Chapter 7

Multiple Division Techniques for Traffic Channels

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Outline

- Introduction
- Concepts and Models for Multiple Divisions
  - Frequency Division Multiple Access (FDMA)
  - Time Division Multiple Access (TDMA)
  - Code Division Multiple Access (CDMA)
  - Orthogonal Frequency Division Multiplexing (OFDM)
  - Space Division Multiple Access (SDMA)
  - Comparison of FDMA, TDMA, and CDMA
- Modulation Techniques
  - Amplitude Modulation (AM)
  - Frequency Modulation (FM)
  - Frequency Shift Keying (FSK)
  - Phase Shift Keying (PSK)
  - Quadrature Phase Shift Keying (QPSK)
  - $\pi/4$QPSK
  - Quadrature Amplitude Modulation (QAM)
  - 16QAM

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Concepts and Models for Multiple Divisions

- Multiple access techniques are based on orthogonalization of signals
- A radio signal is a function of frequency, time, and code as

$$s(f, t, c) = s(f, t)c(t)$$

where $s(f, t)$ is the function of frequency and time and $c(t)$ is the function of code

  - Use of different frequencies to transmit a signal: FDMA
  - Distinct time slot: TDMA
  - Different codes CDMA
  - Multiple simultaneous channels: OFDM
  - Specially separable sectors: SDMA

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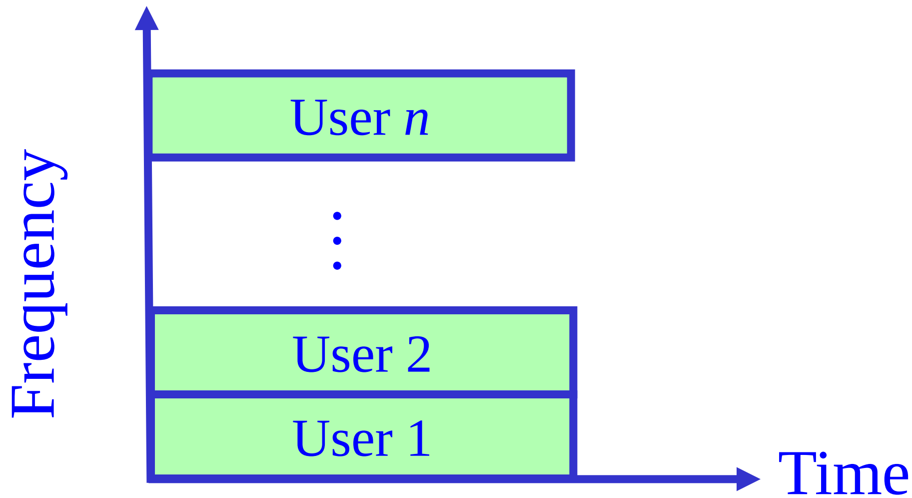
Frequency Division Multiple Access (FDMA)

Orthogonality conditions of two signals in FDMA:

$$\int_F s_i(f,t)\, s_j(f,t)\,df = \begin{cases} 1 & i = j \\ 0 & i \neq j \end{cases}, \quad i, j = 1,2,\ldots,k$$



- Single channel per carrier
- All first generation systems use FDMA

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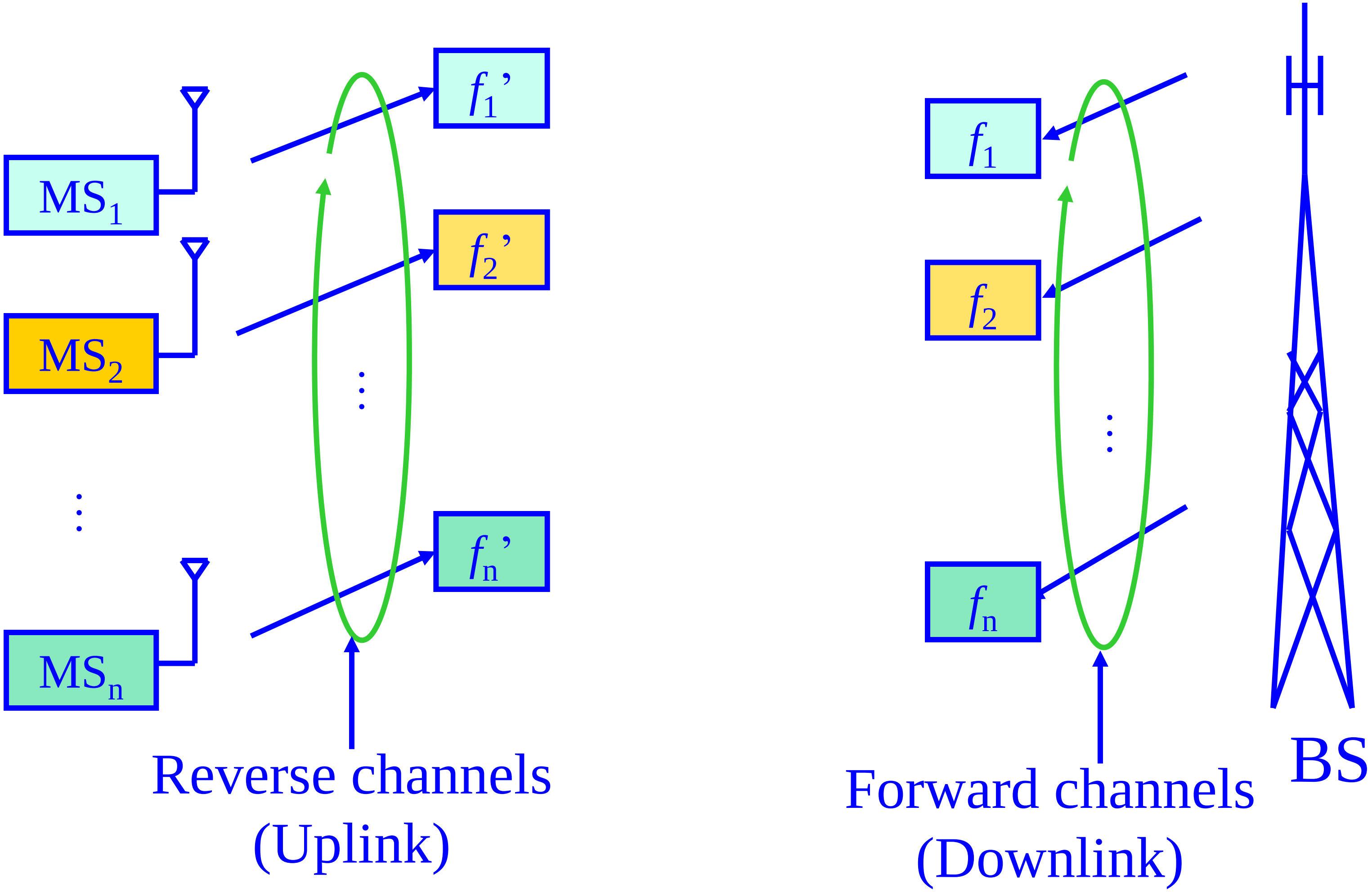
Basic Structure of FDMA



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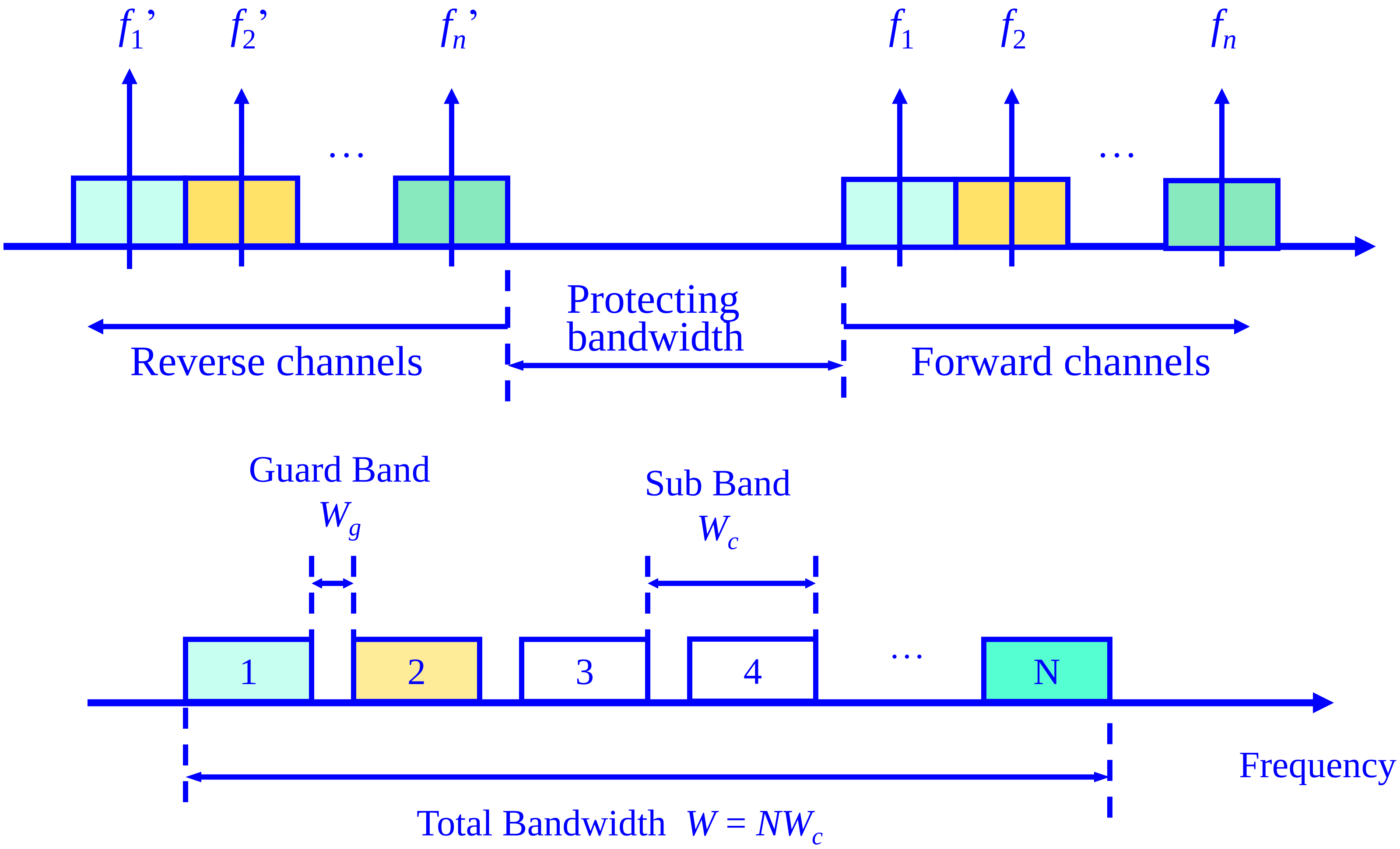
Forward & Reverse Channels in FDMA & Guard Band



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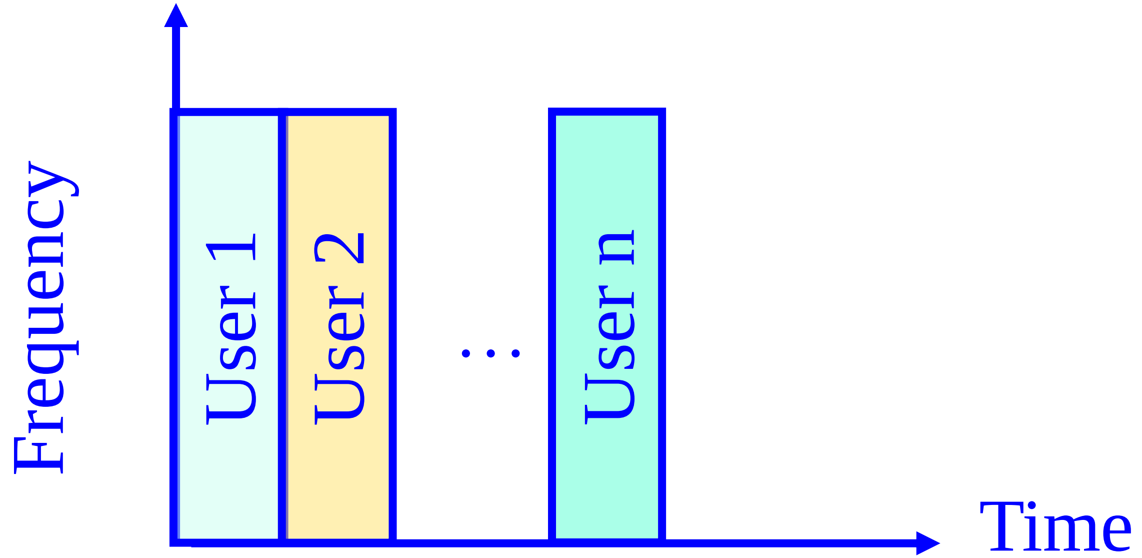
Time Division Multiple Access (TDMA)

Orthogonality conditions of two signals in TDMA:

$$\int_T s_i(f,t)\, s_j(f,t)\,dt = \begin{cases} 1 & i = j \\ 0 & i \neq j \end{cases}, \quad i, j = 1,2,\ldots,k$$



- Multiple channels per carrier
- Most of second generation systems use TDMA

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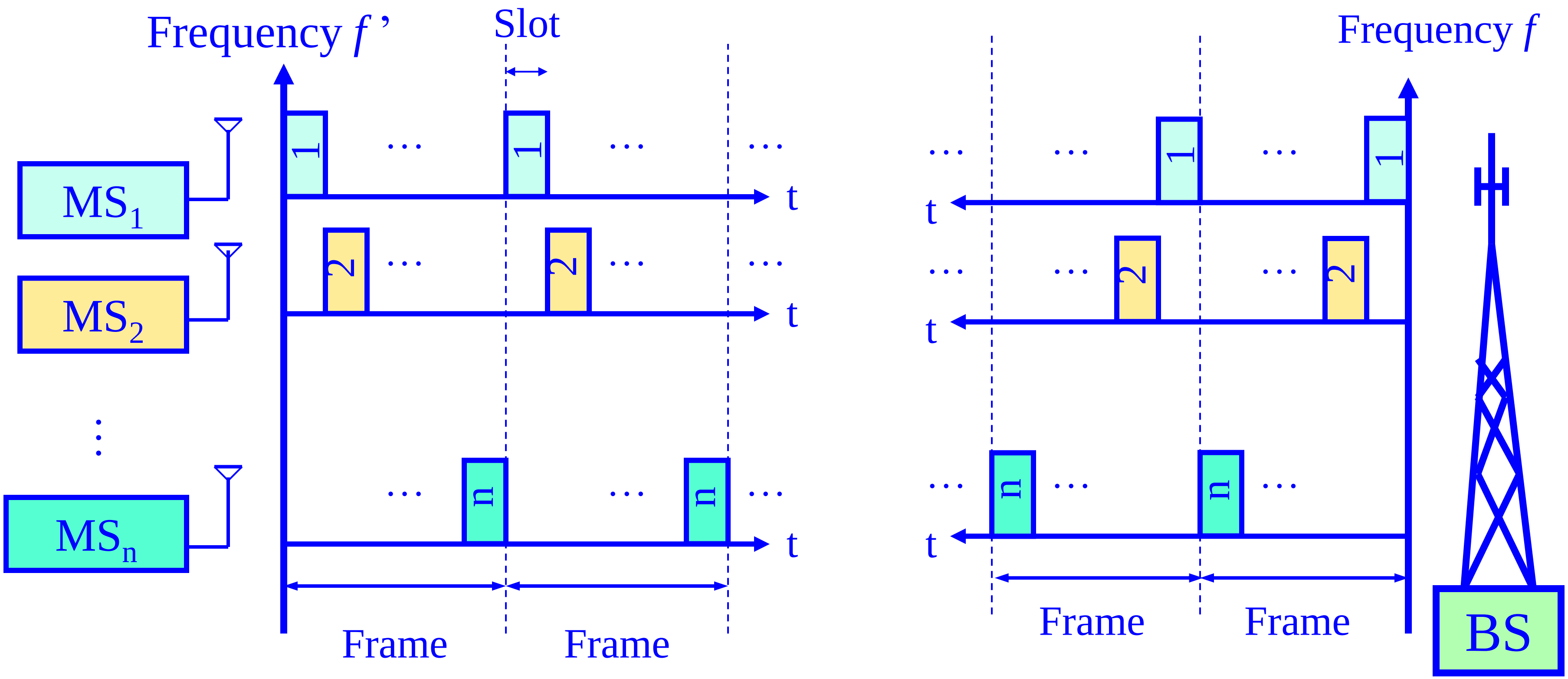
The Concept of TDMA



