# 192620010
# Mobile & Wireless Networking

Lecture 2:
Wireless Transmission (2/2)

[Schiller, Section 2.6 & 2.7]
[Reader Part 1:
OFDM: An architecture for the fourth generation]

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## Outline of Lecture 2

- Wireless Transmission (2/2)
  - Modulation
  - Spread Spectrum
  - Orthogonal Frequency Division Multiplexing (OFDM)

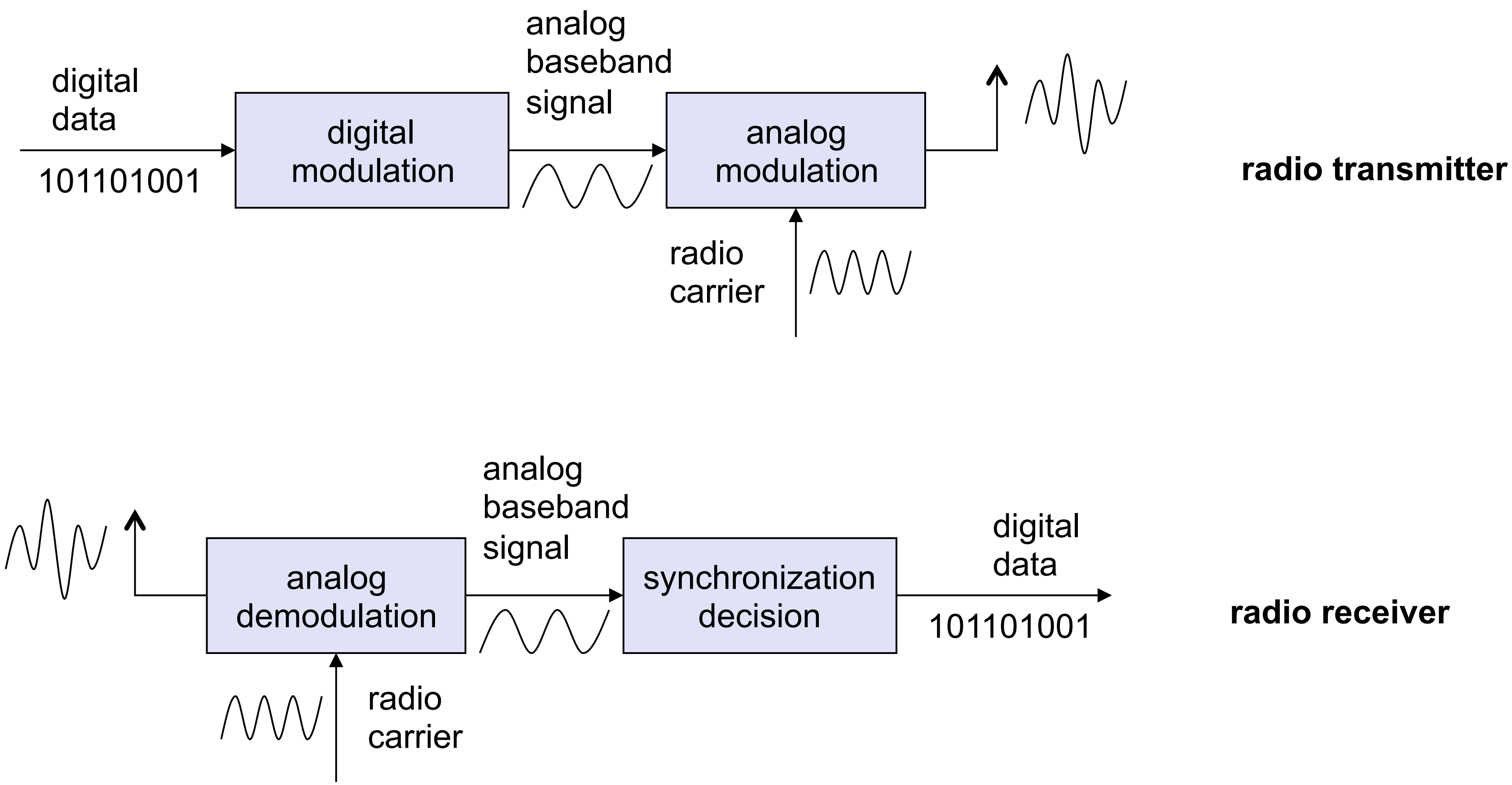
# Modulation

Process of encoding information from a message source in a manner suitable for transmission

Two major steps:

1. Digital modulation
   - digital data is translated into an analog signal (baseband)
2. 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

# Modulation and demodulation



# Modulation

- Carrier

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

- Basic analog modulation schemes schemes
  - Amplitude Modulation (AM)
  - Frequency Modulation (FM)
  - Phase Modulation (PM)
- Digital modulation
  - ASK, FSK, PSK - main focus here
  - differences in spectral efficiency, power efficiency, robustness

# Digital modulation

Modulation of digital signals known as Shift Keying

Amplitude Shift Keying (ASK):

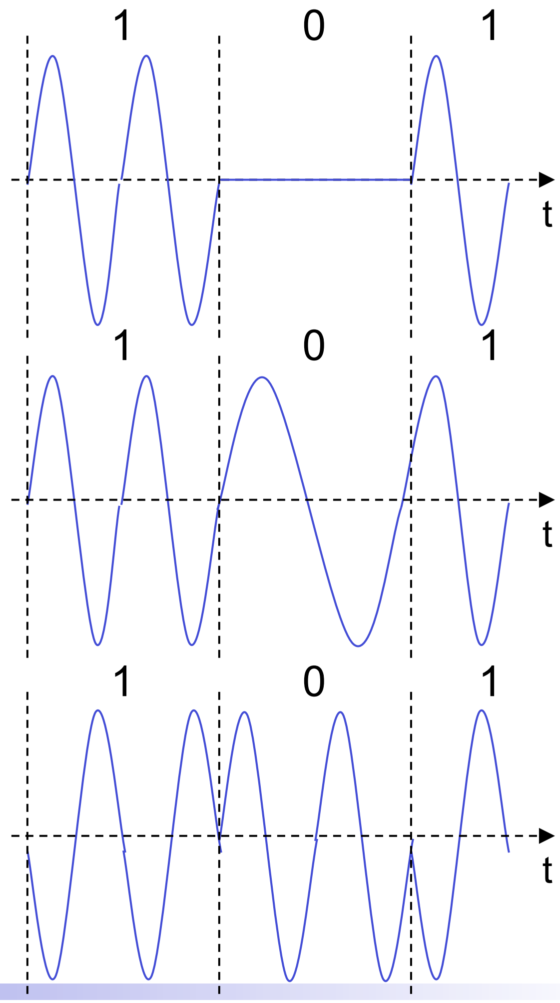
- very simple
- low bandwidth requirements
- very susceptible to interference

Frequency Shift Keying (FSK):

- binary FSK (BFSK)
- continuous phase modulation (CPM)
- needs larger bandwidth

Phase Shift Keying (PSK):

