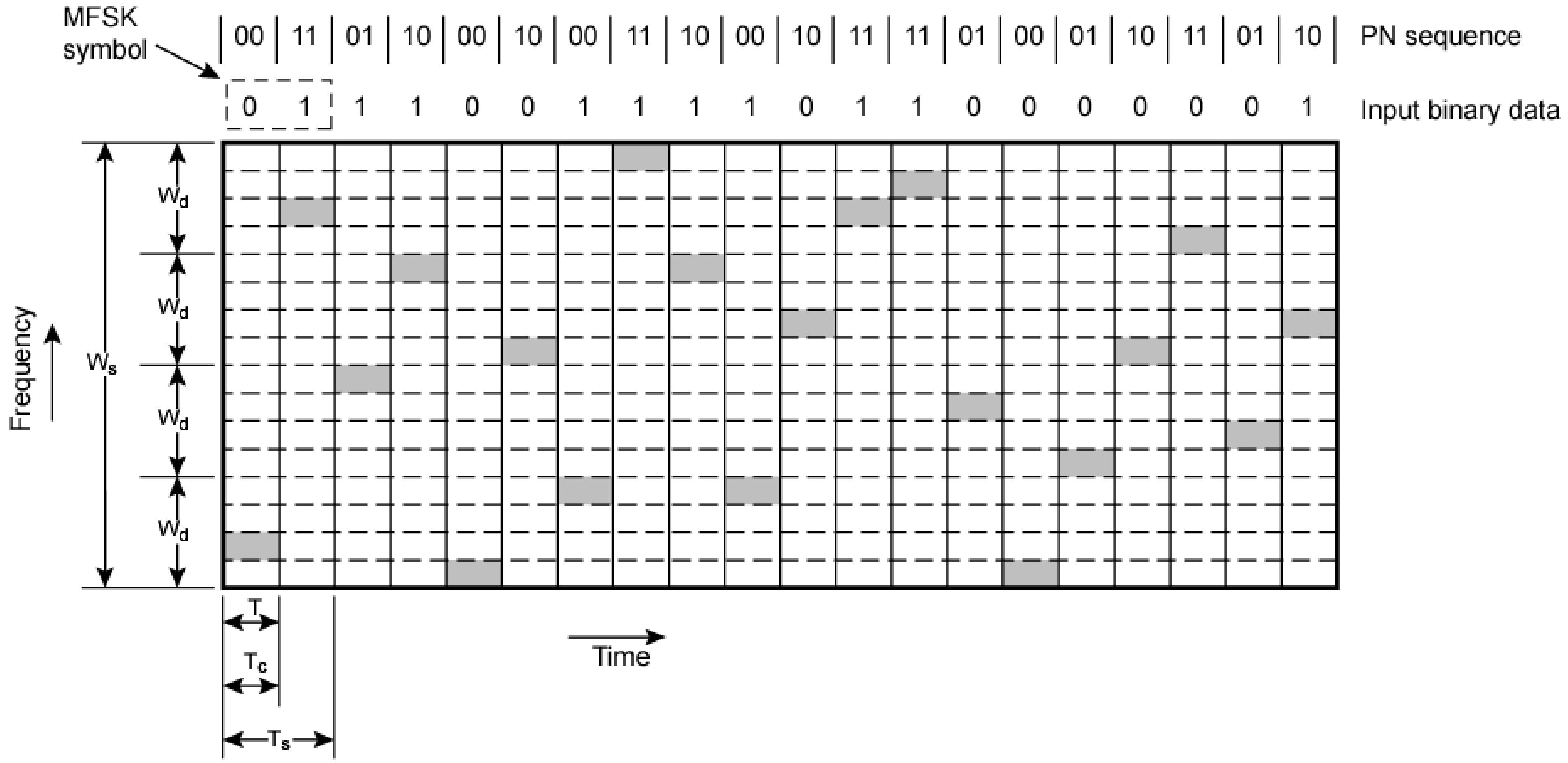
Fast FHSS has $T_c < T_s$

Generally fast FHSS gives improved performance in noise (or jamming)

SLOW FREQUENCY HOP SPREAD SPECTRUM USING MFSK (M=4, K=2)



FAST FREQUENCY HOP SPREAD SPECTRUM USING MFSK (M=4, K=2)



FHSS AND WLAN ACCESS POINTS

IEEE 802.11 FHSS WLAN specifies 78 hopping channels separated by 1 MHz in 3 groups

(0,3,6,9,…, 75), (1,4,7,…, 76), (2,5,8,…,77)

Allows installation of 3 AP’s in the same area.