

# Data and Computer Communications

Tenth Edition  
by William Stallings

# **CHAPTER 17**

## **Wireless Transmission Techniques**

*“All creative people want to do the unexpected.”*

*—Ecstasy and Me: My Life as a Woman,*  
HedyLamarr



# MIMO Antennas

- Multiple-input-multiple-output
- Has become a key technology in evolving high-speed wireless networks
- Exploits the space dimension to improve wireless systems in terms of capacity, range, and reliability
- Cornerstone of emerging broadband wireless networks

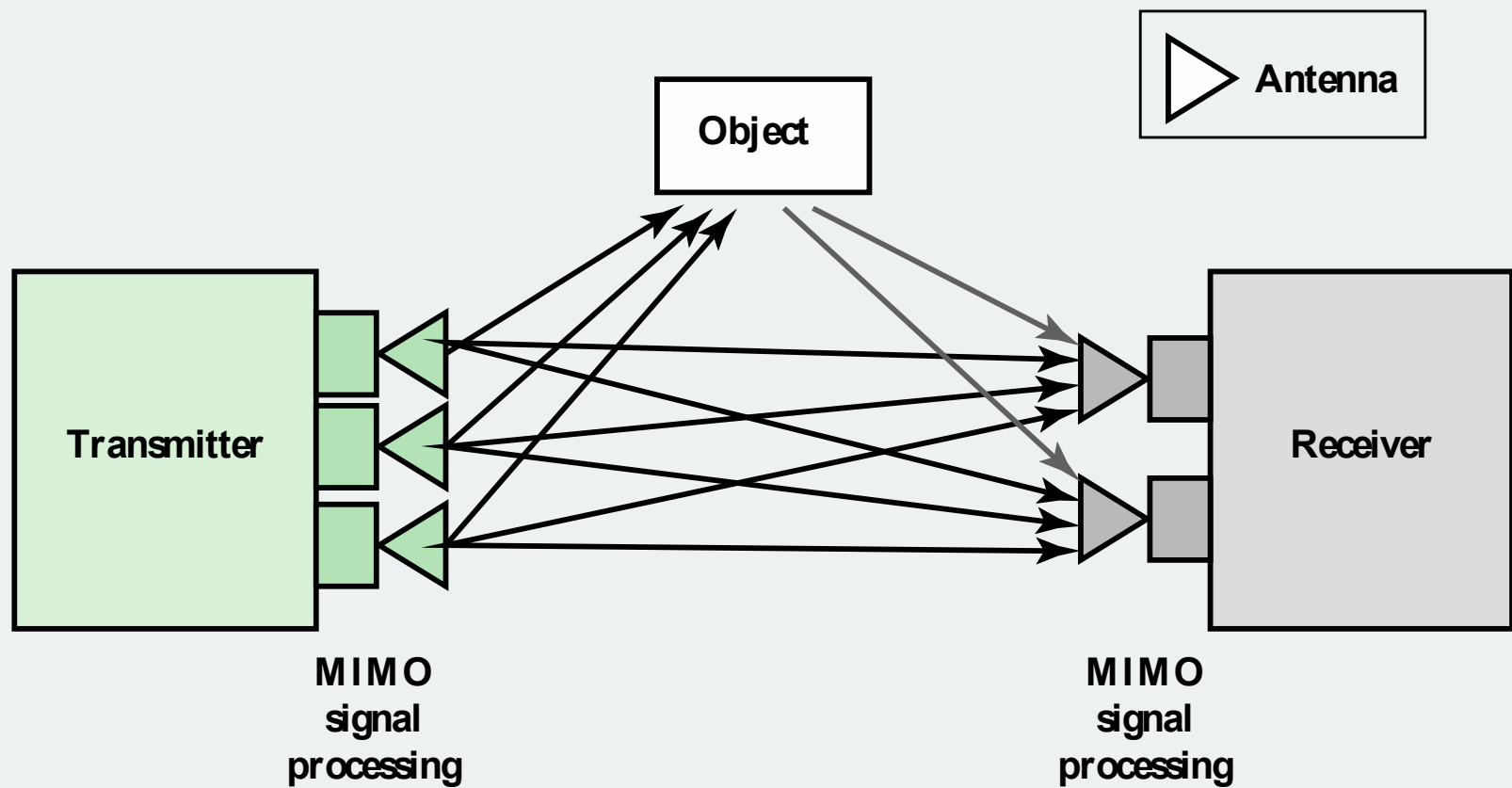


Figure 17.1 MIMO Scheme

# MIMO Principles

## ➤ Two types of transmission schemes:

### Spatial diversity

The same data is coded and transmitted through multiple antennas, which effectively increases the power in the channel proportional to the number of transmitting antennas