- Binary PSH (BPSK)
- more complex
- robust against interference

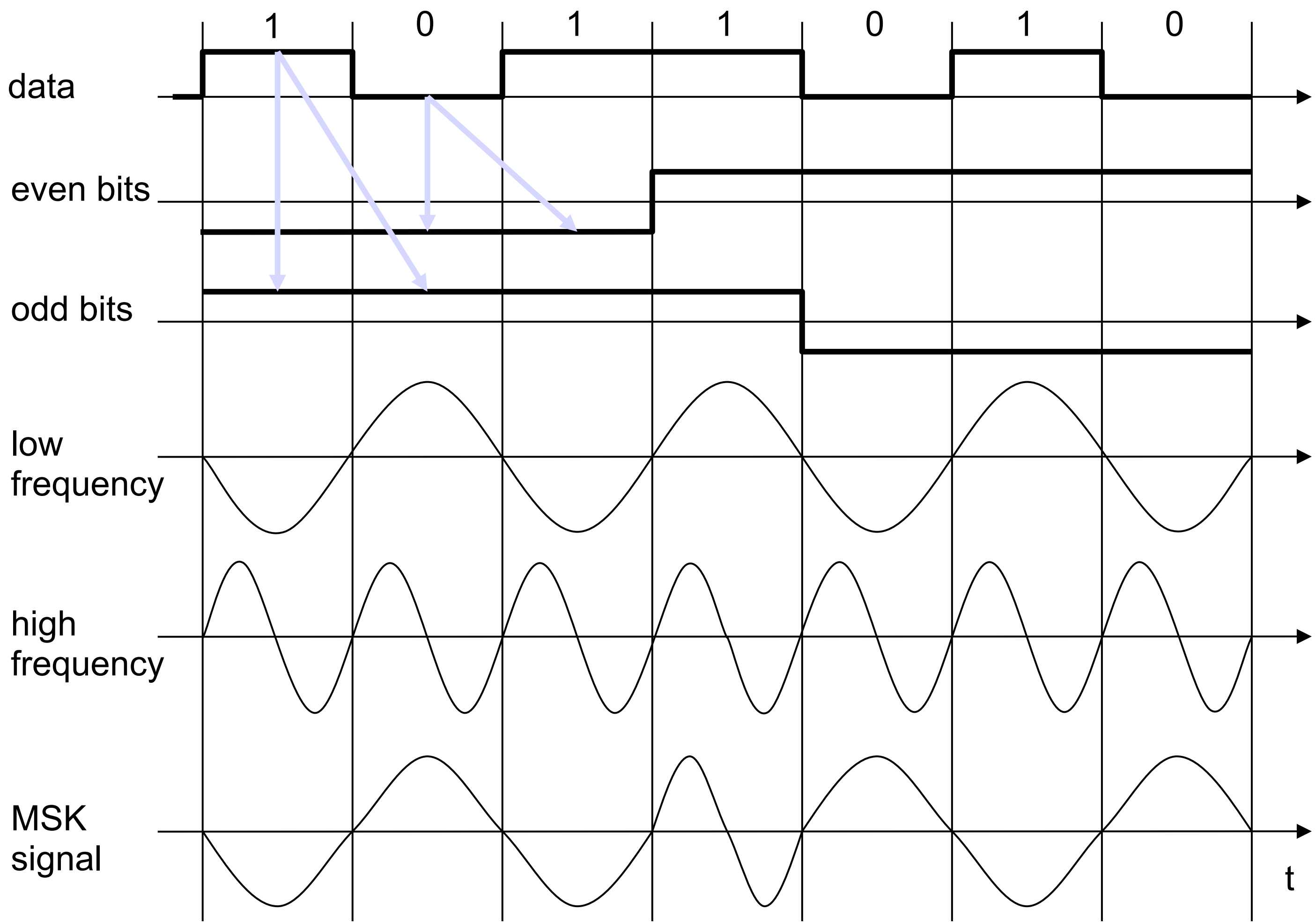


# Advanced Frequency Shift Keying

- bandwidth needed for FSK depends on the distance between the carrier frequencies (and bit rate of source signal)
- special pre-computation avoids sudden phase shifts
  ➔ MSK (Minimum Shift Keying)
- bits separated into even and odd bits,
  the duration of each bit is doubled
- depending on the bit values (even, odd) the higher or lower frequency, original or inverted is chosen
- the frequency of one carrier is twice the frequency of the other

- even higher bandwidth efficiency using a Gaussian low-pass filter ➔ GMSK (Gaussian MSK), used in GSM

# Example of MSK




| bit | |
|---|---|
| even | 0 1 0 1 |
| odd | 0 0 1 1 |
| signal value | h n n h<br>- - + + |

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

No phase shifts!

# Advanced Phase Shift Keying

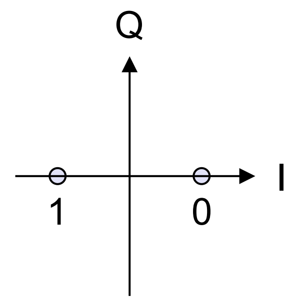
BPSK (Binary Phase Shift Keying):

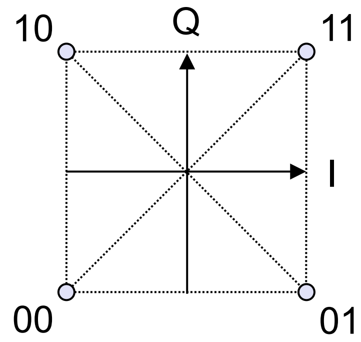
- bit value 0: sine wave
- bit value 1: inverted sine wave
- very simple PSK
- low spectral efficiency
- robust, used e.g. in satellite systems

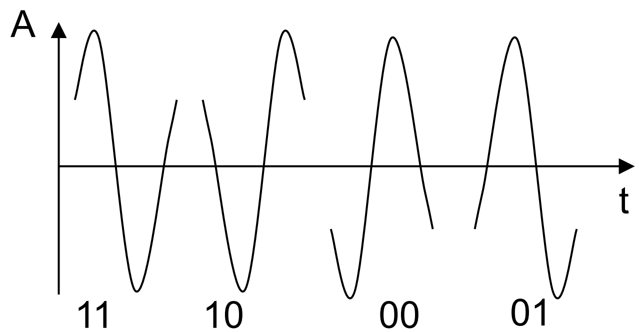
QPSK (Quadrature Phase Shift Keying):

- 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)