Reverse channels
(Uplink)

Forward channels
(Downlink)

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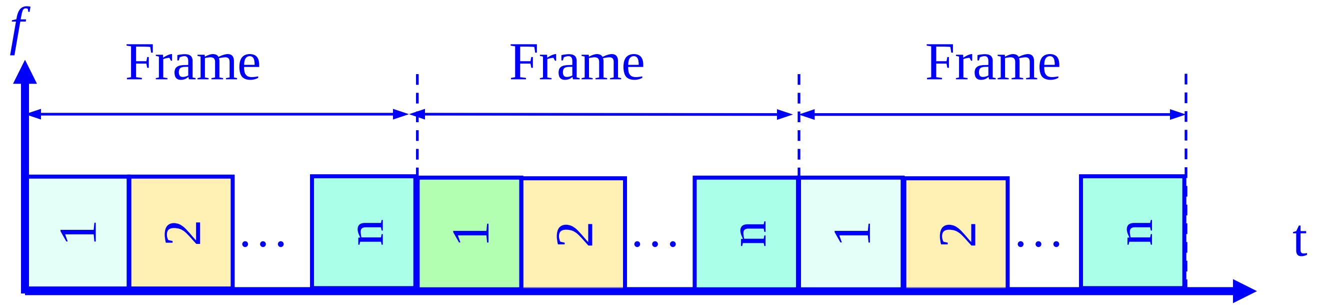
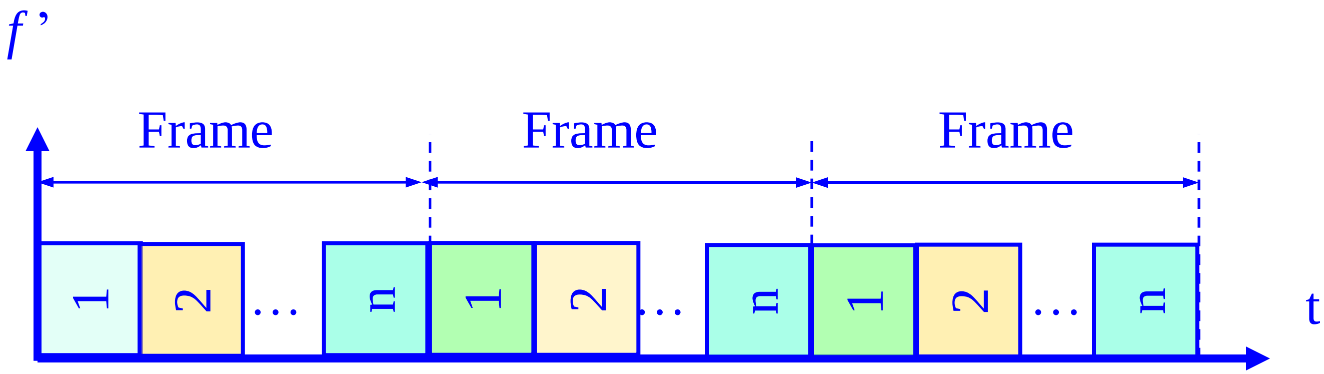
TDMA: Channel Structure



(a). Forward channel



(b). Reverse channel

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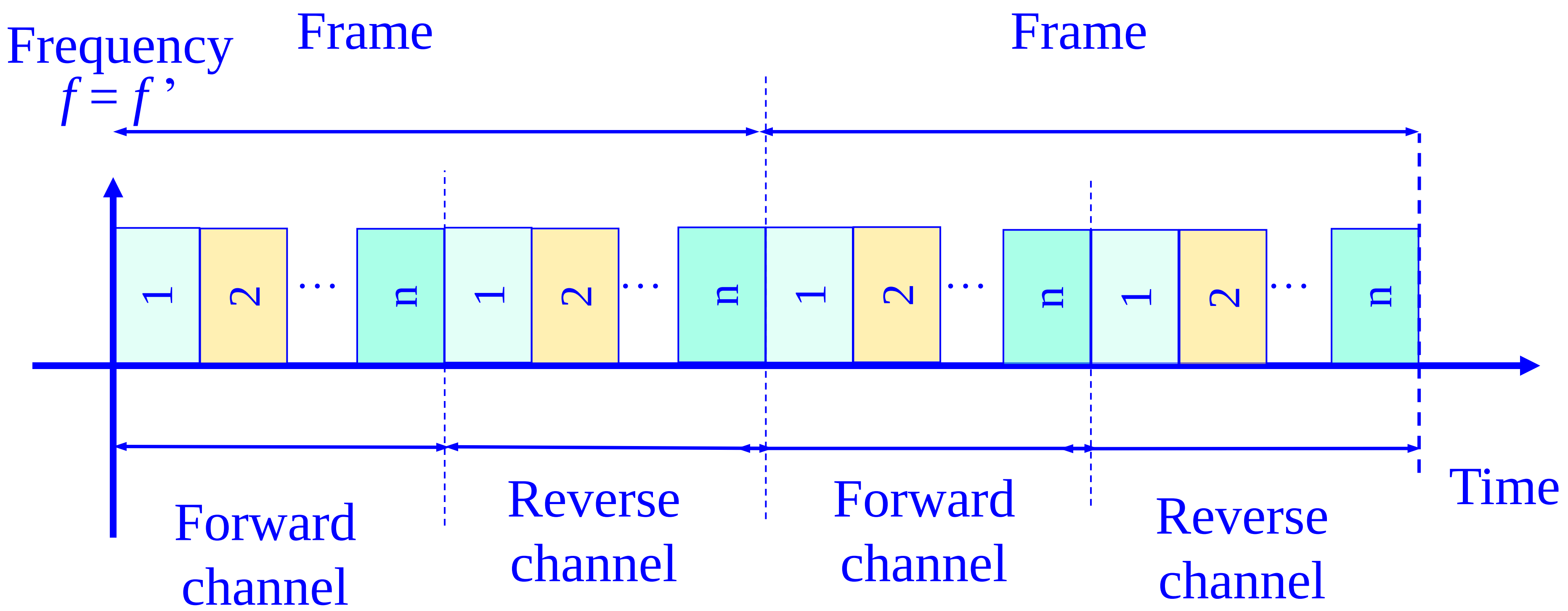
Forward and Reverse Channels in TDMA



Channels in TDMA/TDD

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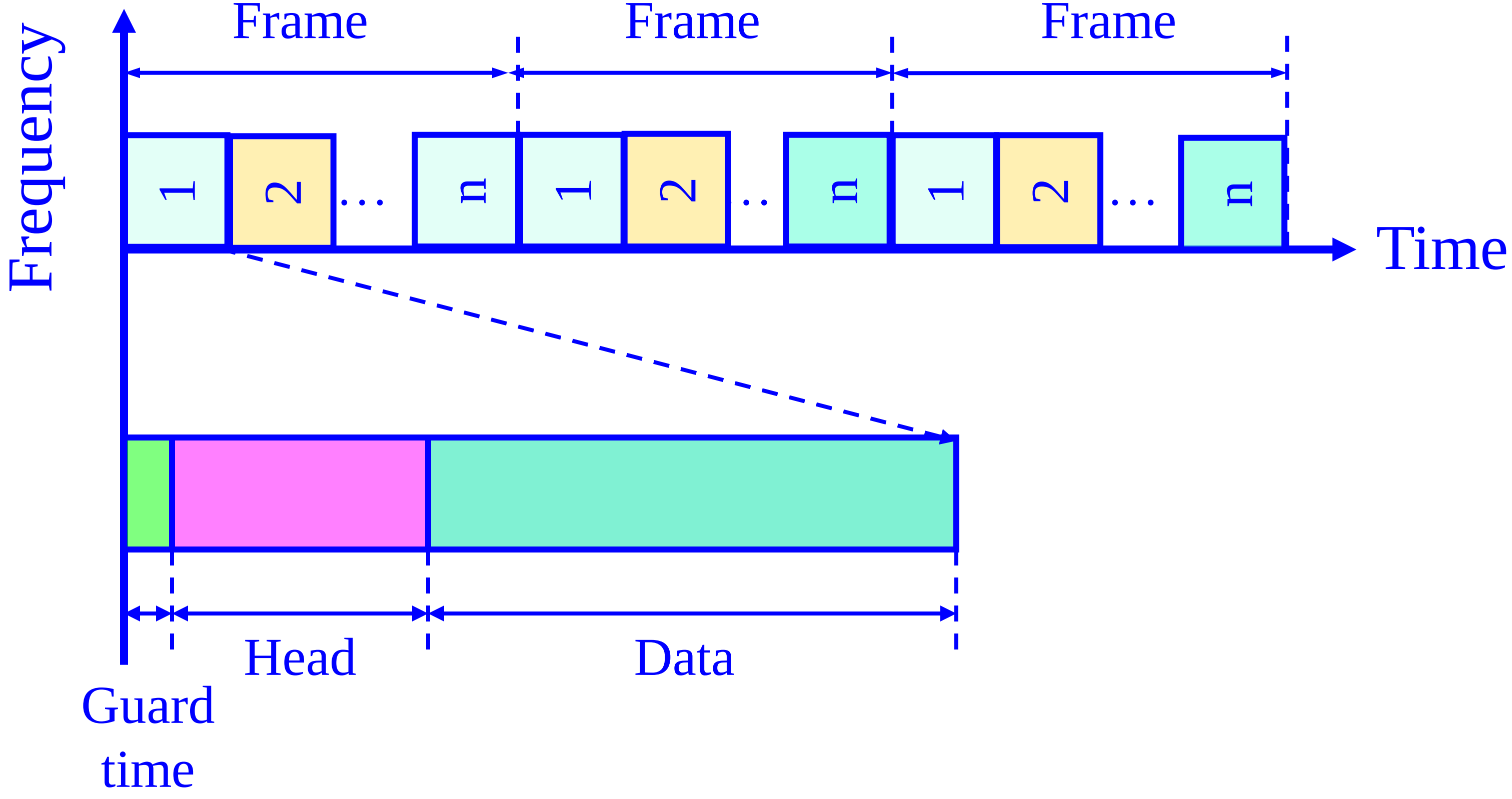
Frame Structure of TDMA



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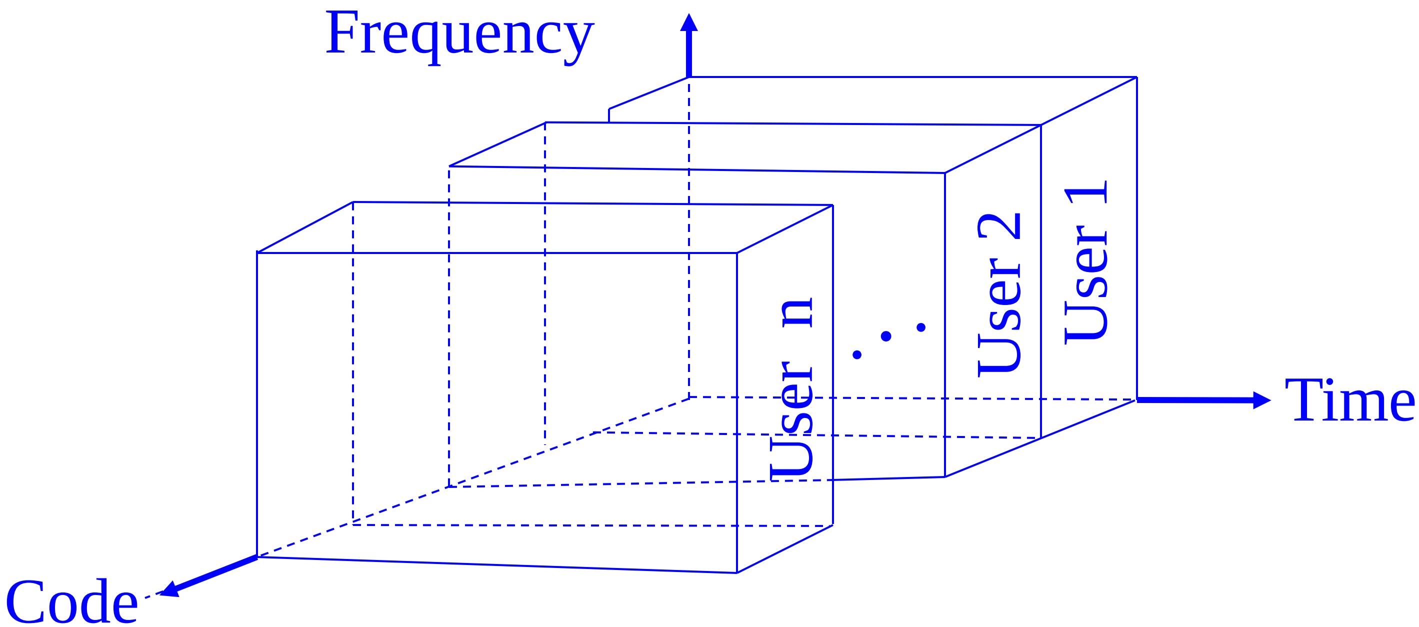
Code Division Multiple Access (CDMA)

Orthogonality conditions of two signals in CDMA:

$$\int_C s_i(t)\, s_j(t)dt = \begin{cases} 1 & i = j \\ 0 & i \neq j \end{cases}, \quad i, j = 1,2,\ldots,k$$



- Users share bandwidth by using code sequences that are orthogonal to each other
- Some second generation systems use narrowband CDMA
- Most of third generation systems use wideband CDMA