Improves SNR for cell edge performance

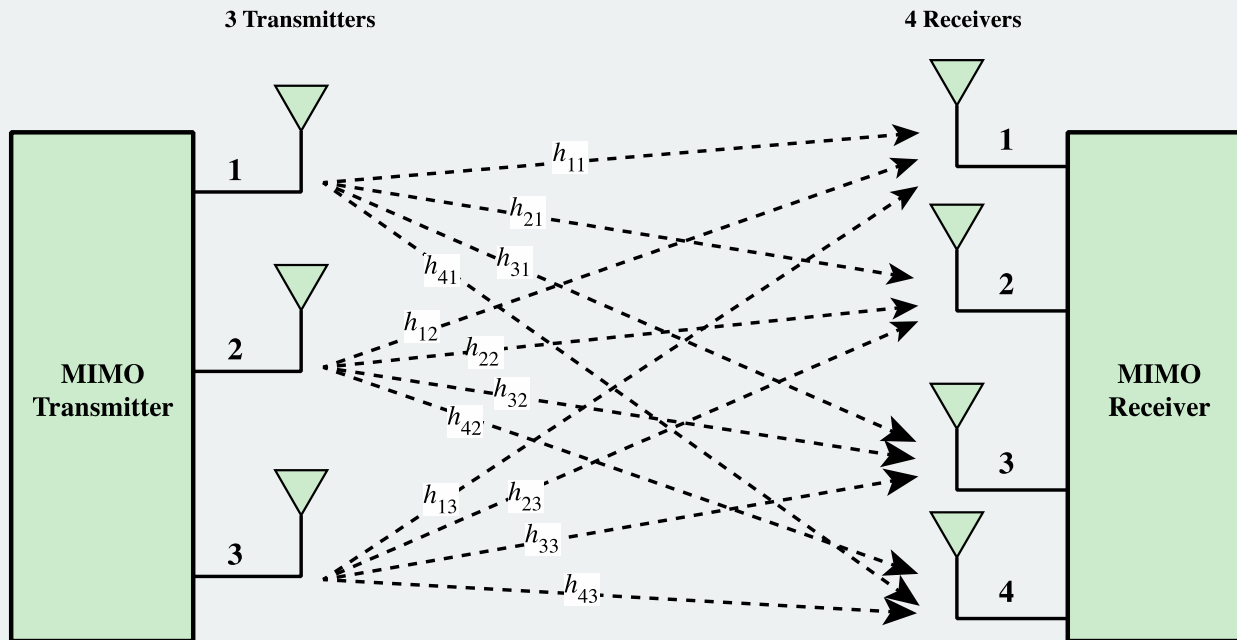
There is a high probability that if one antenna is suffering a high level of fading, another antenna has sufficient signal level

### Spatial multiplexing

A source data stream is divided among the transmitting antennas

Gain in channel capacity is proportional to the available number of antennas at the transmitter or receiver, whichever is less

Can be used when transmitting conditions are favorable and for relatively short distances



3 transmit antennas

$$H = \begin{bmatrix} h_{11} & h_{12} & h_{13} \\ h_{21} & h_{22} & h_{23} \\ h_{31} & h_{32} & h_{33} \\ h_{41} & h_{42} & h_{43} \end{bmatrix}$$

4 receive antennas

**Figure 17.2 3×4 MIMO Scheme**

# Multiple-User MIMO

- MU-MIMO
- Extends the basic MIMO concept to multiple endpoints, each with multiple antennas
- Advantage is that the available capacity can be shared to meet time-varying demands
- Used in both Wi-Fi and 4G cellular networks



# Applications of MU-MIMO

- Uplink – Multiple Access Channel, MAC
  - Multiple end users transmit simultaneously to a single base station
- Downlink – Broadcast Channel, BC
  - The base station transmits separate data streams to multiple independent users
- MIMO-MAC
  - Systems outperform point-to-point MIMO, particularly if the number of receiver antennas is greater than the number of transmit antennas at each user
  - A variety of multiuser detection techniques are used to separate the signals transmitted by the users
- MIMO-BC
  - Used to enable the base station to transmit different data streams to multiple users over the same frequency band
  - More challenging to implement
  - Techniques employed involve processing of the data symbols at the transmitter to minimize interuser interference