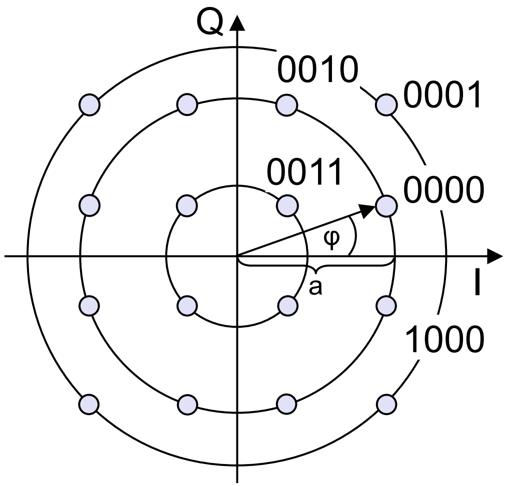



# Quadrature Amplitude Modulation

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



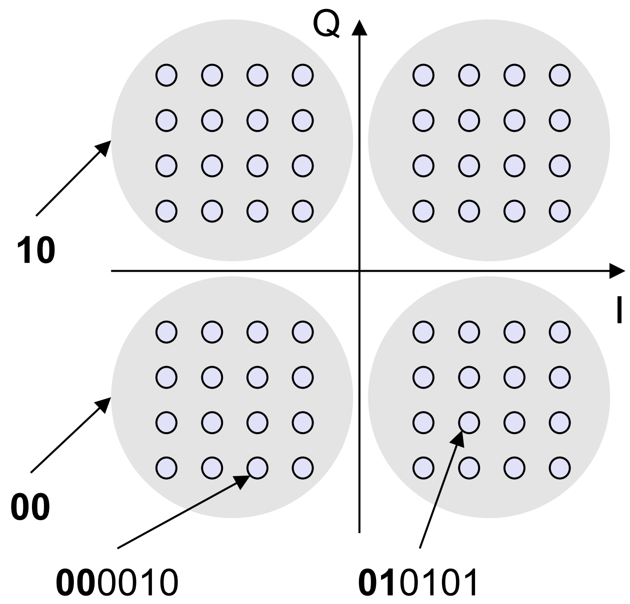

Example: 16-QAM (4 bits = 1 symbol)

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



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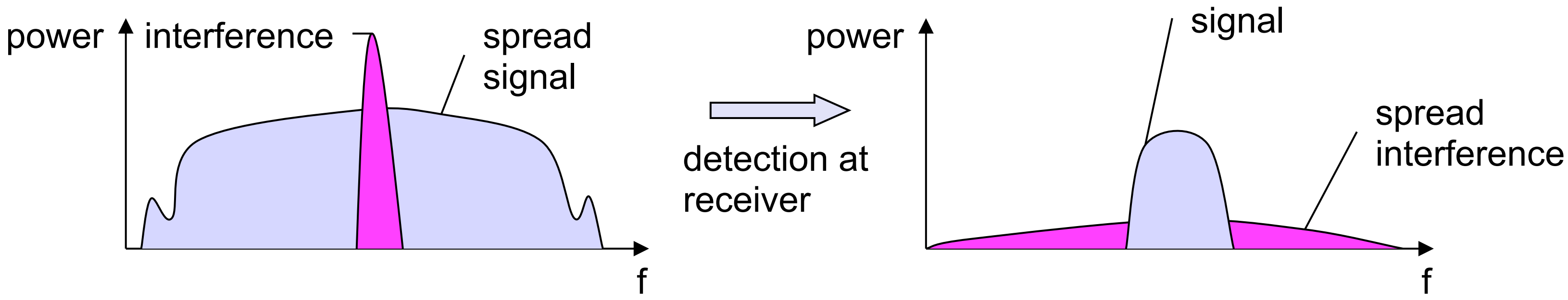
  - Spread Spectrum
  - Orthogonal Frequency Division Multiplexing (OFDM)

# Spread spectrum technology

Problem of radio transmission: frequency dependent fading can wipe out narrow band signals for duration of the interference

Solution: spread the narrow band signal into a broad band signal using a special code

protection against narrow band interference

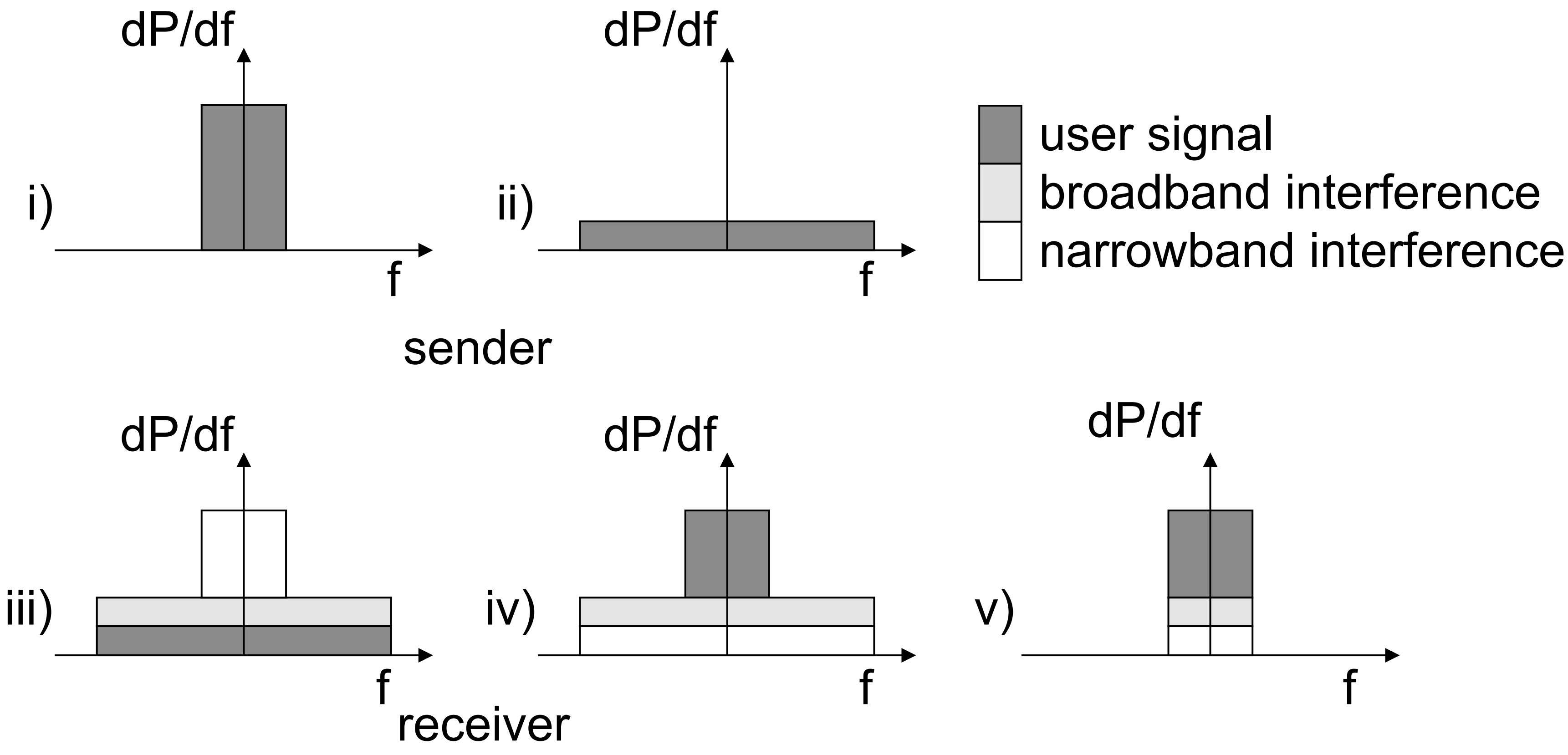



Side effects:

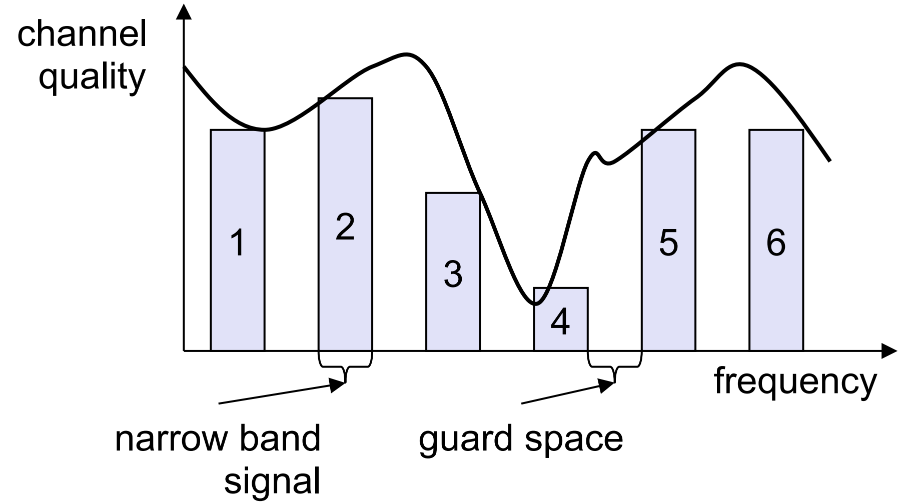
- coexistence of several signals without dynamic coordination
- tap-proof

Alternatives: Direct Sequence, Frequency Hopping

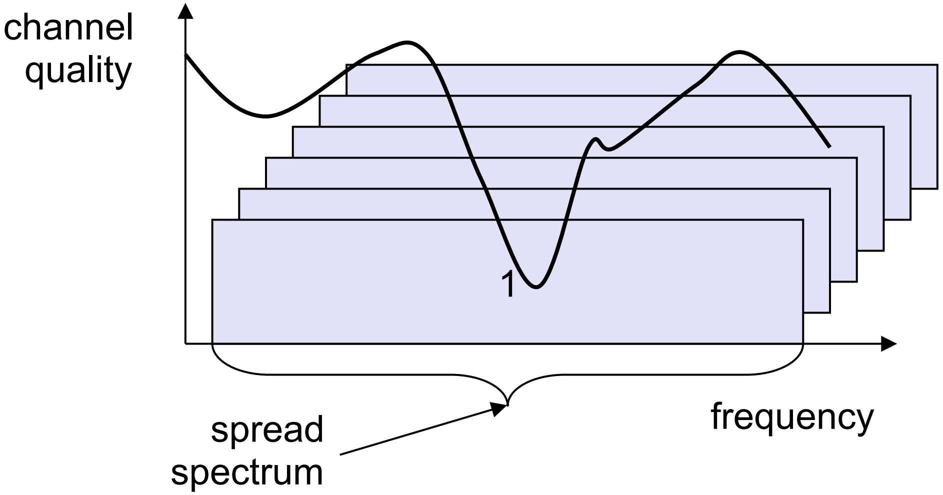
# Effects of spreading and interference



# Spreading and frequency selective fading




narrowband channels




spread spectrum channels

# Spread spectrum technology

- Protection against narrow band interference
- Tightly coupled to CDM
  - coexistence of several signals without dynamic coordination
  - High security
- Military use
- Overlay of new SS technologies on the same spectrum as old NB
- Civil applications
  - IEEE802.11
  - Bluetooth
  - UMTS
- Disadvantages
  - High complexity
  - Large transmission bandwidth
- Alternatives: Direct Sequence, Frequency Hopping

# DSSS (Direct Sequence Spread Spectrum) I

XOR of the signal with pseudo-random number (chipping sequence)

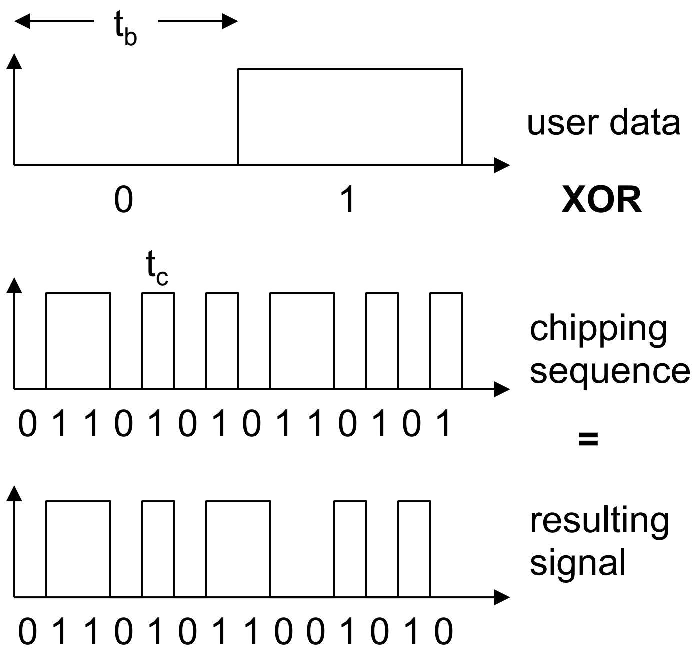
- many chips per bit (e.g., 128) result in higher bandwidth of the signal