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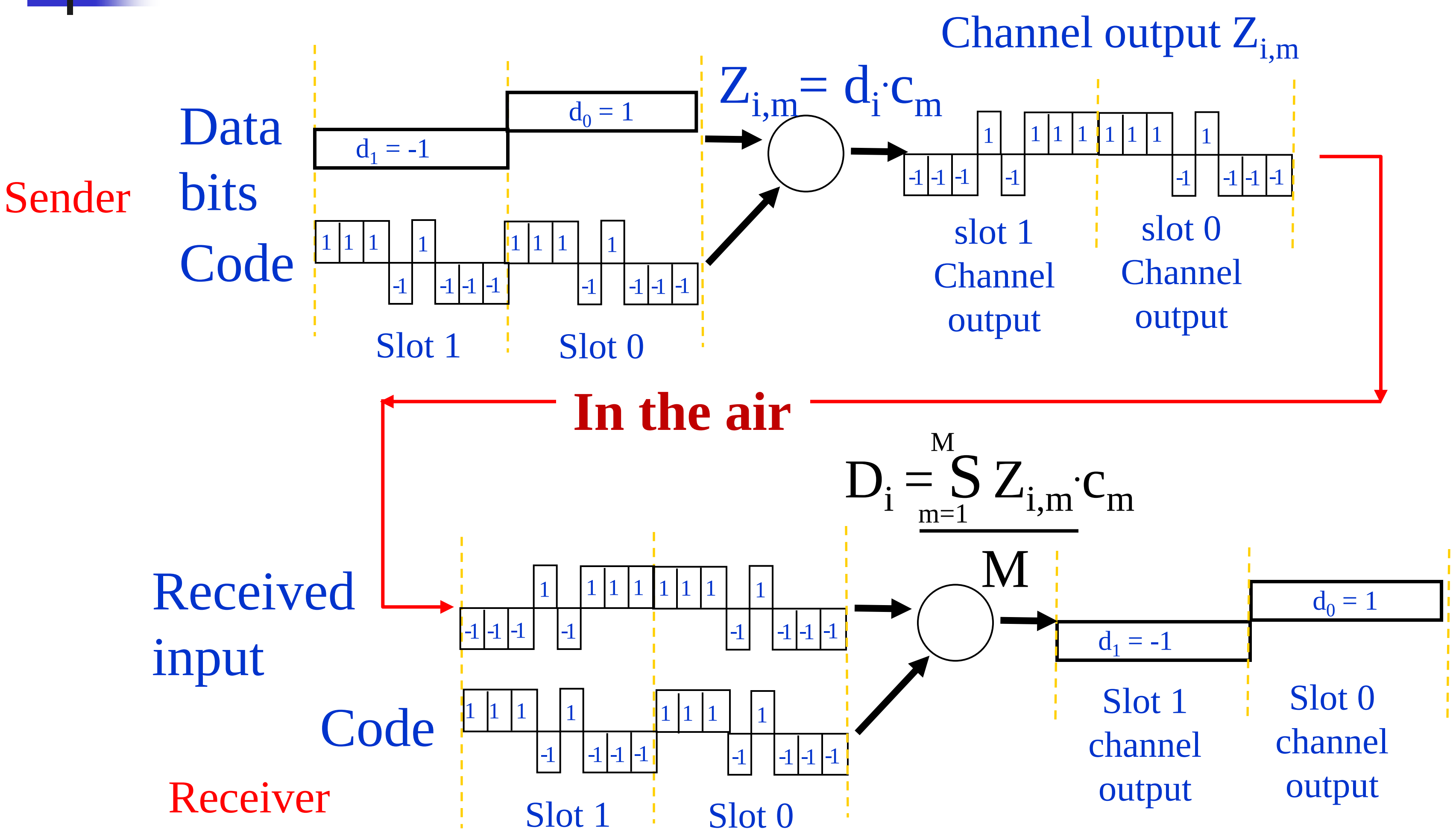
CDMA Encode and Decode



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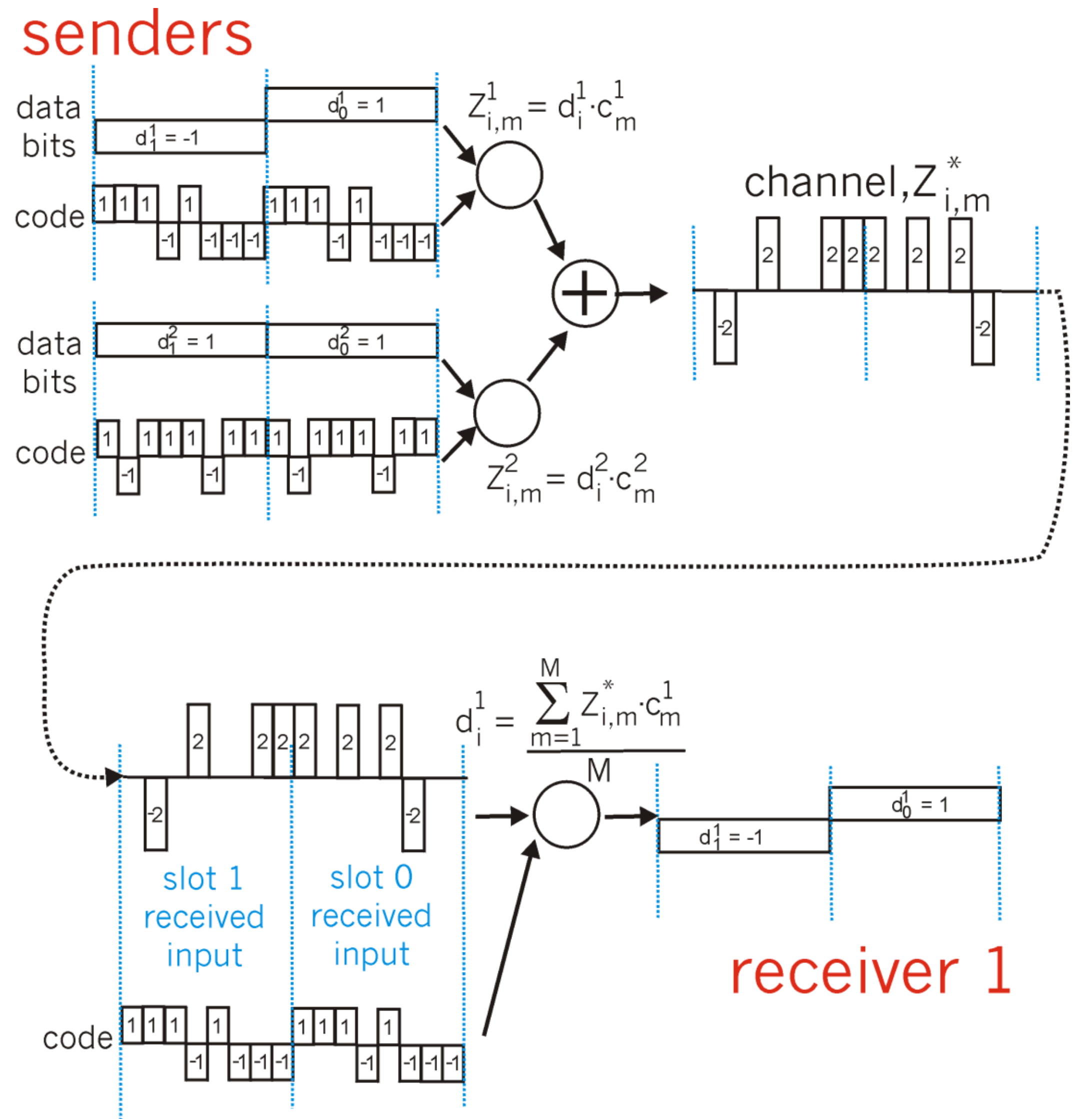
CDMA: Two-sender Interference



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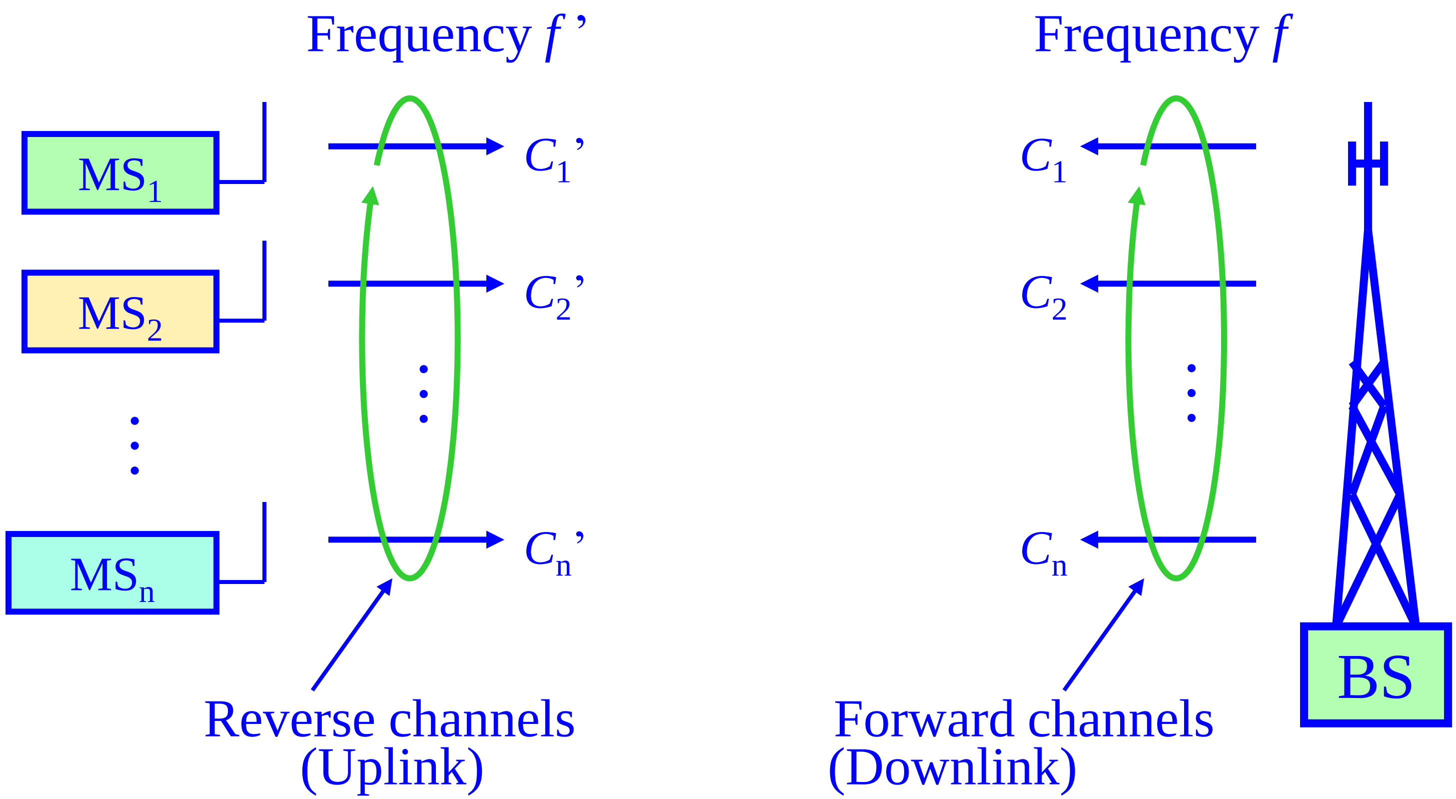
Structure of a CDMA System



C_i’ x C_j’ = 0, i.e., C_i’ and C_j’ are orthogonal codes
C_i x C_j = 0, i.e., C_i and C_j are orthogonal codes

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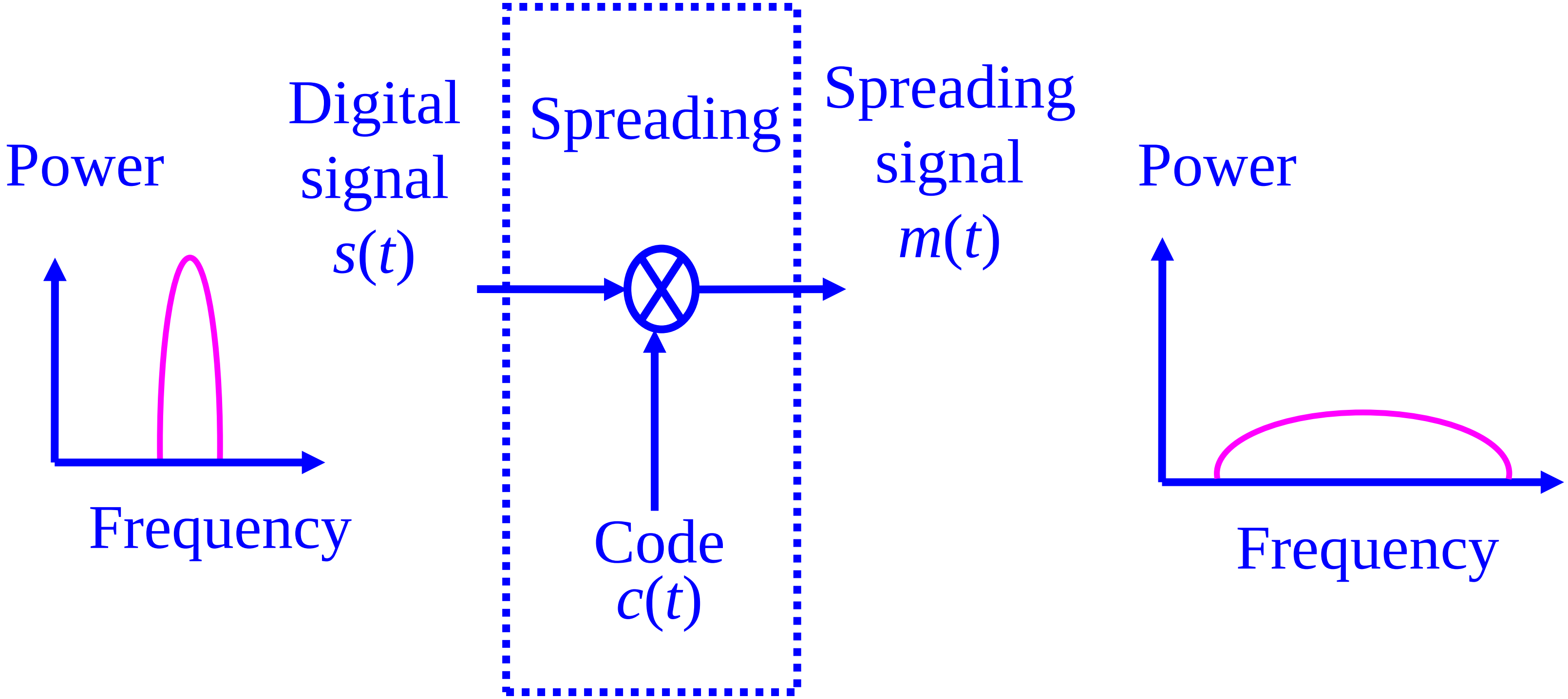
Spread Spectrum