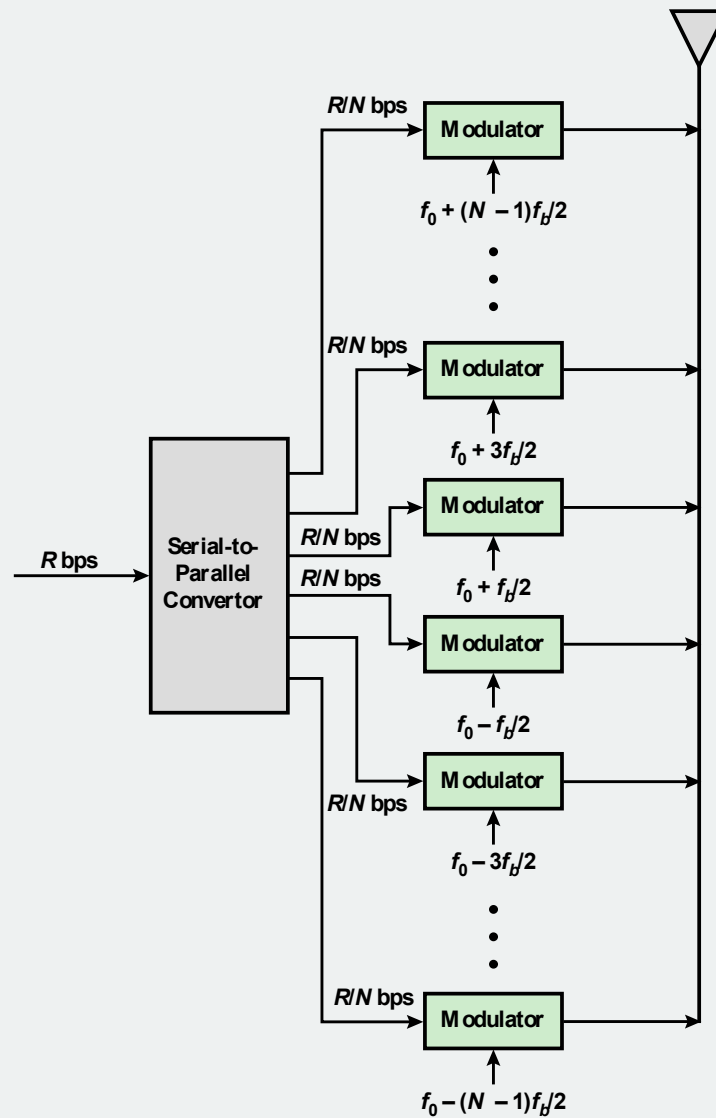
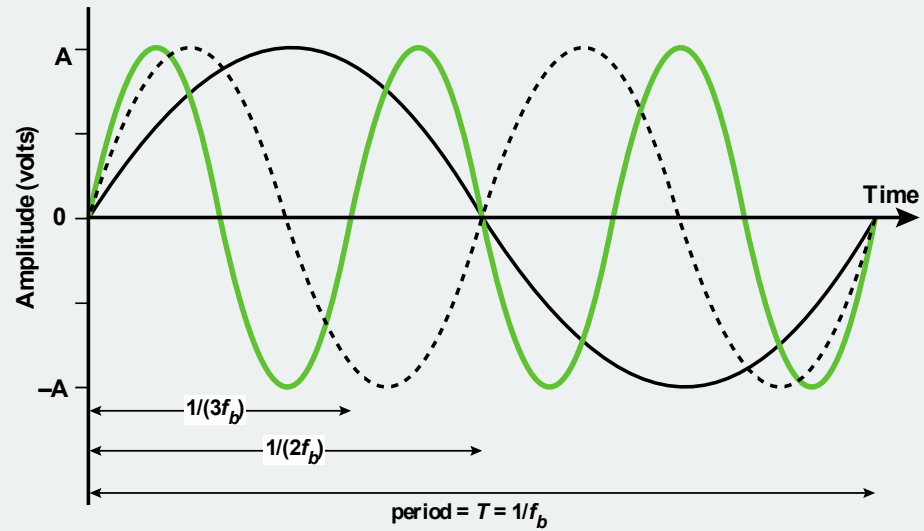
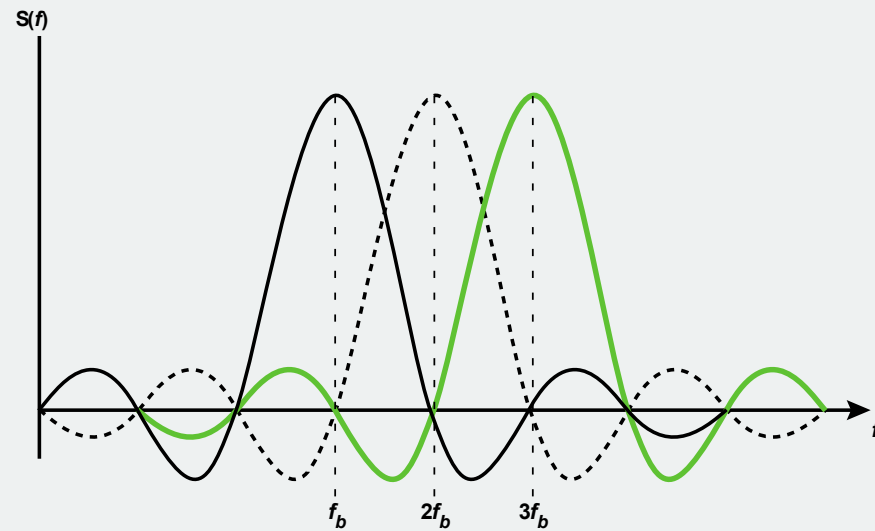