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

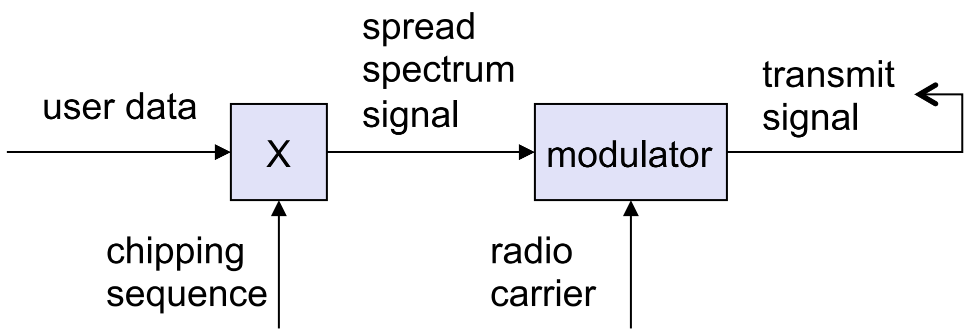
Disadvantages

- precise power control necessary

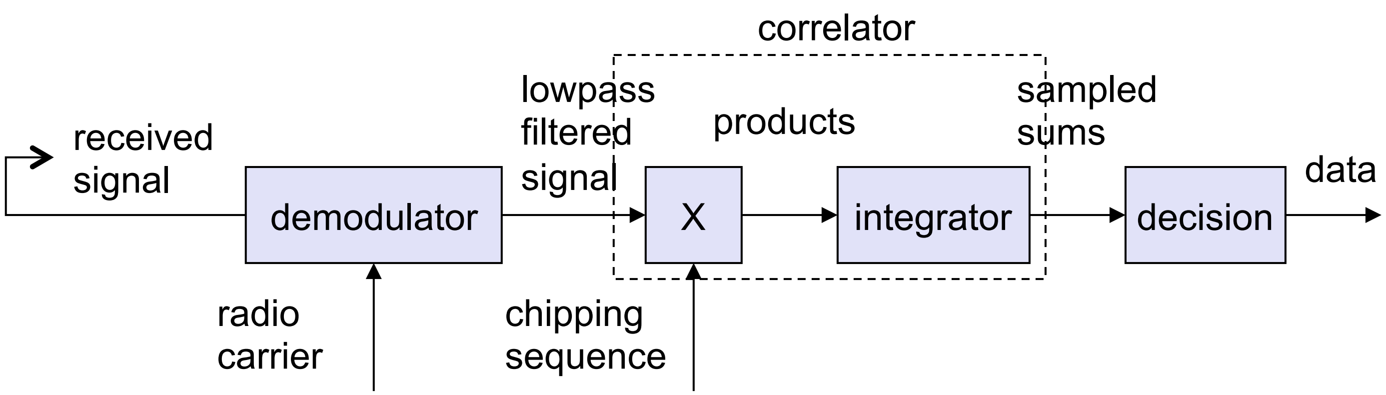



$t_b$: bit period
$t_c$: chip period

# DSSS (Direct Sequence Spread Spectrum) II




**transmitter**



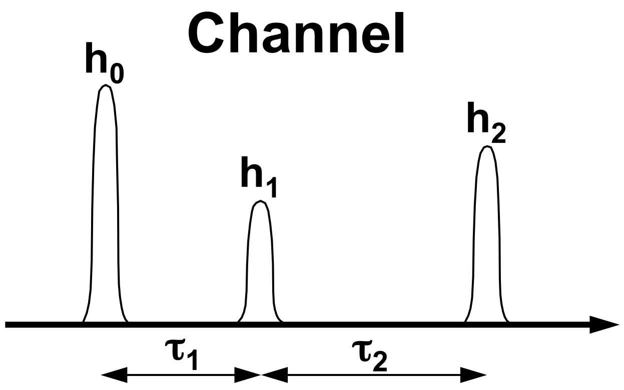

**receiver**

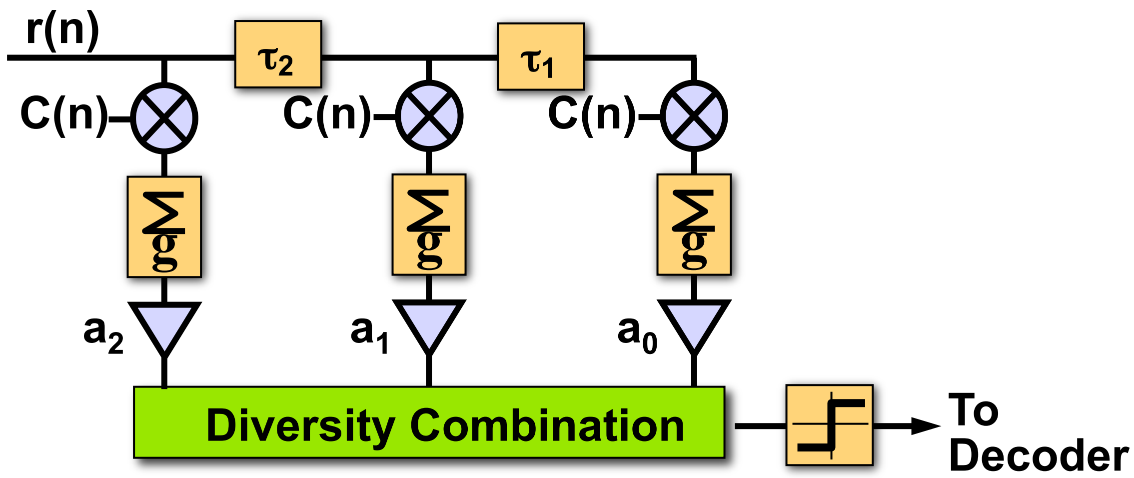
# The Rake Receiver

- Takes advantage of multipath propagation
- Each multipath component is called a “finger”
- Need to estimate delay, amplitude and phase for each finger
- The Rake receiver combines multipath components with a separation in time ≥ one chip period Tchip

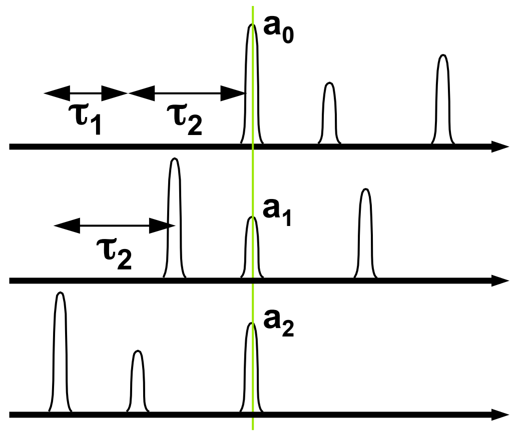
  Example: 3.84 Mcps ⇒ Tchip = 0.26 μs ⇒ 78 m

# Time Dispersion – Rake receiver – Channel Estimation




| Diversity Combination | Channel Estimation | $a_2$ | $a_1$ | $a_0$ |
|---|---|---|---|---|
| Selective | Delay | 0 | 0 | 1 |
| Equal gain | Delay | 1/3 | 1/3 | 1/3 |
| Maximum Ratio | Delay and complex amplitudes | $h_2^*$ | $h_1^*$ | $h_0^*$ |