Spreading of data signal $s(t)$ by the code signal $c(t)$ to result in message signal $m(t)$ as

$$m(t) = s(t) \otimes c(t)$$



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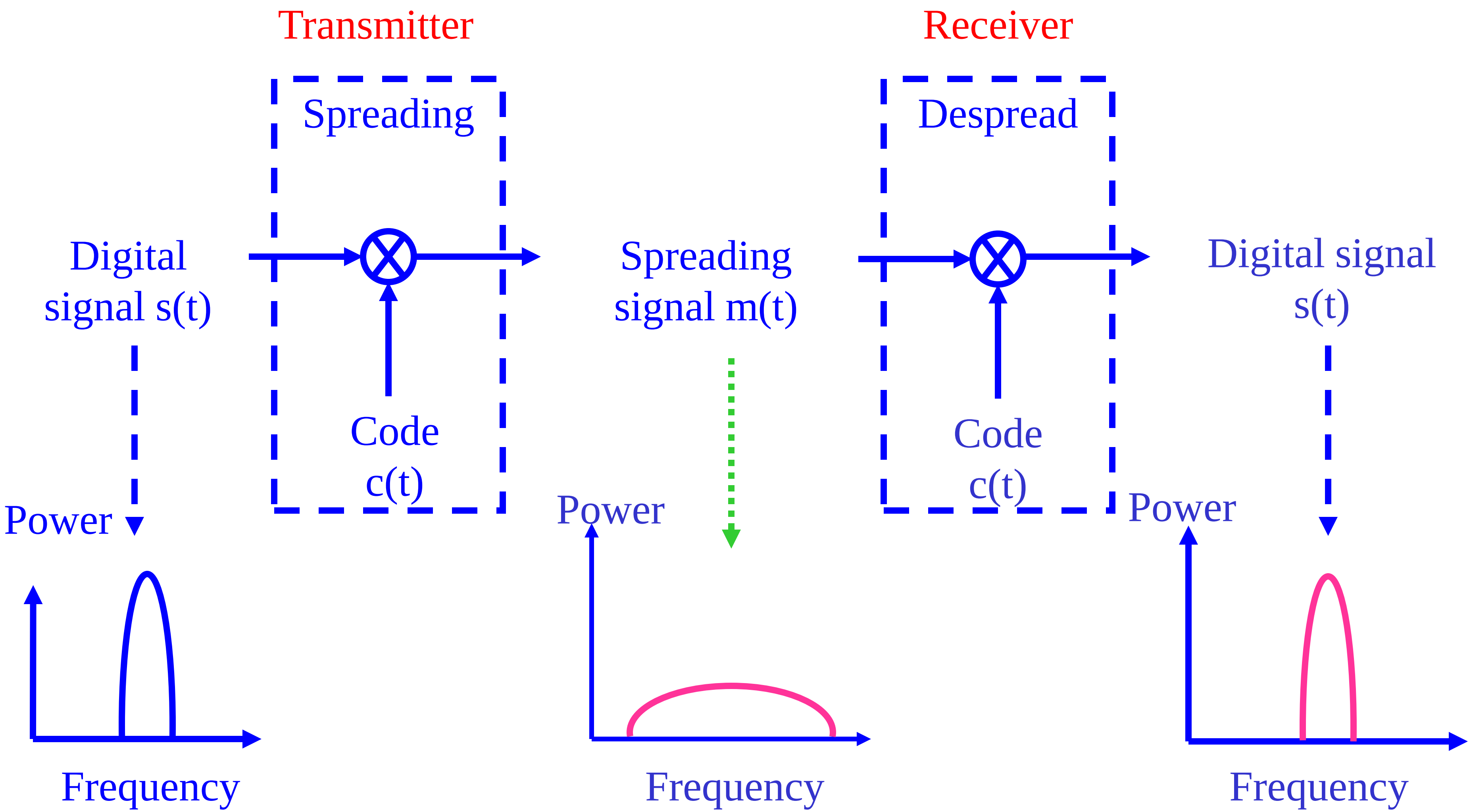
Direct Sequence Spread Spectrum (DSSS)



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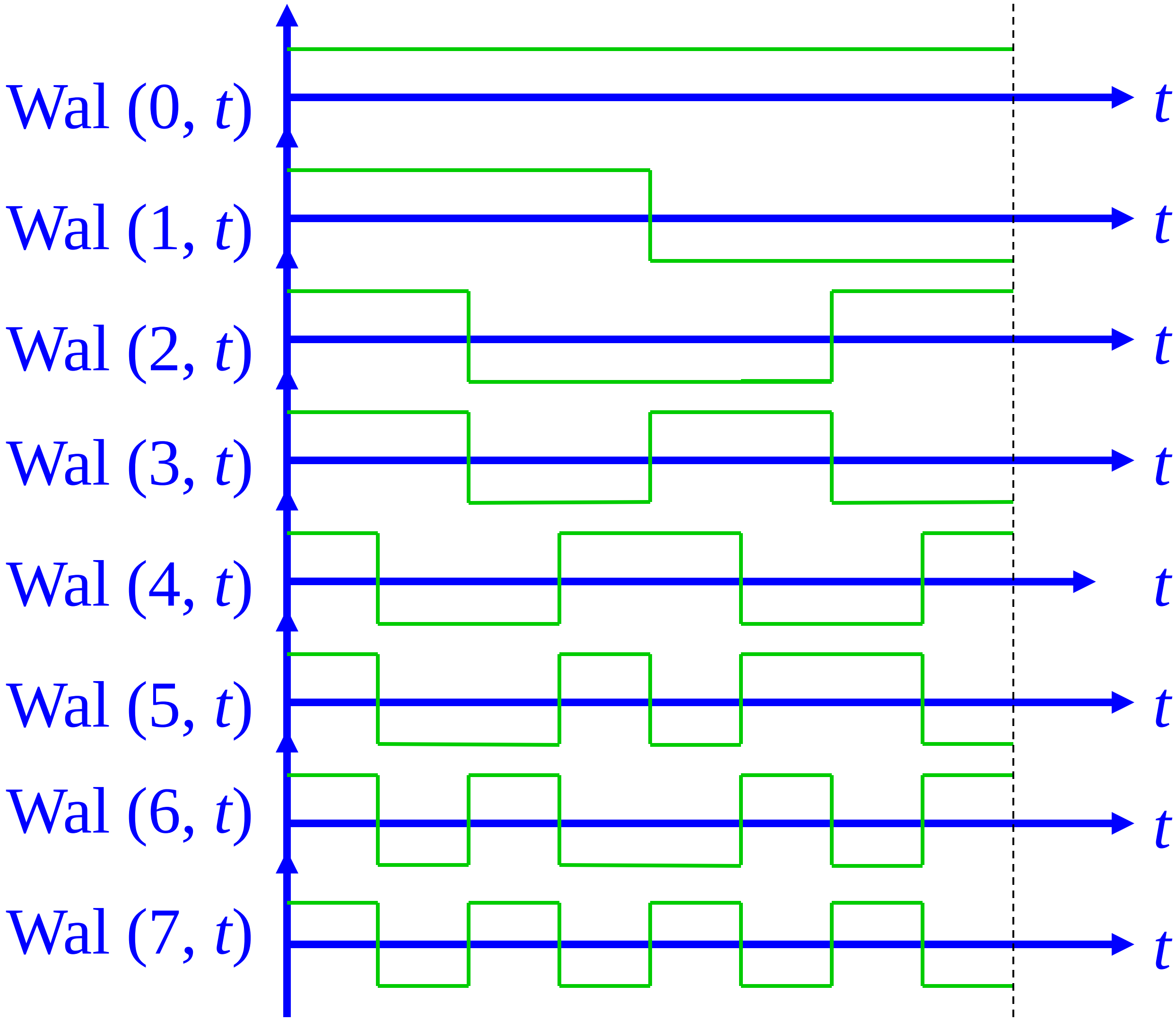
Walsh Codes (Orthogonal Codes)



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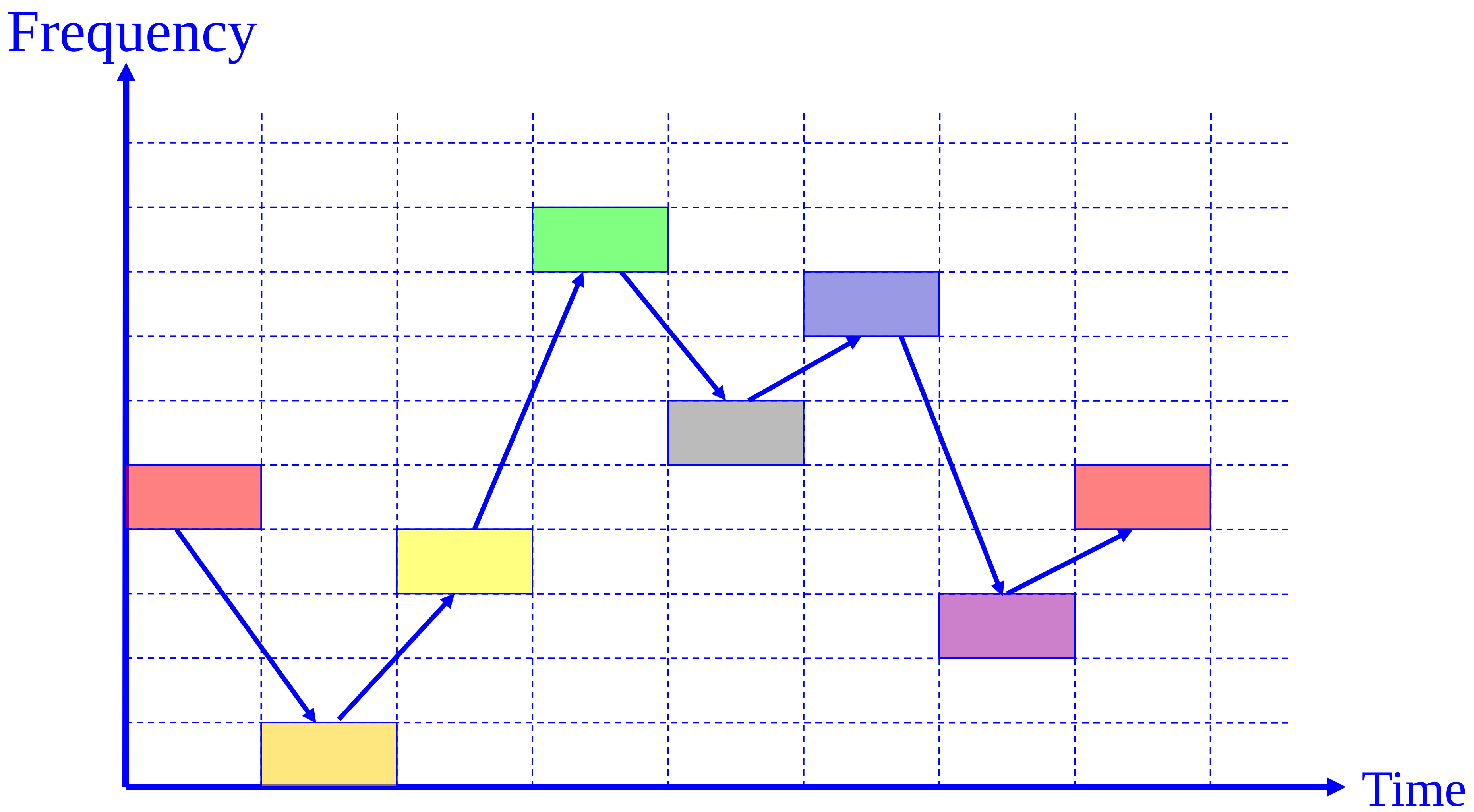
An Example of Frequency Hopping Pattern



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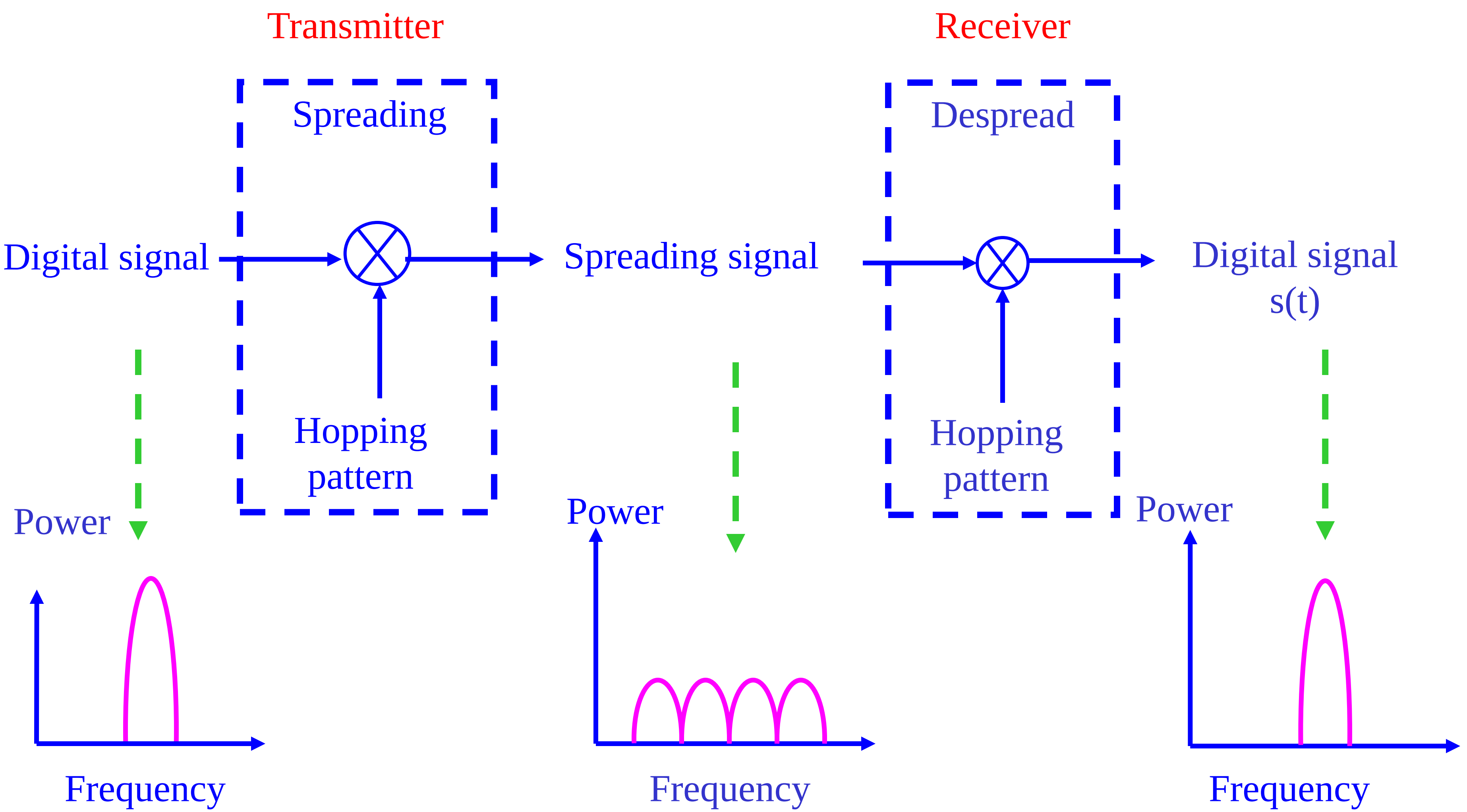
Frequency Hopping Spread Spectrum (FHSS)