Figure 17.3 Orthogonal Frequency Division Multiplexing



(a) Three subcarriers in time domain

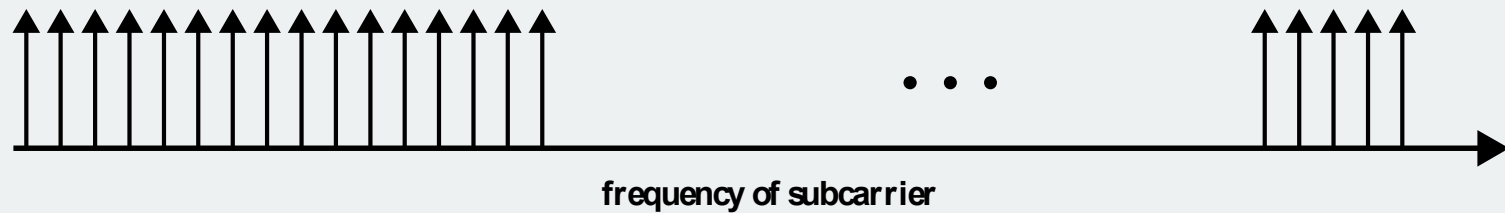


(b) Three subcarriers in frequency domain

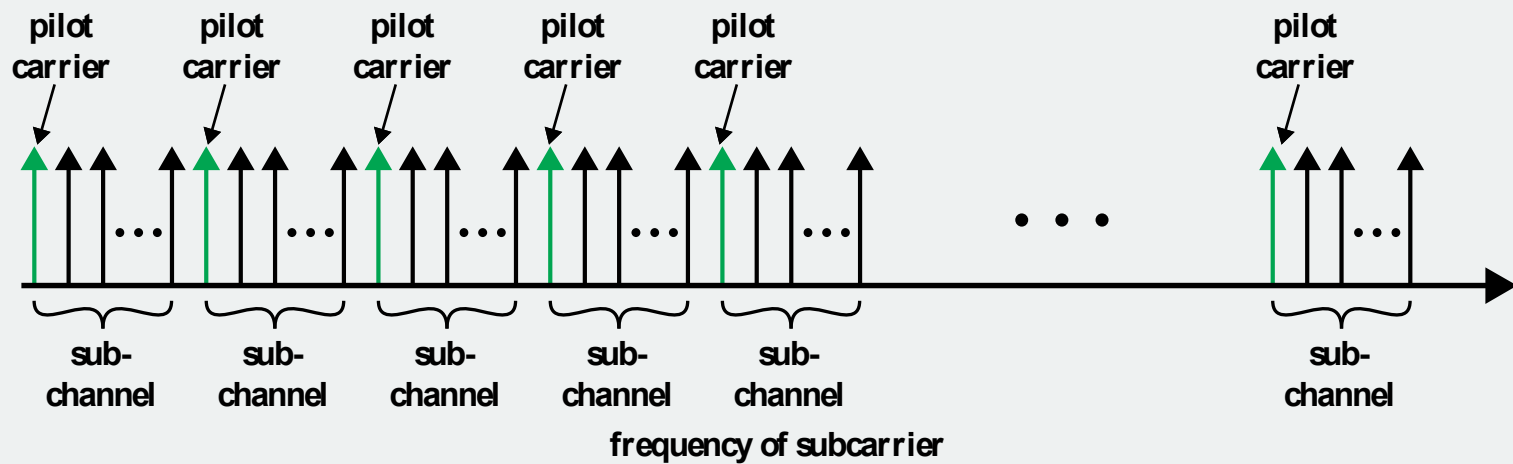
Figure 17.4 Illustration of Orthogonality of OFDM