# FHSS (Frequency Hopping Spread Spectrum) I

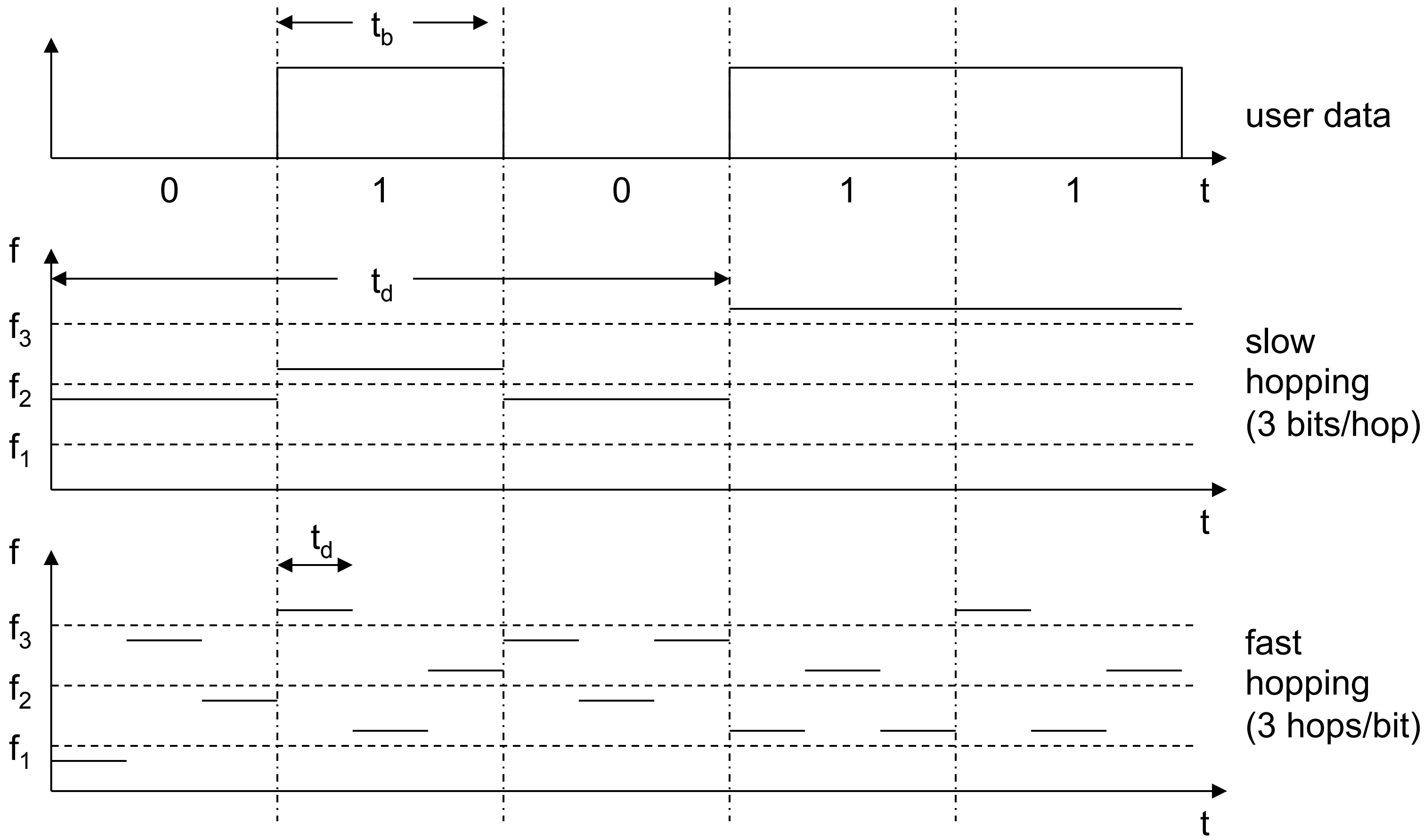
Discrete changes of carrier frequency

- sequence of frequency changes determined via pseudo random number sequence

Two versions

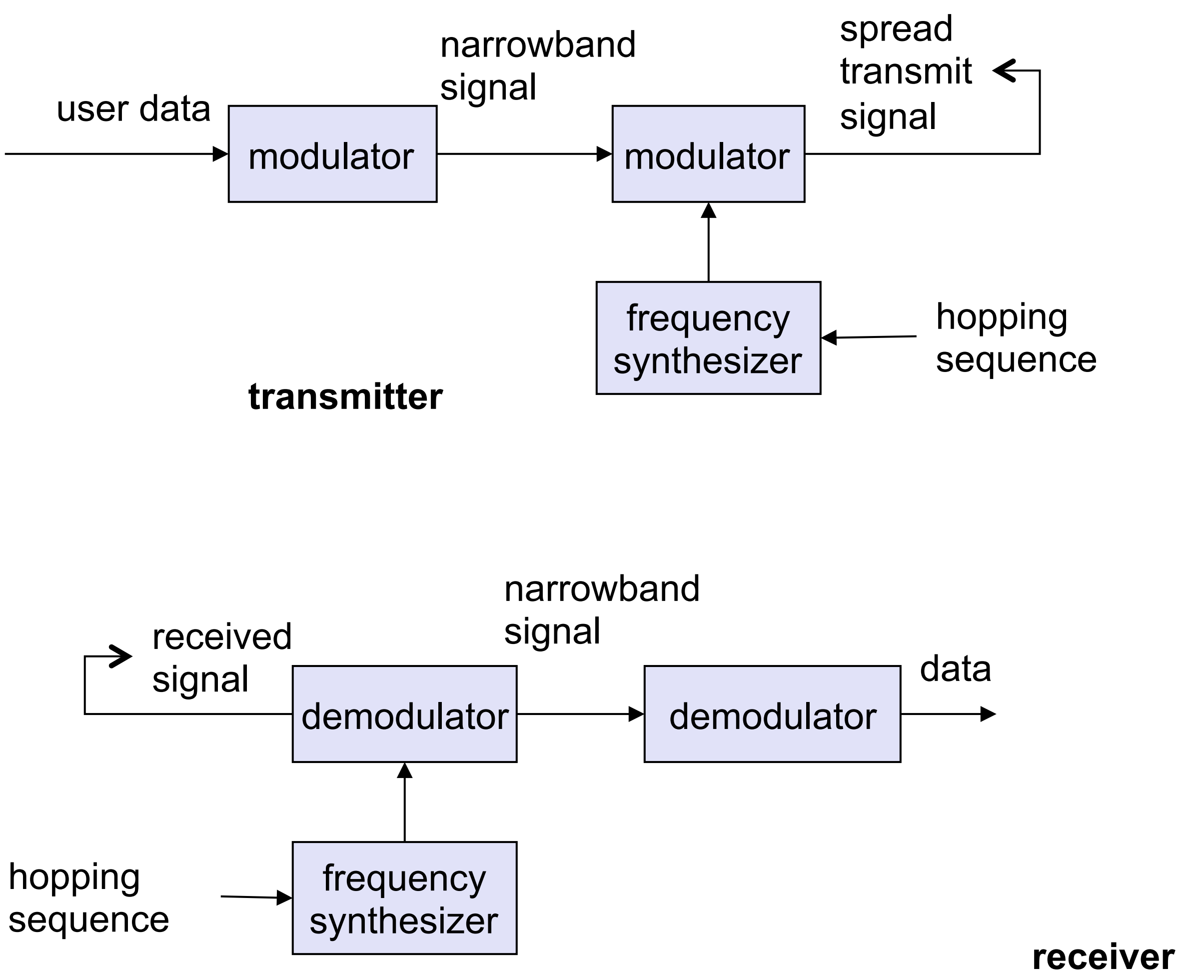
- Fast Hopping:
  several frequencies per user bit
- Slow Hopping:
  several user bits per frequency