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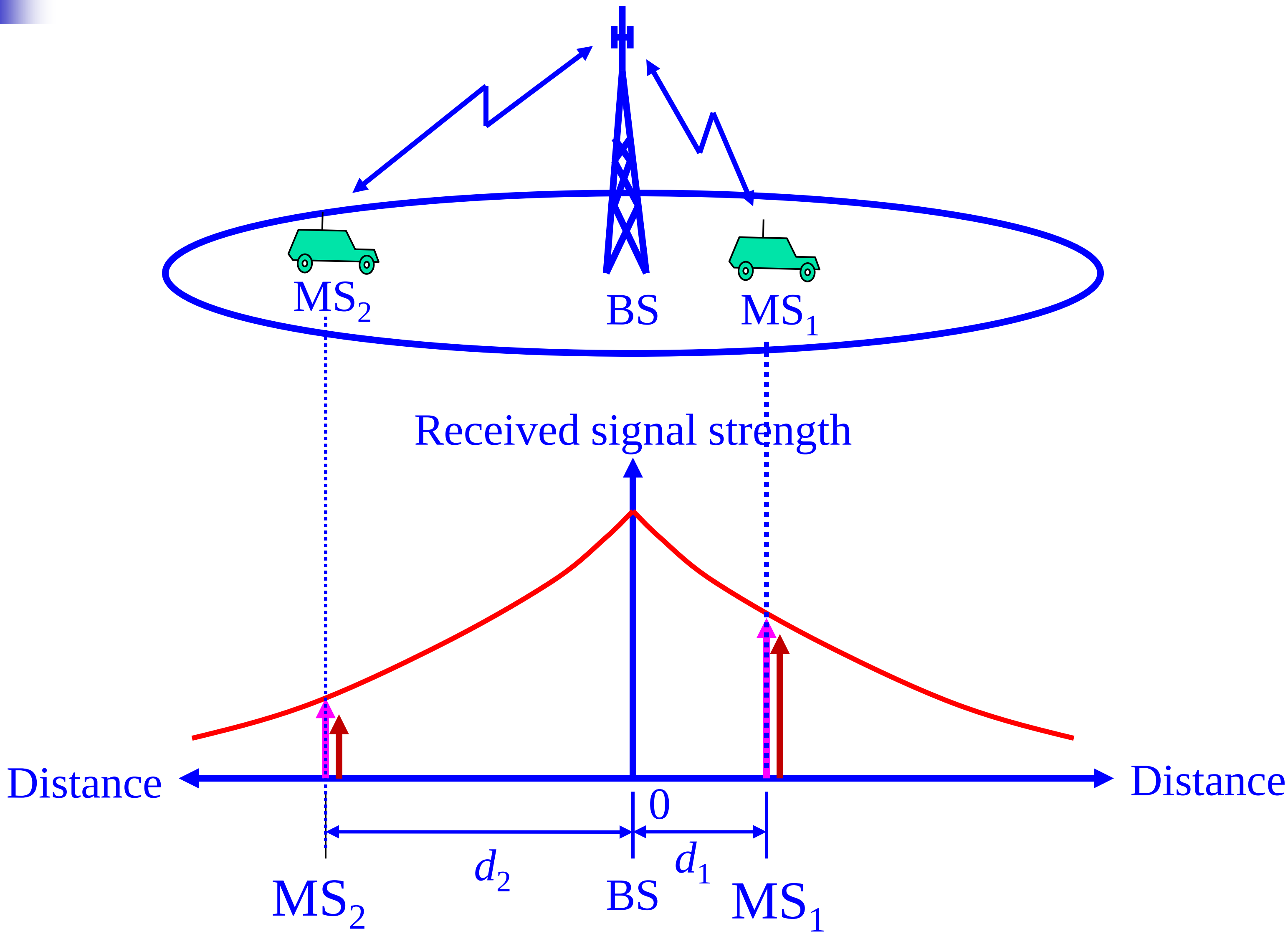
Near-far Problem



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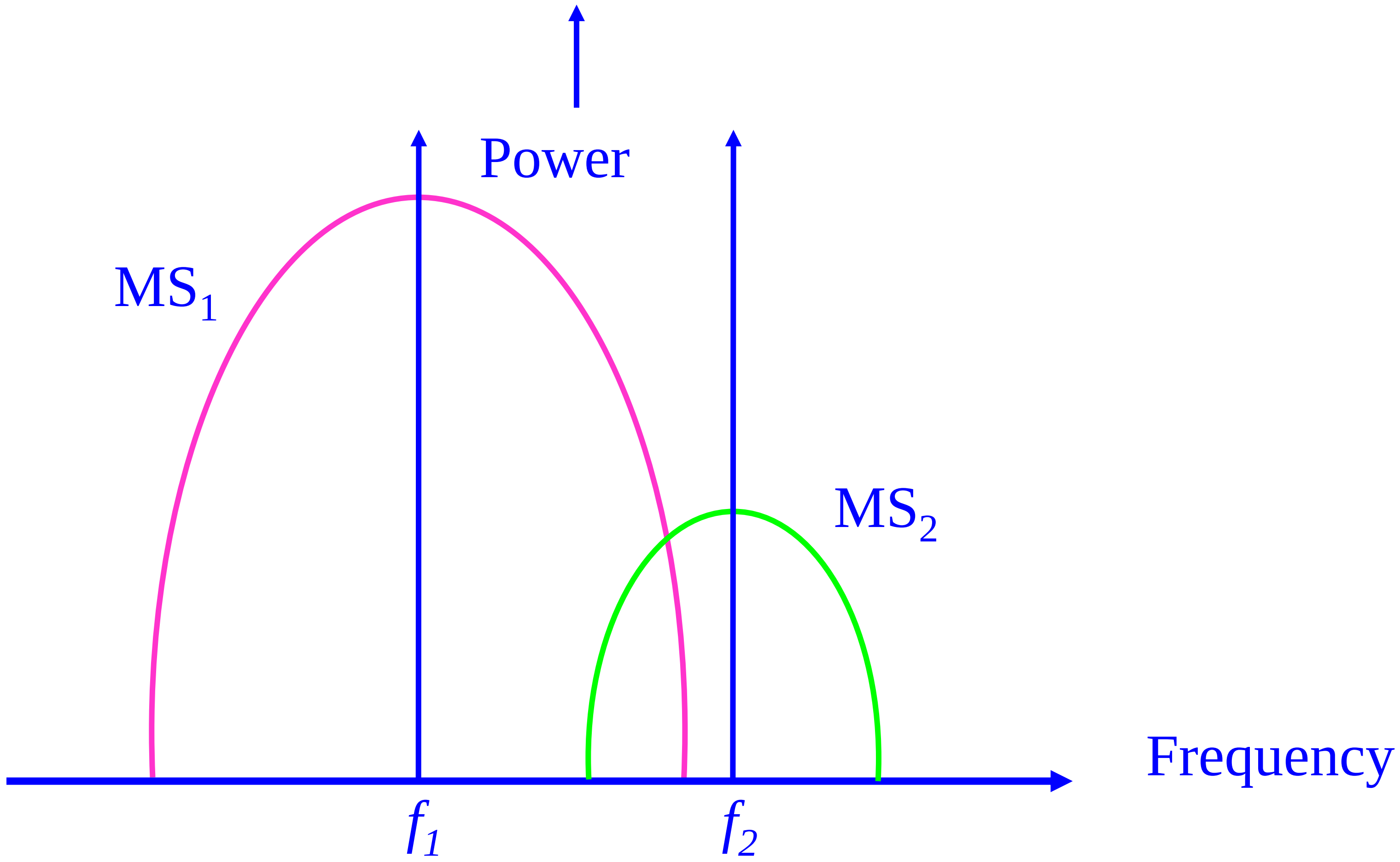
Adjacent Channel Interference



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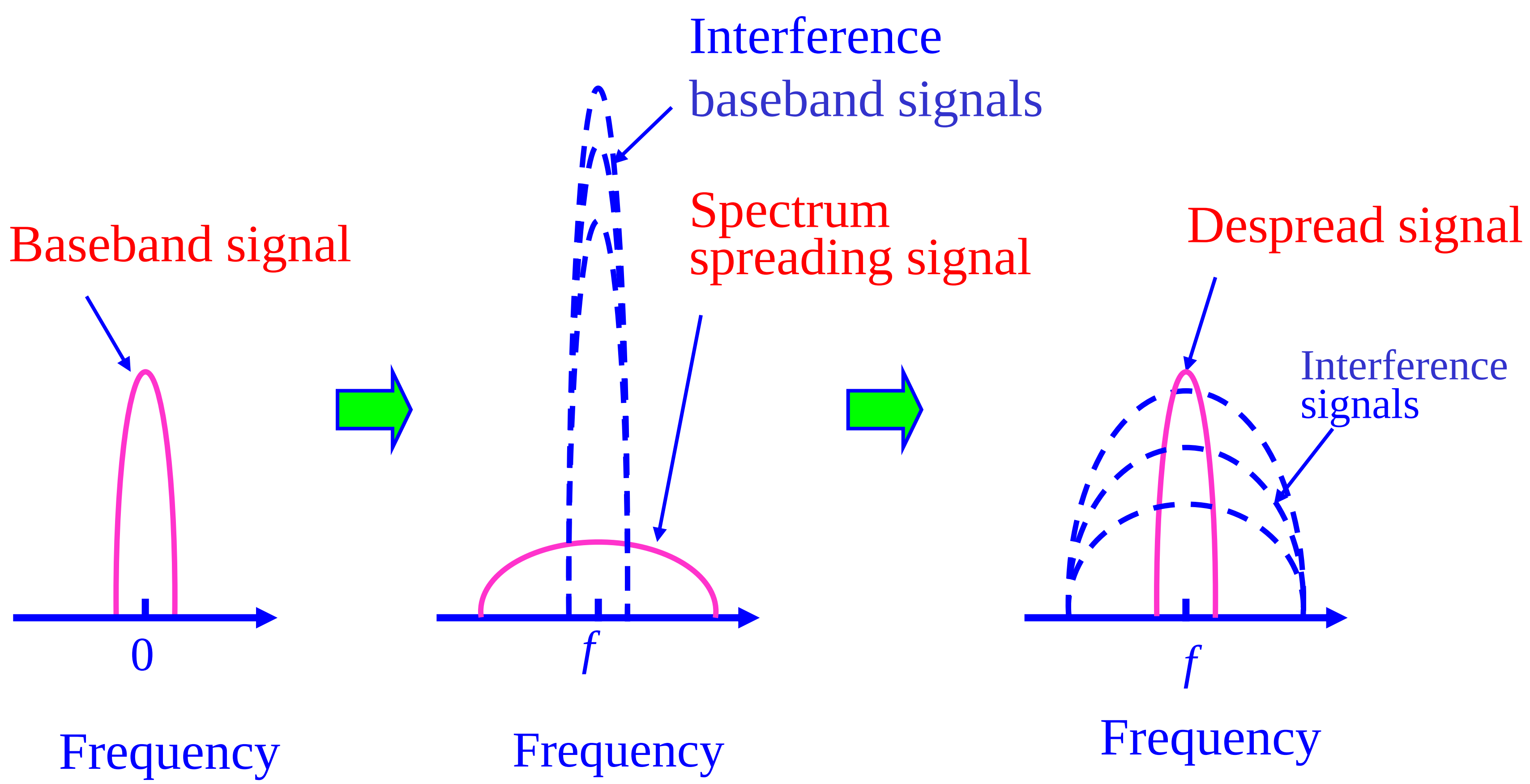
Interference in Spread Spectrum



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Power Control in CDMA

Controlling transmitted power affects the CIR

$$\frac{P_r}{P_t} = \frac{1}{\left(\frac{4\pi df}{c}\right)^{\alpha}}$$

P_r = Received power in free space

P_t = Transmitted power

d = Distance between receiver and transmitter

f = Frequency of transmission

c = Speed of light

α = Attenuation constant (2 to 4)

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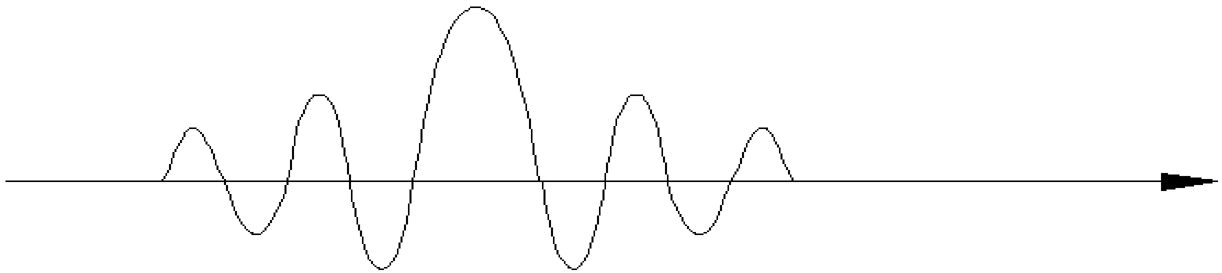
Orthogonal Frequency Division Multiplexing (OFDM)

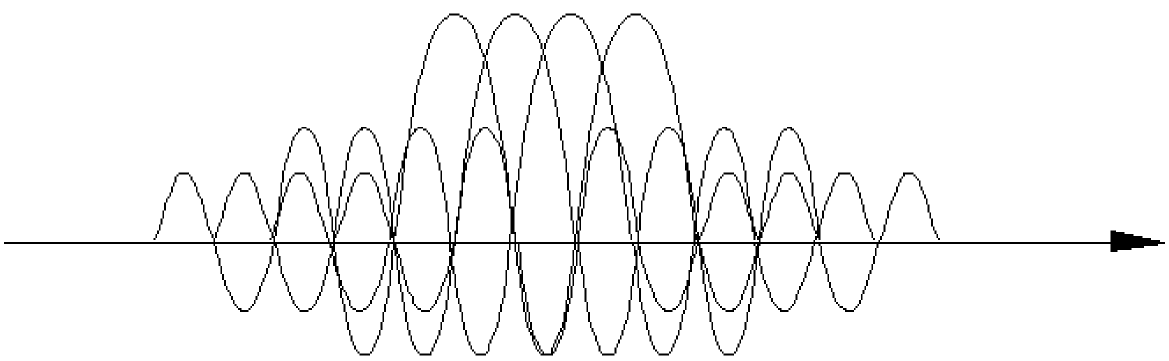
Divide a channels in to multiple sub-channels and do parallel transmission

Orthogonality of two signals in OFDM can be given by a complex conjugate relation indicated by *:

$$\int_F s(f,t)s_j^*(f,t)dt = \begin{cases} 1, & i = j \\ 0, & i \neq j \end{cases}, \quad i, j = 1,2,\ldots,k$$