# OFDM Advantages

- If the data stream is protected by a forward error-correcting code frequency selective fading is easily handled
- Overcomes intersymbol interference (ISI) in a multipath environment
- QPSK is a common modulation scheme used with OFDM
- Signal processing involves two functions:
  - Fast Fourier transform (FFT)
    - Algorithm that converts a set of uniformly spaced data points from the time domain to the frequency domain
  - Inverse fast Fourier transform (IFFT)
    - Reverses the FFT operation
    - Has the effect of ensuring that the subcarriers do not interfere with each other

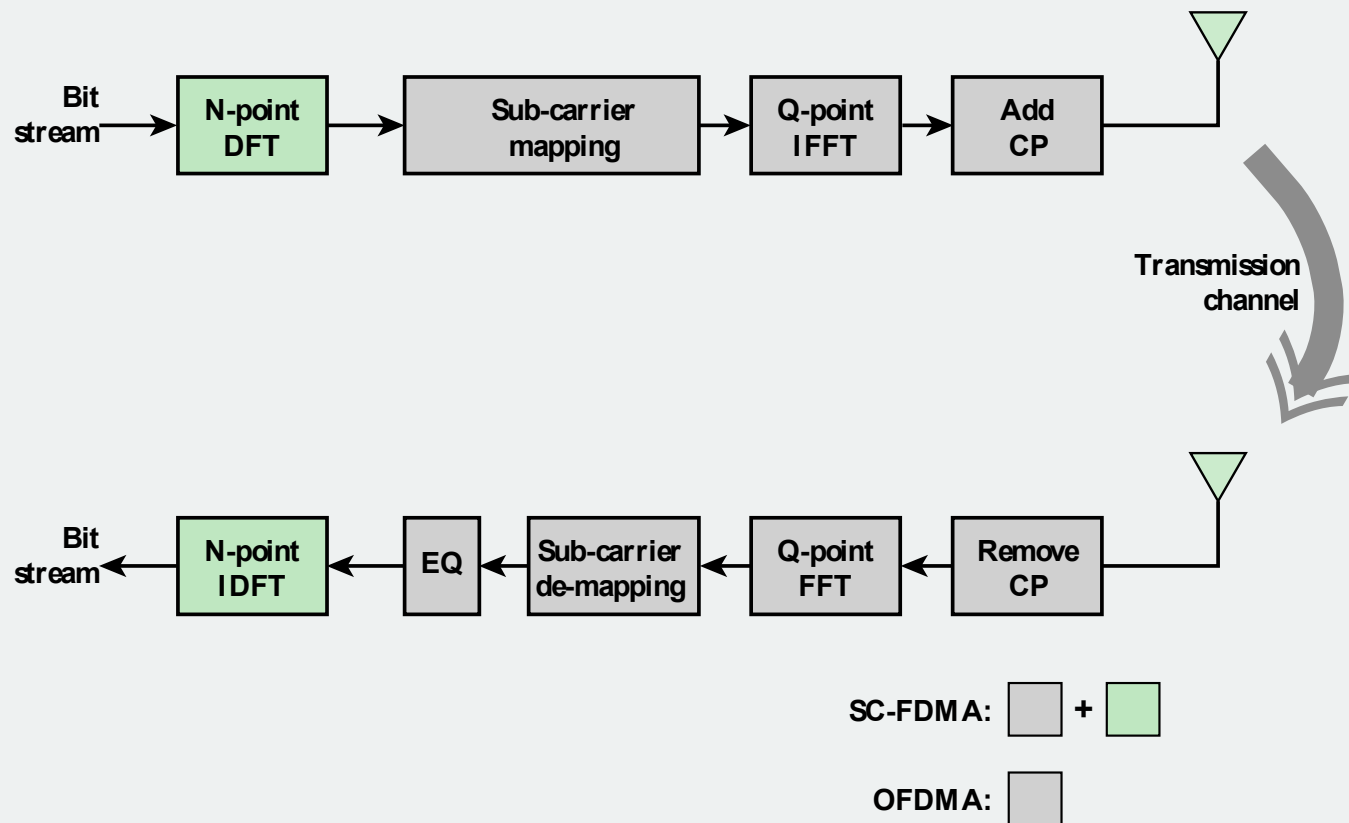


(a) OFDM



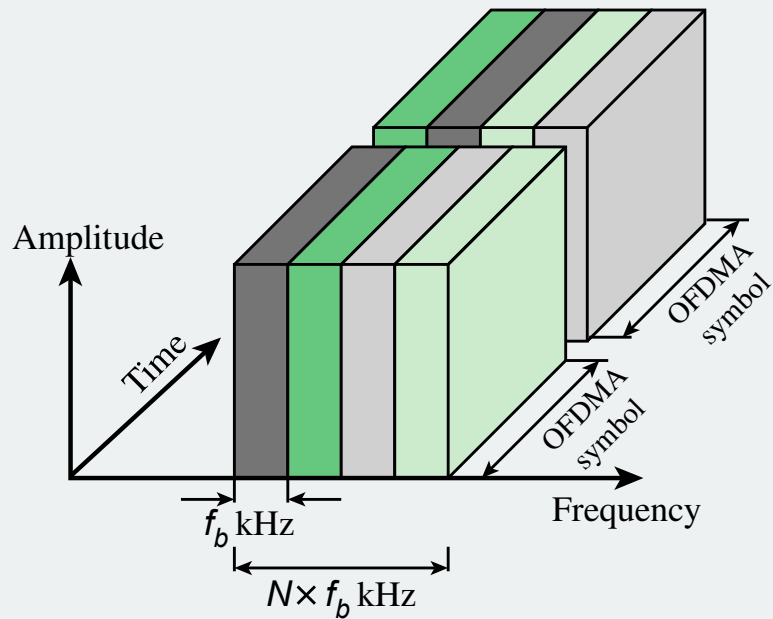
(b) OFDMA (adjacent subcarriers)

Figure 17.5 OFDM and OFDMA

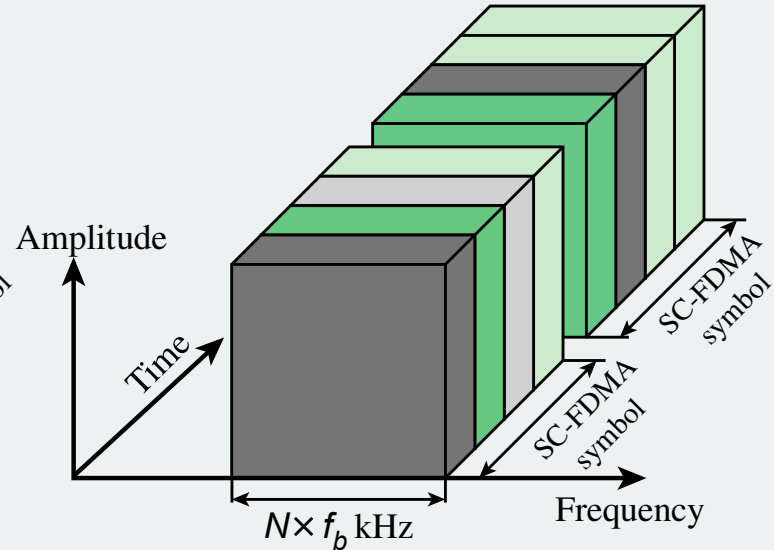


DFT = discrete Fourier transform  
 IDFT = Inverse discrete Fourier transform  
 FFT = fast Fourier transform  
 IFFT = inverse fast Fourier transform  
 EQ = subcarrier equalization  
 CP = cyclic prefix