# FHSS (Frequency Hopping Spread Spectrum) II




$t_b$: bit period $\qquad$ $t_d$: dwell time

# FHSS (Frequency Hopping Spread Spectrum) III



# FHSS (Frequency Hopping Spread Spectrum) IV

Example:

- Bluetooth (1600 hops/sec on 79 carriers)

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

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- Wireless Transmission (2/2)
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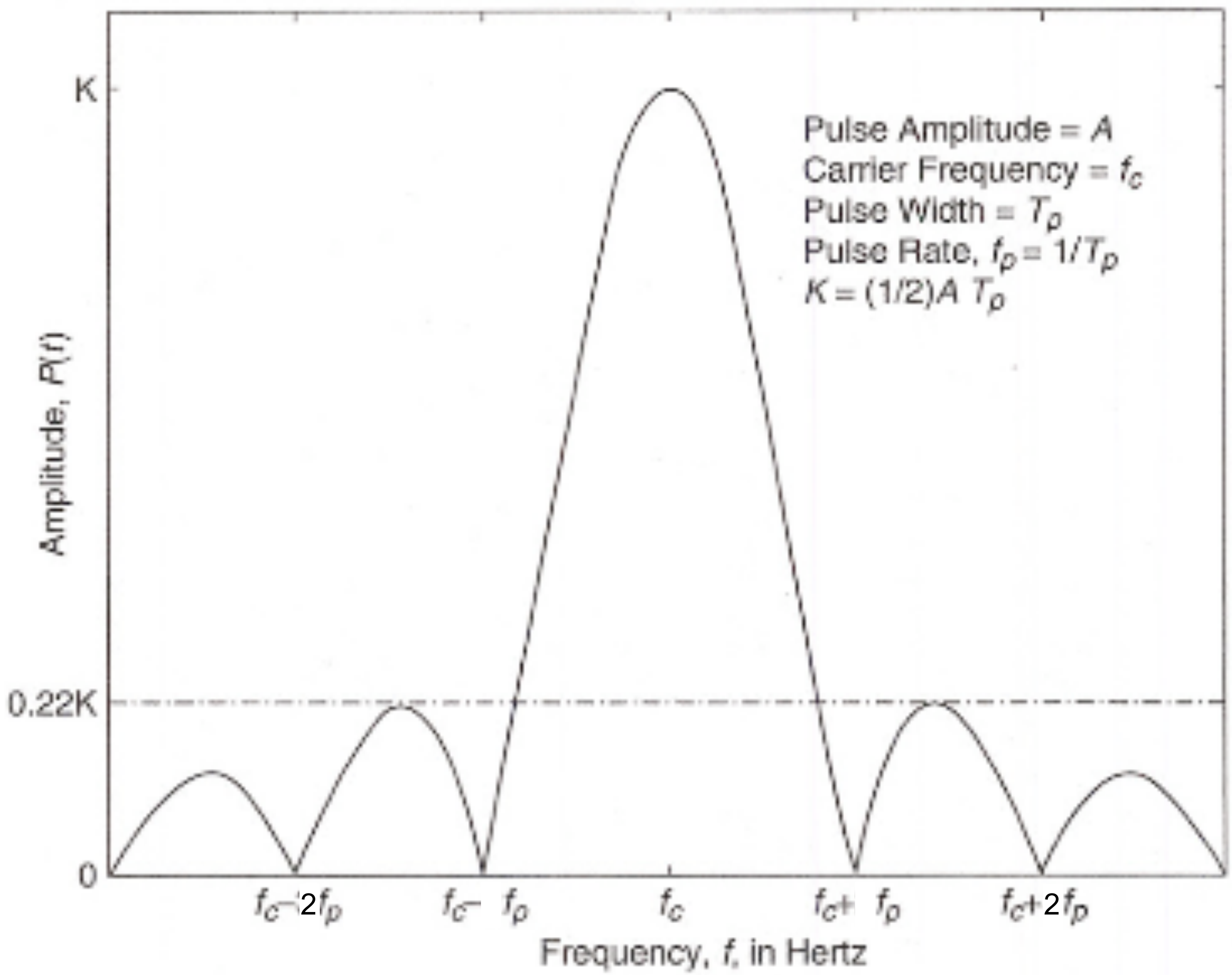
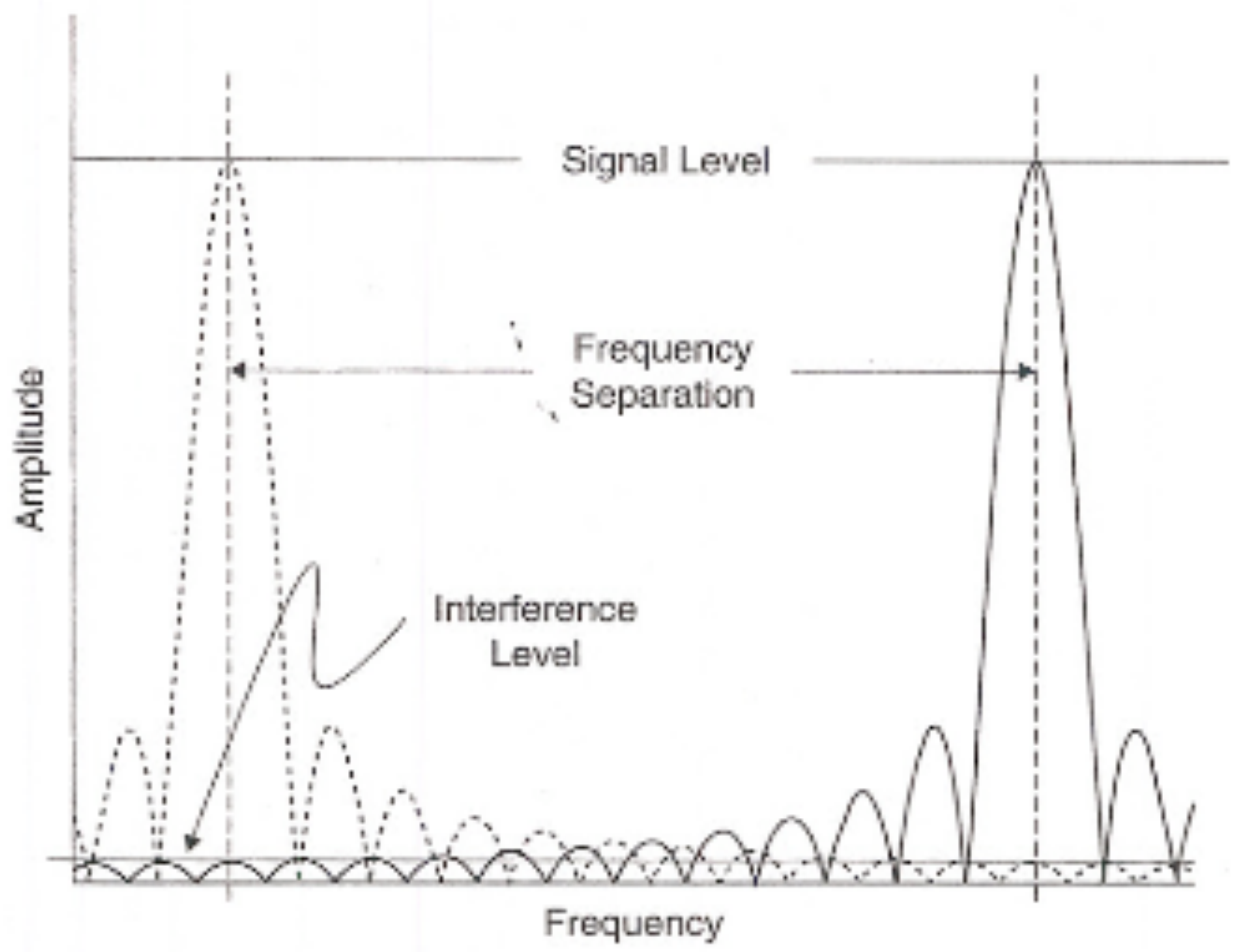
# Multicarrier modulation