Spectrum of a single OFDM subchannel



Spectrun of an OFDM signal with multiple subchannels

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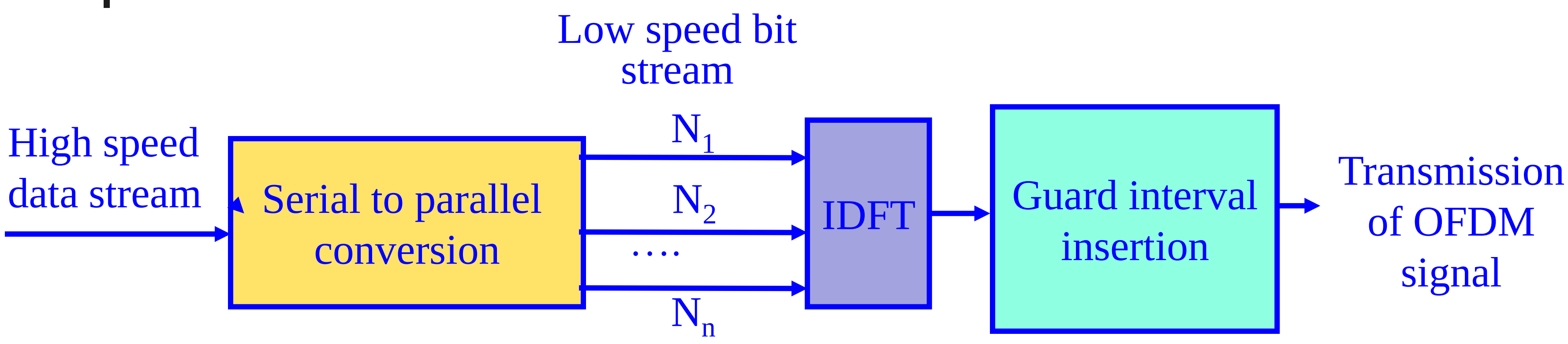
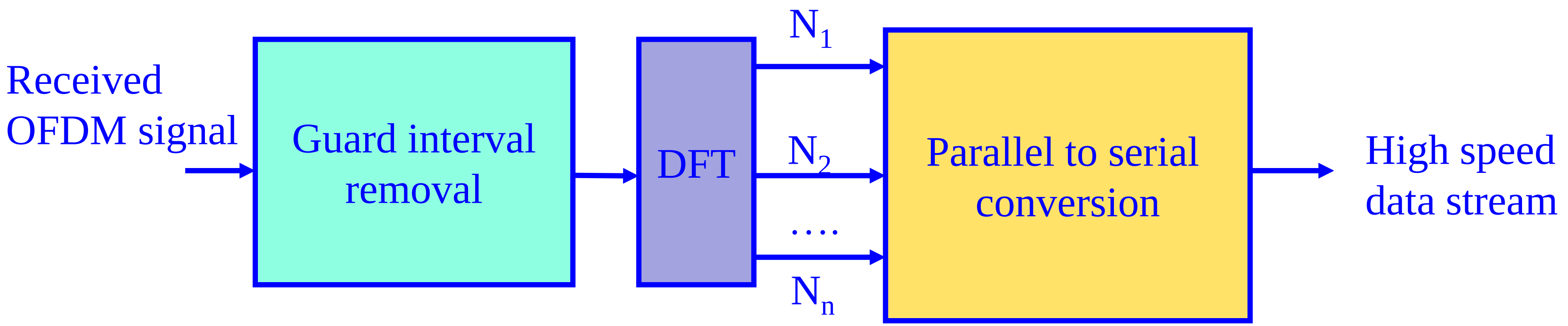
Modulation/Demodulation Steps in OFDM



Modulation operation at the OFDM transmitter



Demodulation steps at the OFDM receiver

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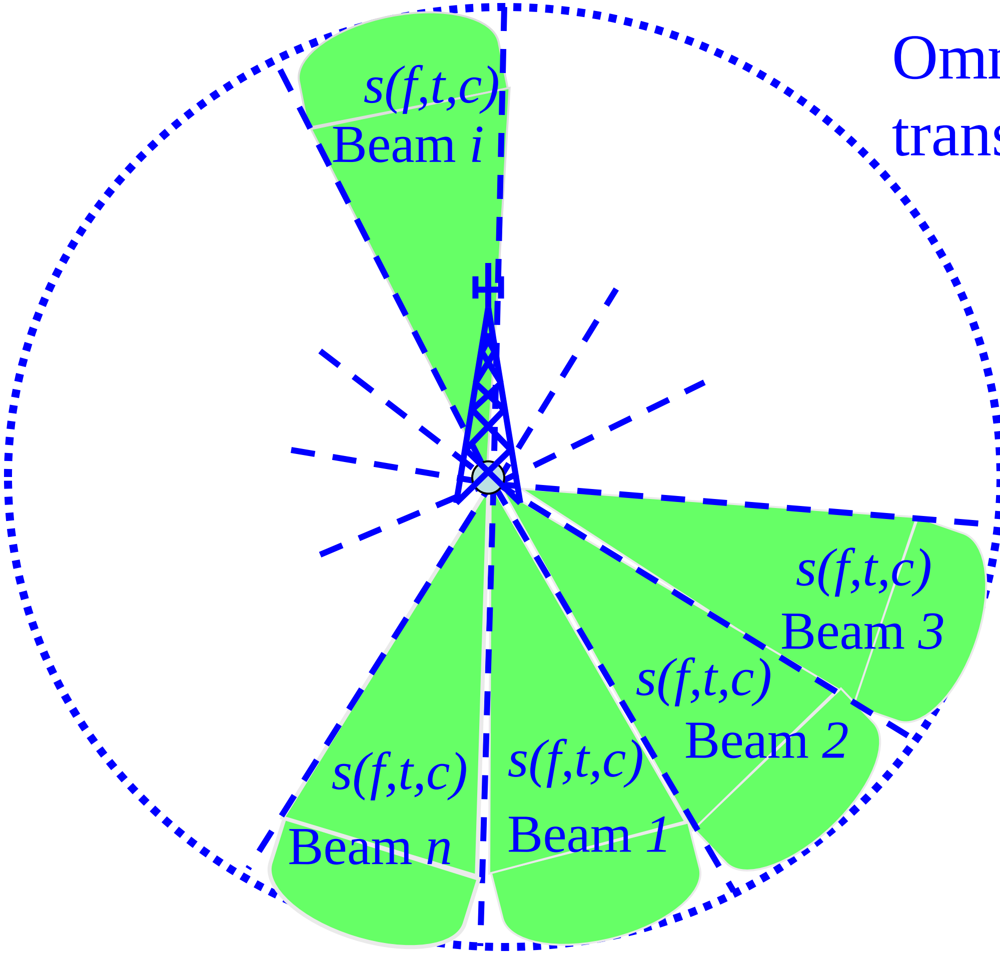
Space Division Multiple Access (SDMA)

Space divided into spatially separate sectors



Omni-directional transmission

The concept of SDMA

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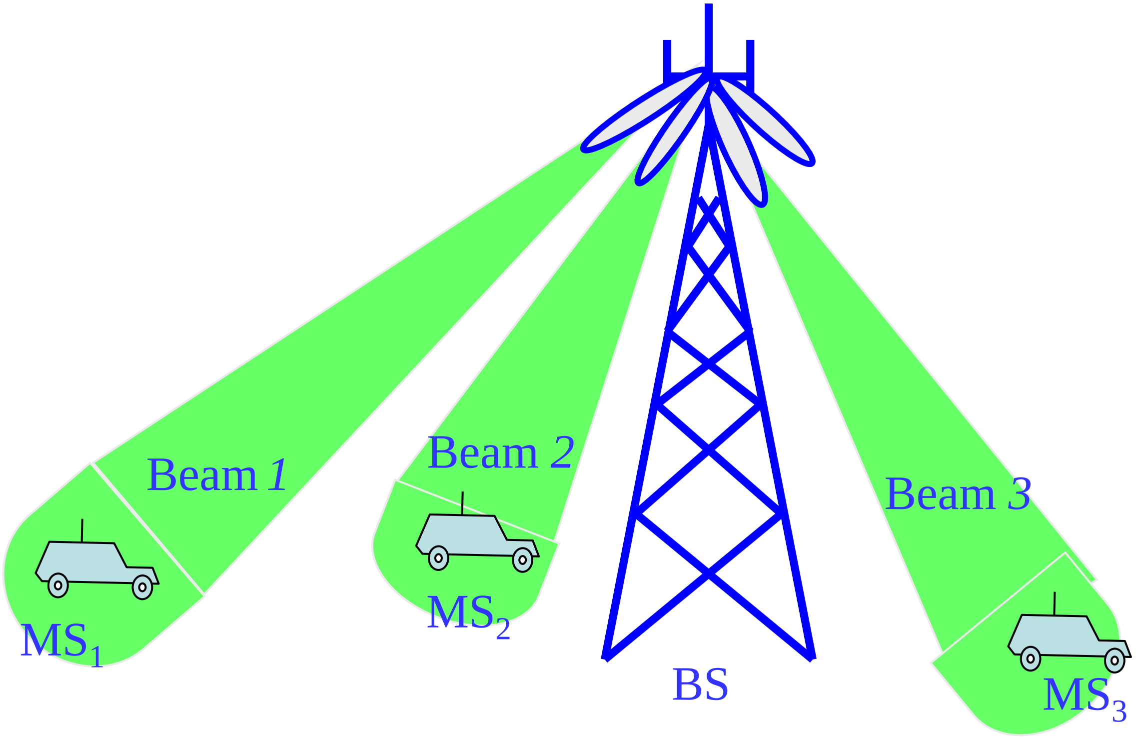
Transmission in SDMA



The basic structure of a SDMA system.

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Comparison of various Multiple Division Techniques

Technique	FDMA	TDMA	CDMA	SDMA
Concept	Divide the frequency band into disjoint subbands	Divide the time into non-overlapping time slots	Spread the signal with orthogonal codes	Divide the space in to sectors
Active terminals	All terminals active on their specified frequencies	Terminals are active in their specified slot on same frequency	All terminals active on same frequency	Number of terminals per beam depends on FDMA/ TDMA/CDMA
Signal separation	Filtering in frequency	Synchronization in time	Code separation	Spatial separation using smart antennas
Handoff	Hard handoff	Hard handoff	Soft handoff	Hard and soft handoffs
Advantages	Simple and robust	Flexible	Flexible	Very simple, increases system capacity
Disadvantages	Inflexible, available frequencies are fixed, requires guard bands	Requires guard space, synchronization problem	Complex receivers, requires power control to avoid near-far problem	Inflexible, requires network monitoring to avoid intracell handoffs
Current applications	Radio, TV and analog cellular	GSM and PDC	2.5G and 3G	Satellite systems, other being explored

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Modulation Techniques

- Why need modulation?
  - Small antenna size

    Antenna size is inversely proportional to frequency (wavelength)

    e.g., 3 kHz → 50 *km* antenna

    3 GHz → 5 *cm* antenna
  - Limits noise and interference,

    e.g., FM (Frequency Modulation)
  - Multiplexing techniques,

    e.g., FDM, TDM, CDMA

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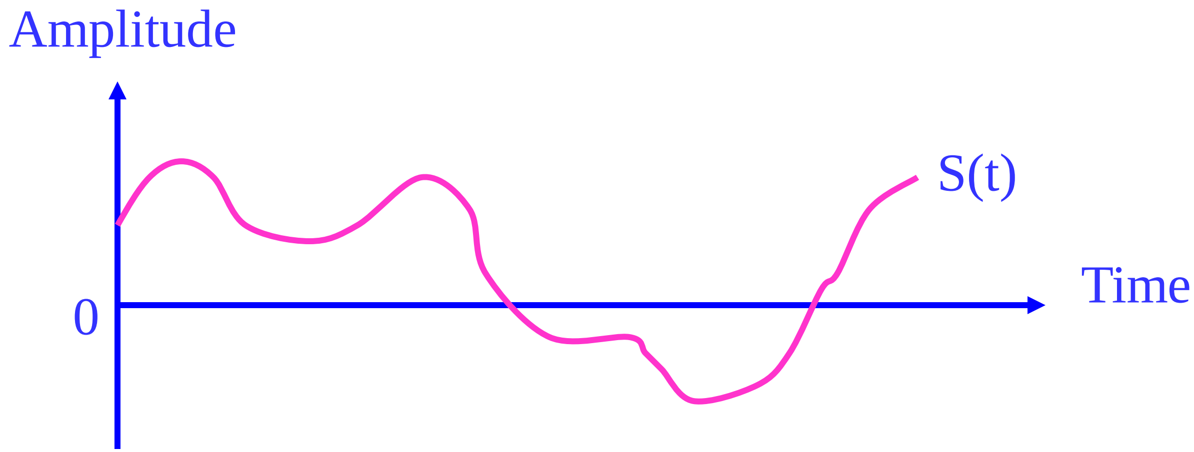
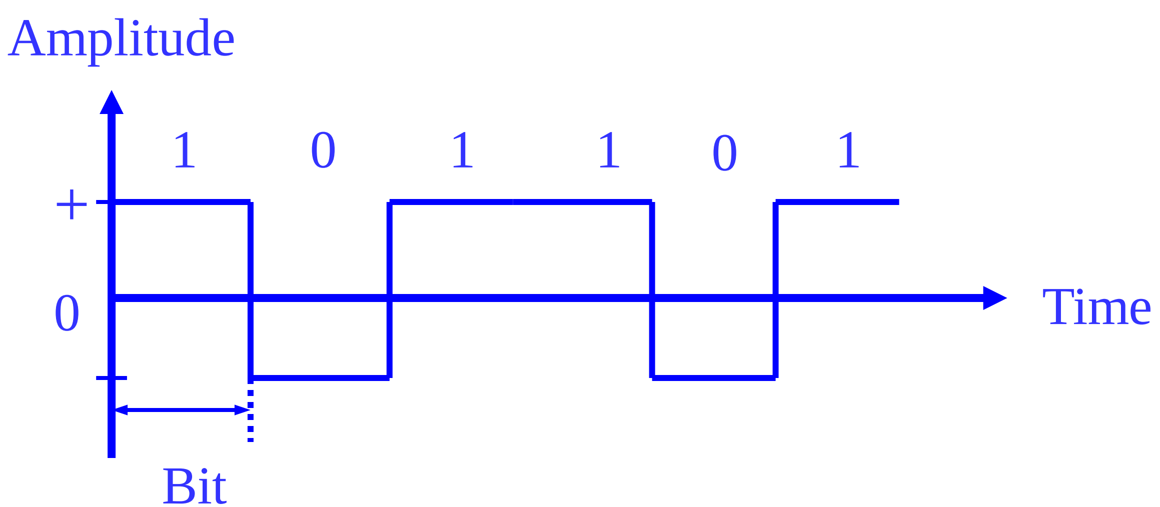
Analog and Digital Signals

- Analog Signal (Continuous signal)



- Digital Signal (Discrete signal)