**Figure 17.6 Simplified Block Diagram of OFDMA and SC-FDMA**



(a) OFDM: Data symbols occupy  $f_b$  kHz for one OFDMA symbol period



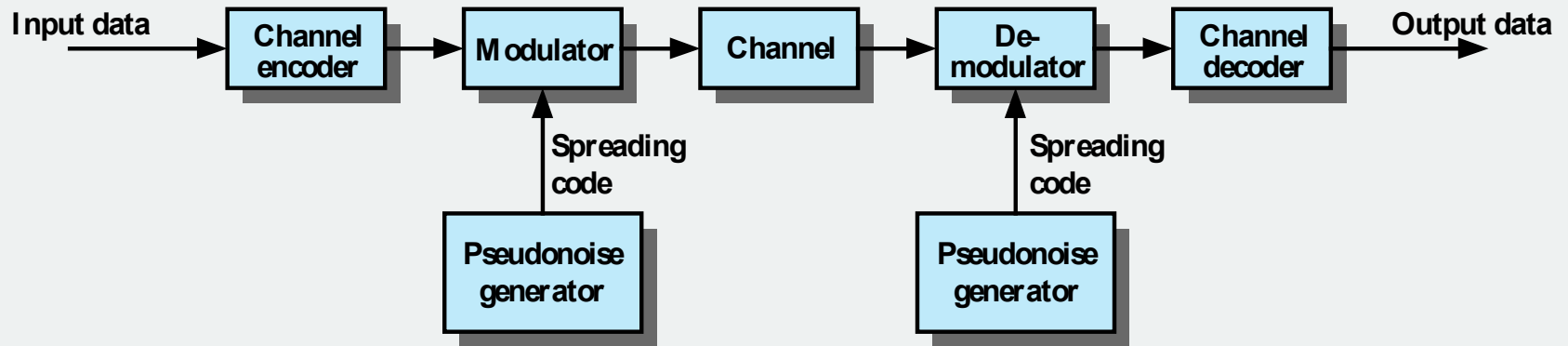
(b) SC-FDMA: Data symbols occupy  $N \times f_b$  kHz for  $1/N$  SC-FDMA symbol period