- Target: increase data rate
  - Increase bandwidth?
  - Increase symbol rate?
- Problem: increase of frequency selective fading and Inter Symbol Interference (ISI)
- Solution:
  - High bit rate signal split into many low bit rate signals
  - Each low bit rate signal used to modulate a different carrier
  - Less vulnerable to ISI and frequency selective fading
- But: How to make multicarrier systems efficient?

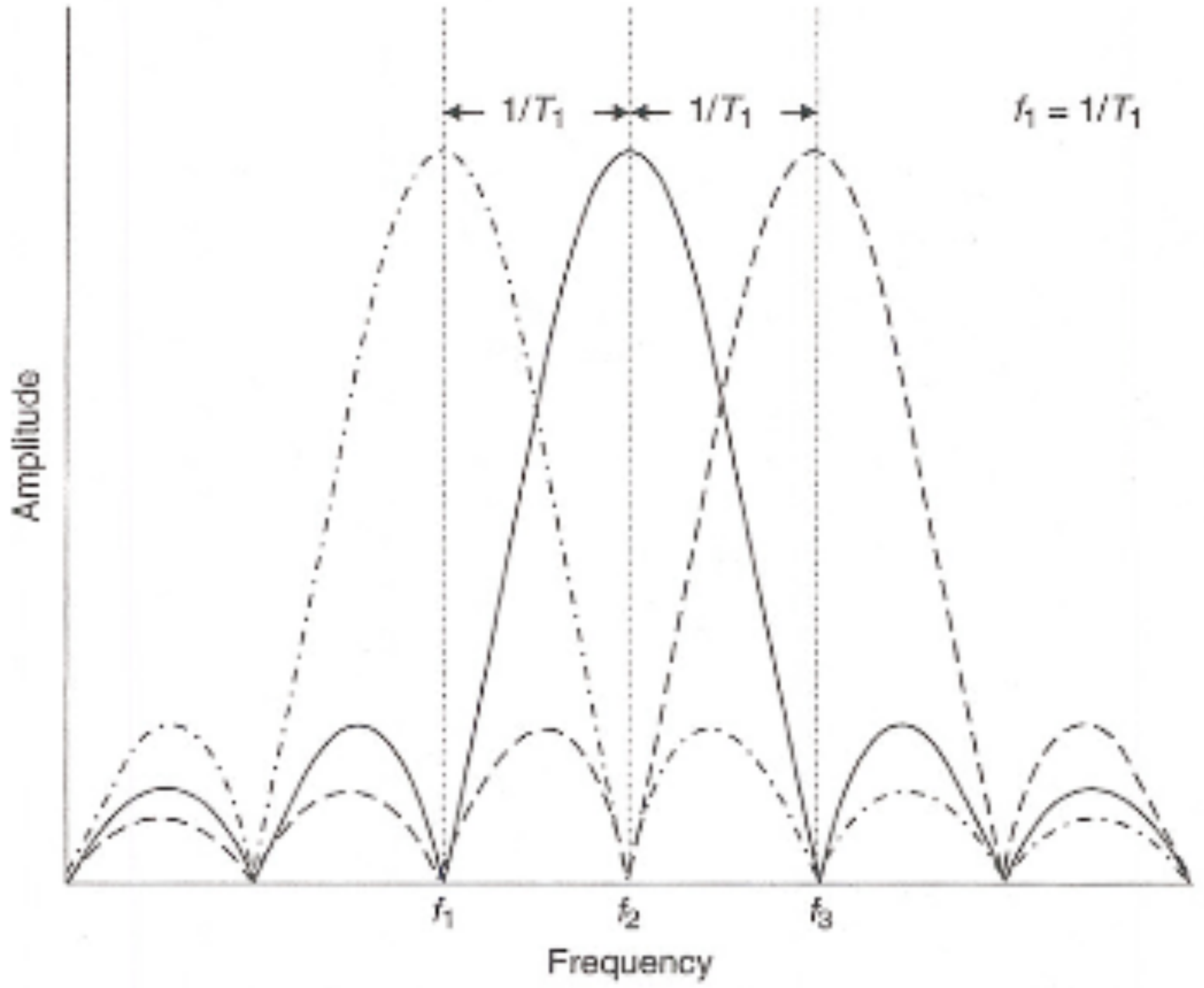
# Spectrum of a rectangular pulse



# Two-carrier pulse spectrum



# Spectra for Three Orthogonal Carriers



# OFDM(A)

A multicarrier system based on orthogonal subcarriers:

→ Orthogonal Frequency-Division Multiplexing (OFDM)

When different subcarriers can be used by different users:

→ Orthogonal Frequency-Division Multiple Access (OFDMA)

Typically uses phase and amplitude modulation on each subcarrier:

→ QAM (BPSK, QPSK, 8PSK, 16QAM, 32QAM, 64QAM)

Composite signal given by: $$f(t) = \sum_{k=0}^{N-1} A_k \cos(k\omega_0 t + \varphi_k) \text{ ,for } 0 \leq t \leq T_p$$

where $T_p$ is symbol width,

$\omega_0 = 2\pi / T_p$ ,

$A_k$ and $\varphi_k$ are QAM amplitude and phase on carrier $k$

→ Can by computed by Inverse Fast Fourier Transform (IFFT)

## OFDM(A) deployment

OFDM is used in IEEE 802.11a and g

48 (+4 pilot) subcarriers of 312.5 kHz (total 20 MHz)

→ 3.2μs time

0.8μs guard space (ISI mitigation) → 250 000 symbols/s

64QAM on 48 carriers results in 6 * 48 = 288 bits/symbol

→ 72 Mbit/s, with ¾ coding rate (error correction): 54 Mbit/s

OFDM is also used in DAB, DVB

OFDMA is used in WiMAX and
LTE with up to 1200 subcarriers of 15 kHz in 20 MHz.