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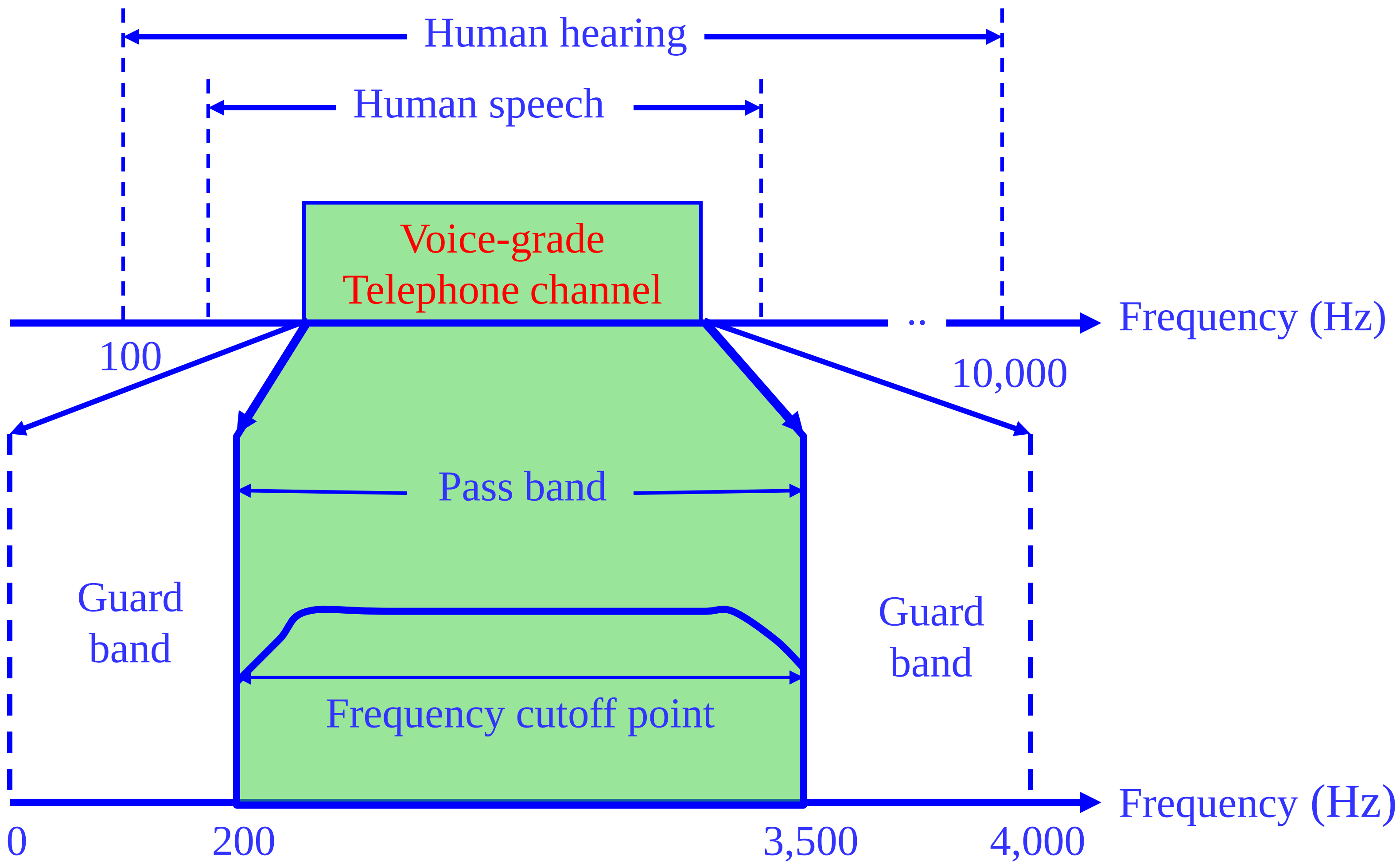
Hearing, Speech, and Voice-band Channels



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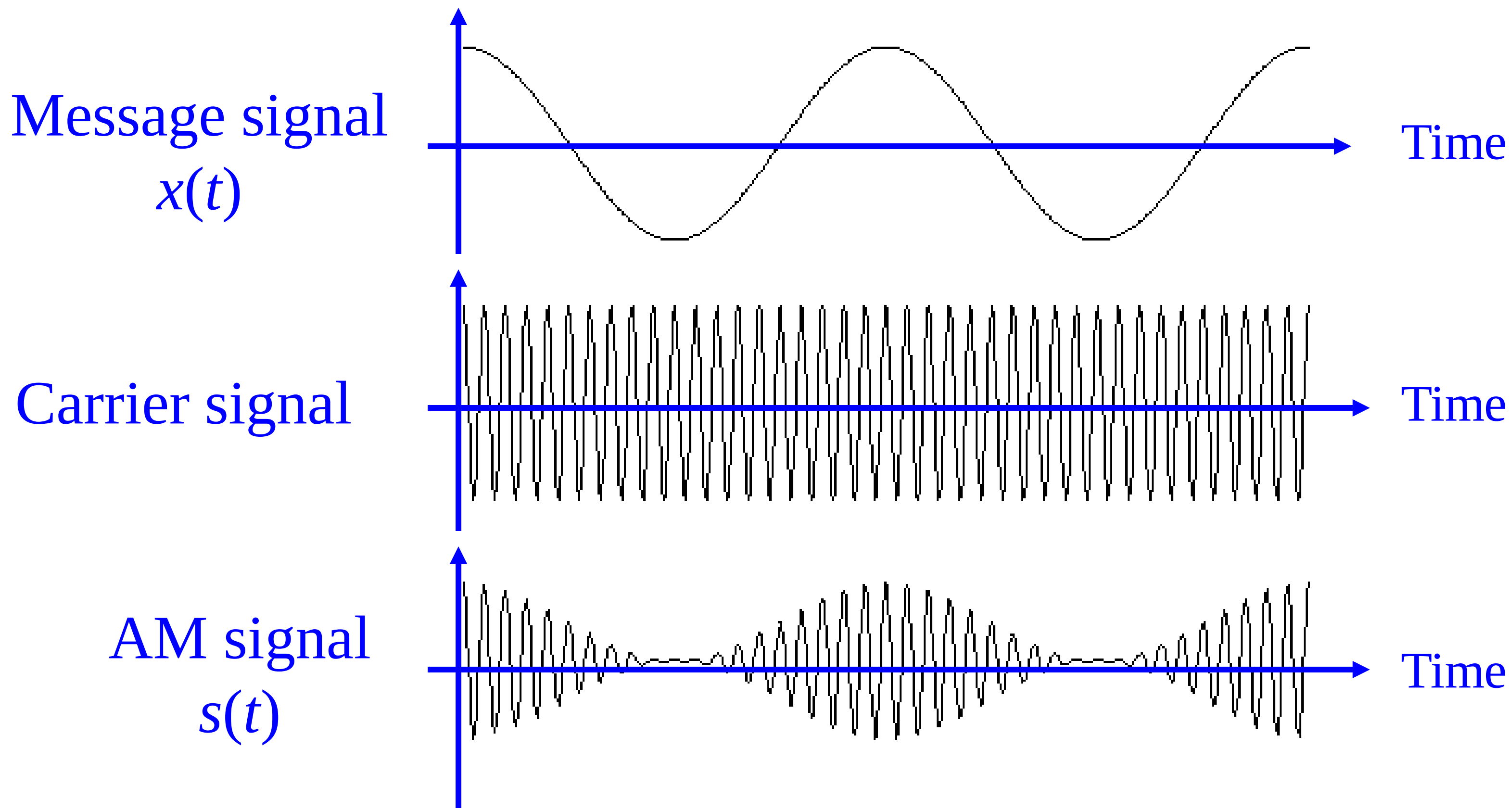
Amplitude Modulation (AM)



The modulated carrier signal $s(t)$ is:

$$s(t) = [A + x(t)]\cos(2\pi f_c t)$$

Where f_c is the carrier frequency and A is amplitude

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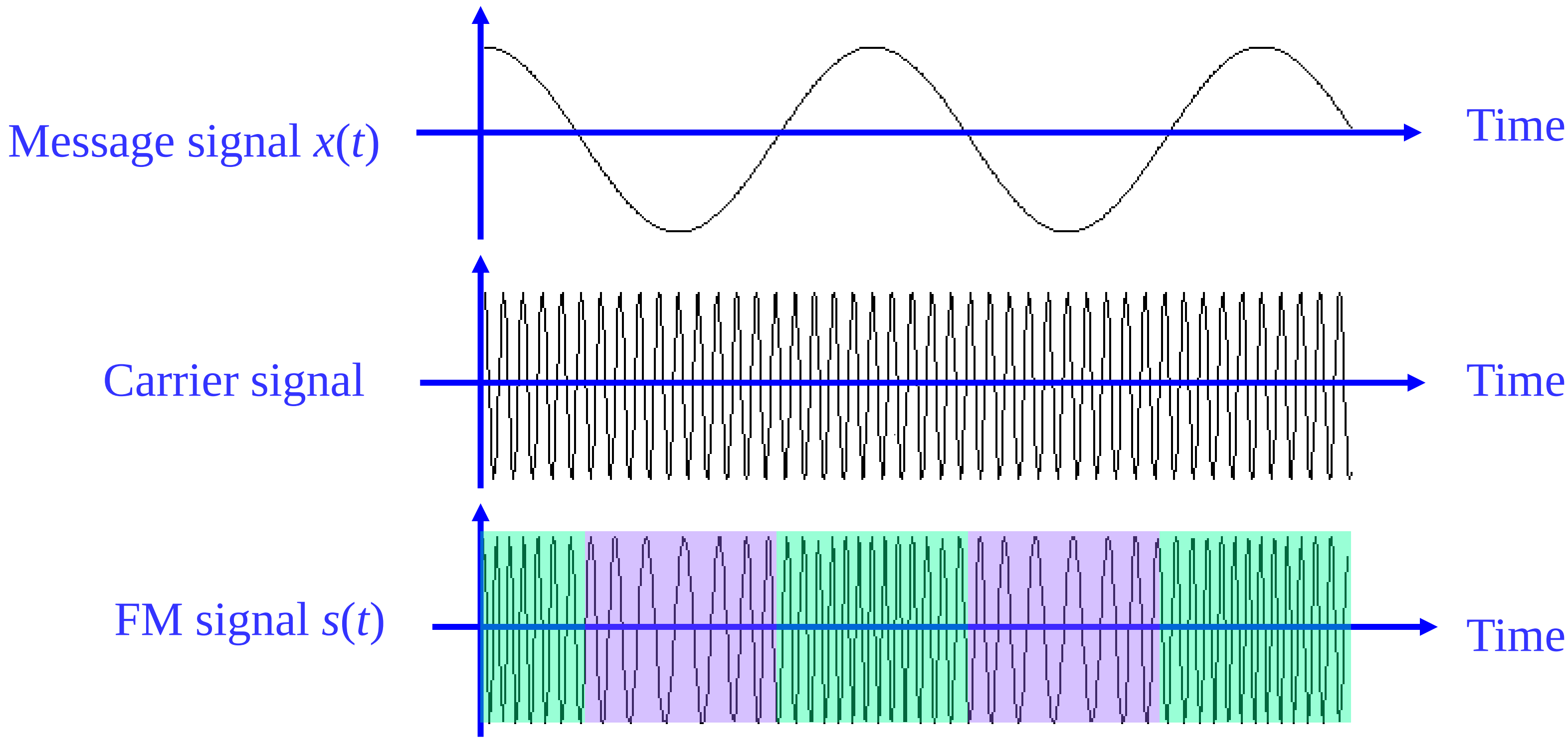
Frequency Modulation (FM)



The modulated carrier signal *s(t)* is:

$$s(t) = A\cos\left((2\pi f_c t + 2\pi f_\Delta \int_{t_0}^{t} x(\tau)d\tau + \theta_0 \right)$$

$BW=2(b+1)f_m$ with $b= f_D/f_m$; f_m is the maximum modulating frequency used

Where f_D is the peak frequency deviation from the original frequency and $f_D << f_c$

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Example on Frequency Modulation

Example 7.1: An FM signal $s(t) = 10\cos\left[2x10^{16}\pi t + 10\cos(2000\pi t)\right]$. Find its peak frequency deviation f_Δ, the index of modulation ß , and its bandwidth (BW).

From the FM signal, the instantaneous phase is given by

$$\theta(t) = 2x10^{16}\pi t + 10\cos(2000\pi t)$$

Therefore, the instantaneous angular frequency can be calculated as

$$\omega(t) = \frac{d\theta(t)}{t} \quad = 2x10^{16}\pi t - 20000\pi \sin(2000\pi t)$$

Based on the definition of peak frequency deviation, we have

$$f_\Delta = \frac{10\omega}{2\pi} = \frac{20000\,\pi}{2\pi} Hz = 10kHz$$

The index of modulation can be calculated by $\beta = \frac{f_\Delta}{f_m} = \frac{10x10^3}{10^3} = 10$

The bandwidth (BW) of the FM signal $S(t)$ is given by

$$BW = 2(\beta + 1) f_m = 2x11x10^3 Hz = 22kHz$$

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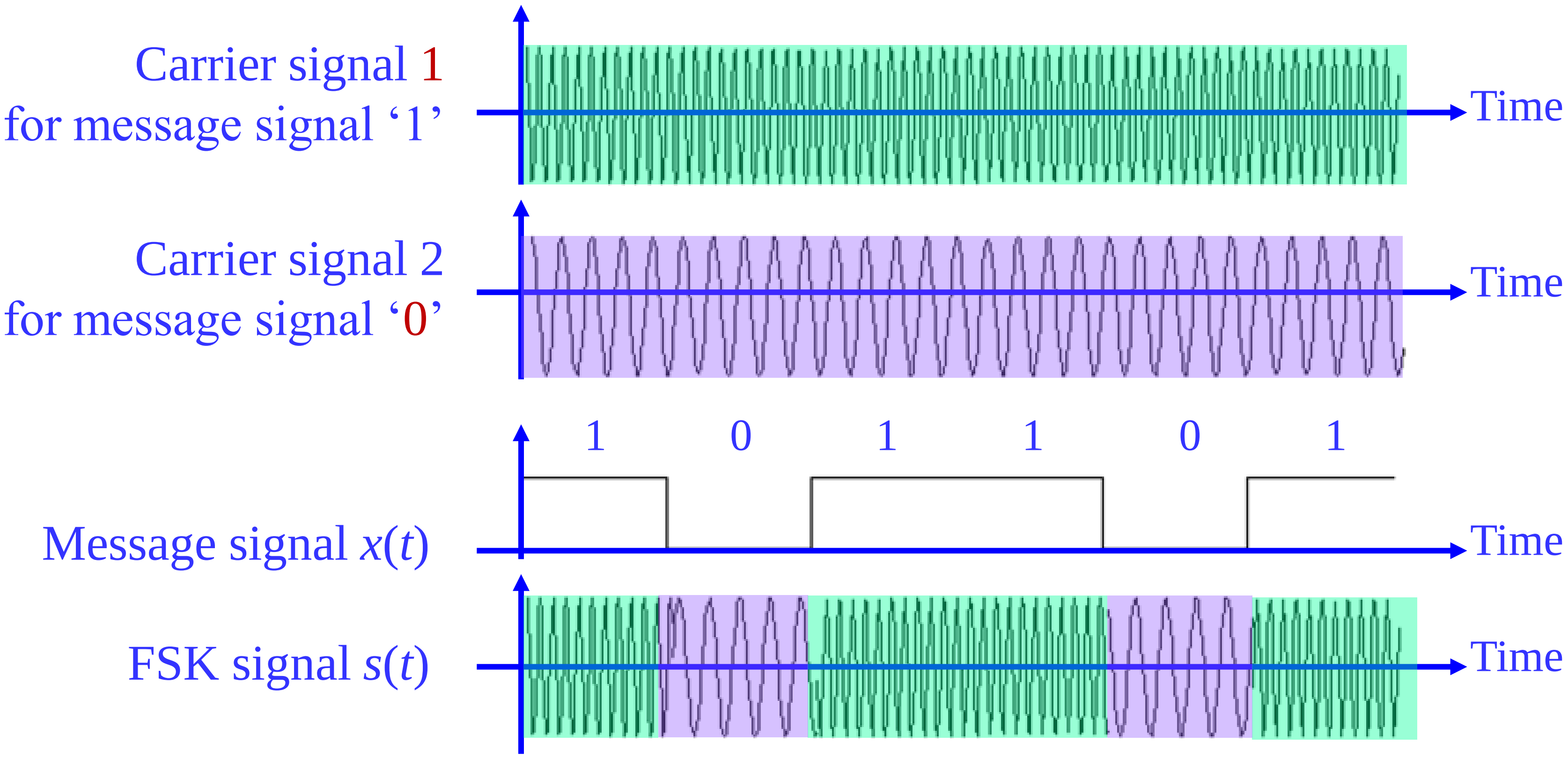
Frequency Shift Keying (FSK)

1/0 represented by two different frequencies



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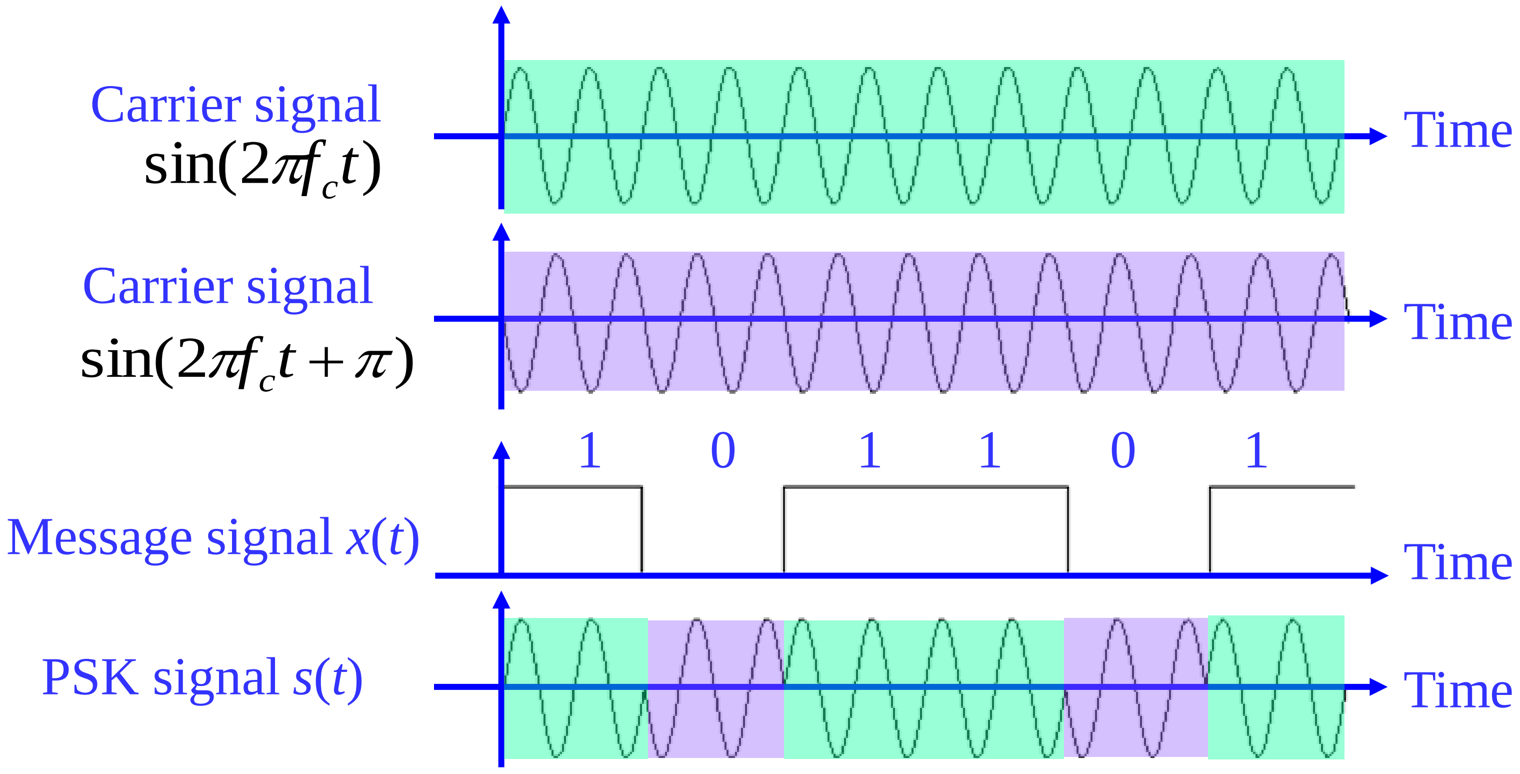
Phase Shift Keying (PSK)

- Use alternative sine wave phases to encode bits



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Quadrature Phase Shift Keying (QPSK)

Four different phase shifts used are:

$$\begin{cases} \phi_{0,0} = 0 \\ \phi_{0,1} = \pi / 2 \\ \phi_{1,0} = \pi \\ \phi_{1,1} = 3\pi / 2 \end{cases} \quad \text{or} \quad \begin{cases} \phi_{0,0} = \pi / 4 \\ \phi_{0,1} = 3\pi / 4 \\ \phi_{1,0} = -3\pi / 4 \\ \phi_{1,1} = -\pi / 4 \end{cases}$$

I (in-phase) and Q (quadrature) modulation used

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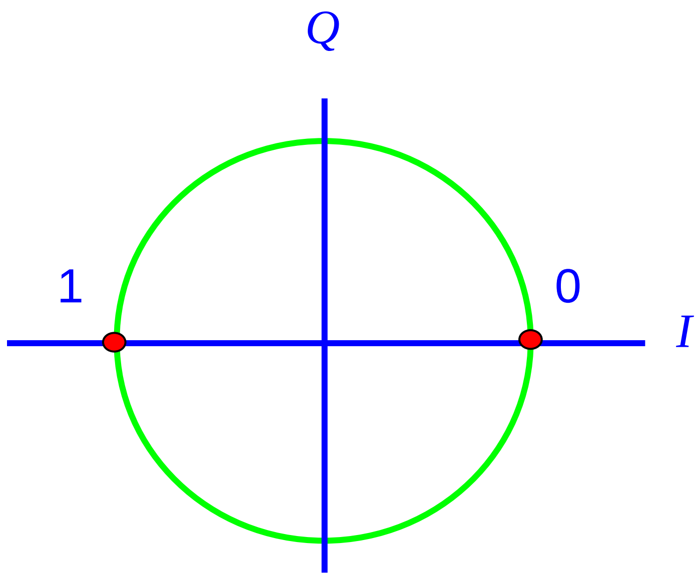
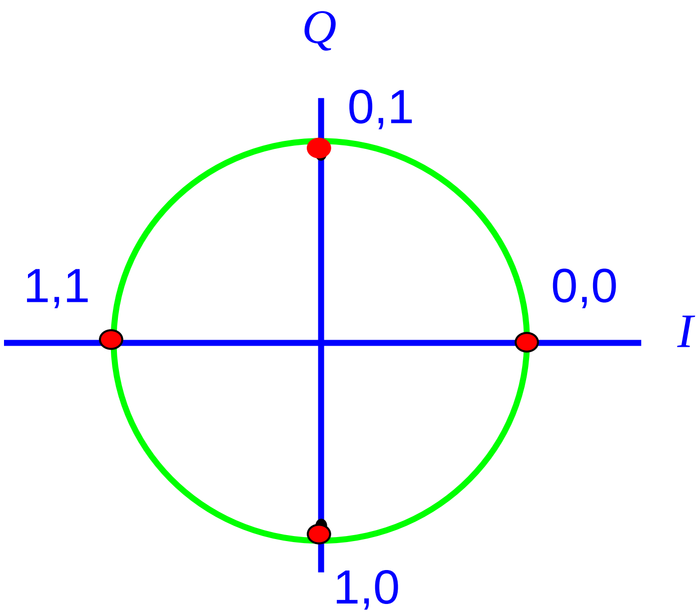
QPSK Signal Constellation



(a) BPSK

(Binary Phase Shift Keying)



(b) QPSK

(Quadrature Phase Shift Keying)

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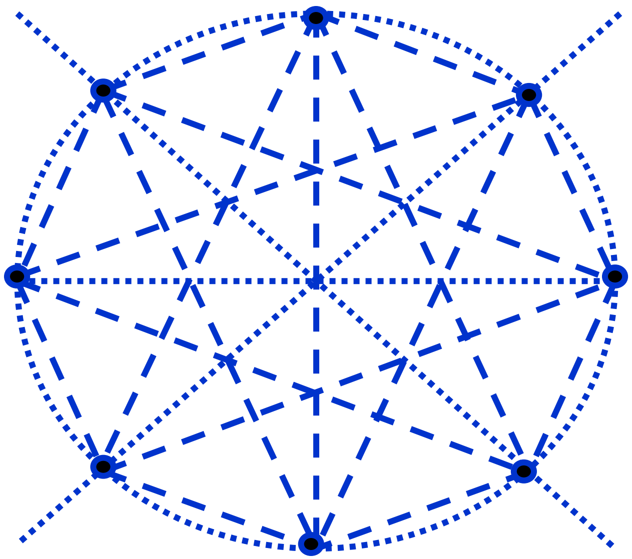
$\pi/4$ QPSK

The phase of the carrier is: $\theta_k = \theta_{k-1} + \phi_k$

Where θ_k is carrier phase shift corresponding to input bit pairs. If θ_k=0, input bit stream is [1011], then:

$$\theta_1 = \theta_0 + \phi_1 = -\pi / 4$$

$$\theta_2 = \theta_1 + \phi_2 = -\pi / 4 + \pi / 4 = 0$$



All possible states in $\pi/4$ QPSK

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Quadrature Amplitude Modulation (QAM)

Combination of AM and PSK: modulate signals using two measures of amplitude and four possible phase shifts

A representative QAM Table

Bit sequence represented	Amplitude	Phase shift
000	1	0
001	2	0
010	1	$\pi/2$
011	2	$\pi/2$
100	1	π
101	2	π
110	1	$3\pi/2$
111	2	$3\pi/2$

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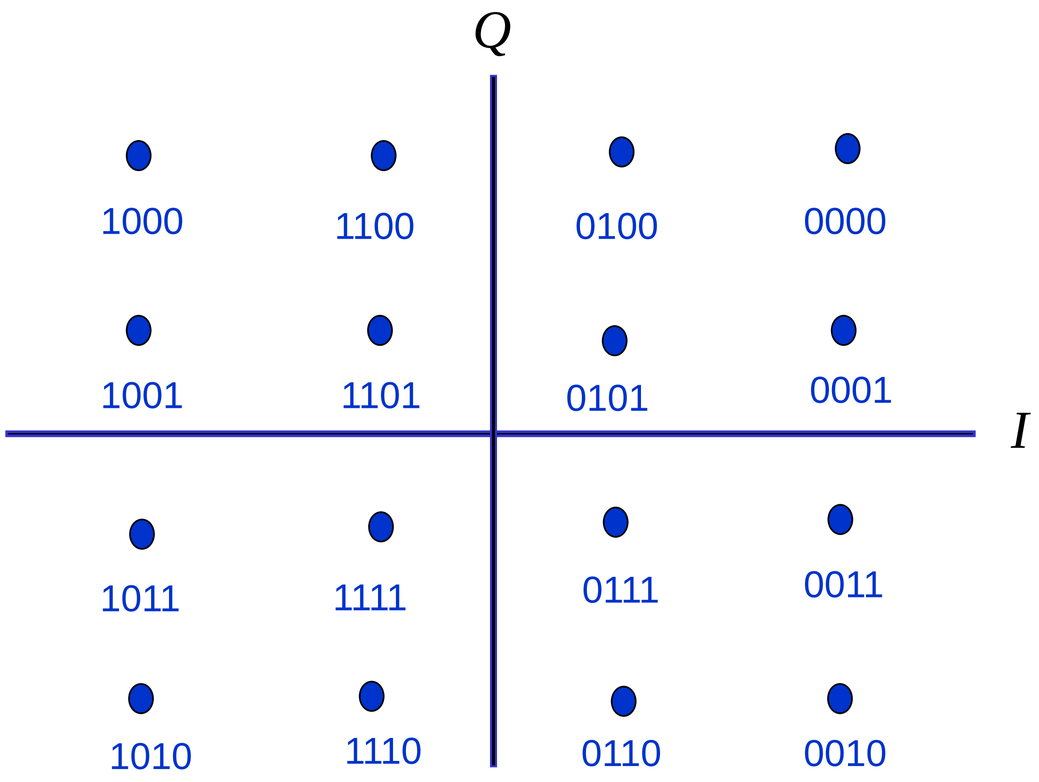
Quadrature Amplitude Modulation (QAM)

Two carriers out of phase by 90 deg are amplitude modulated



Rectangular constellation of 16QAM

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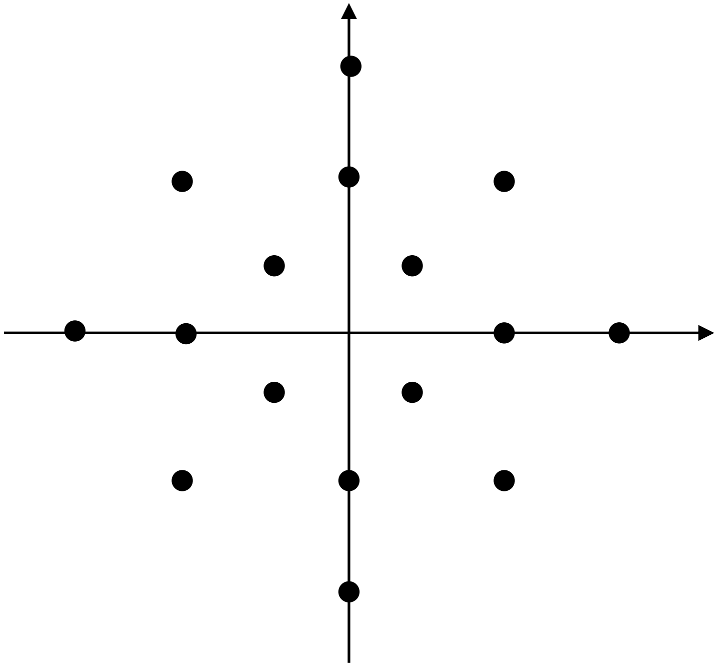
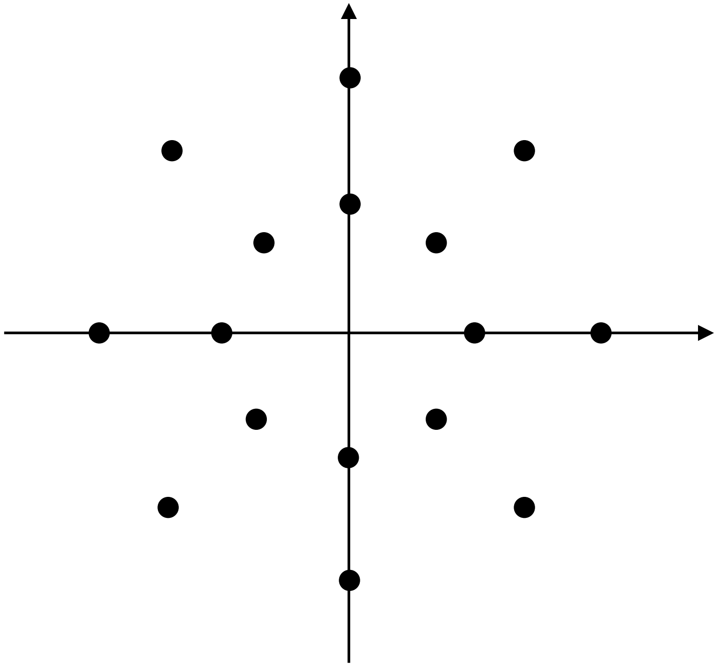
Other Constellations of 16QAM



(a) 8 phases, 4 amplitudes



(b) 8 phases, 2 amplitudes

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