**Figure 17.7 Example of OFDMA and SC-FDMA**

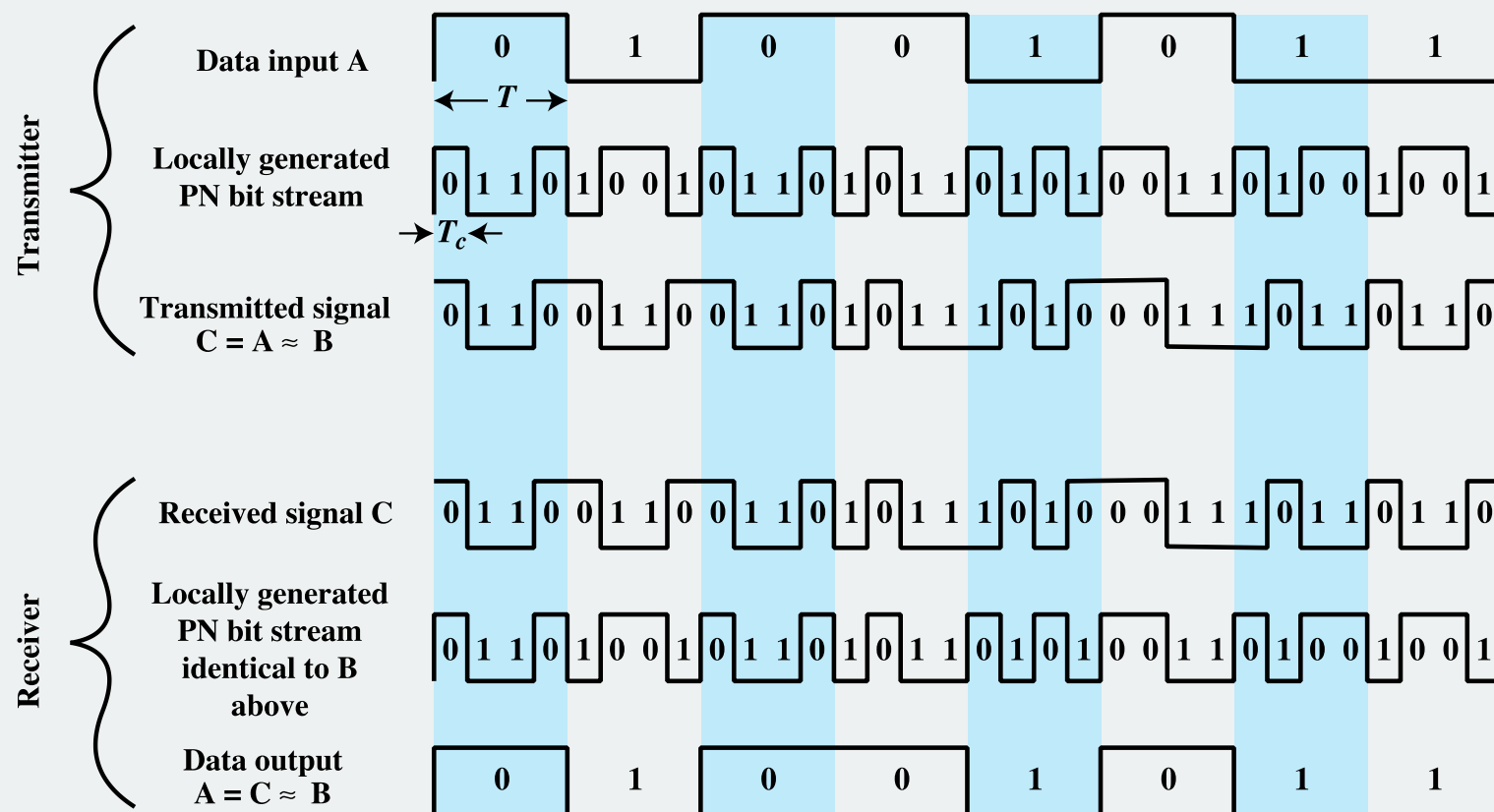
# Spread Spectrum

- Form of encoding for wireless communications
- Can be used to transmit either analog or digital data, using an analog signal
- Was initially developed for military and intelligence requirements
- Essential idea is to spread the information signal over a wider bandwidth to make jamming and interception more difficult
  - Frequency hopping
  - Direct sequence

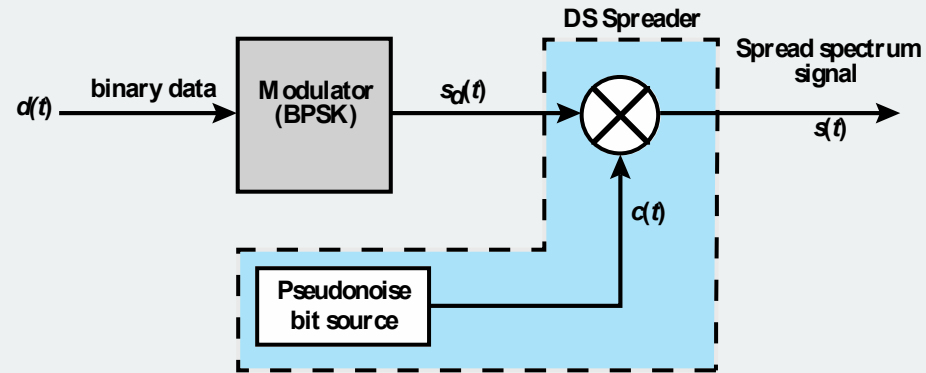




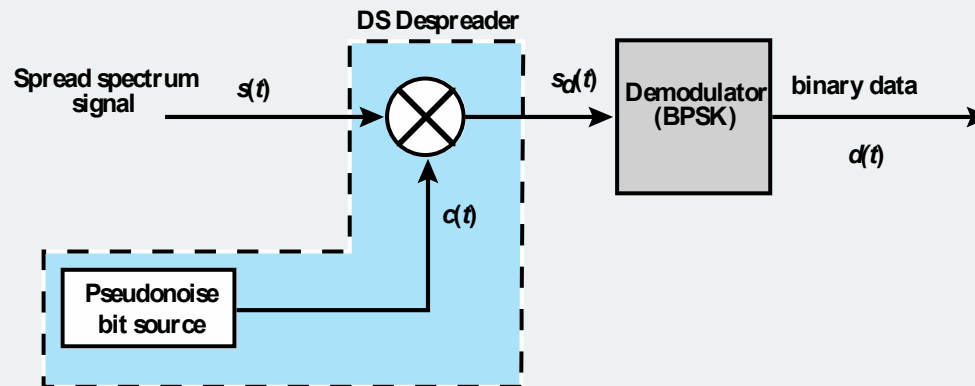
**Figure 17.8 General Model of Spread Spectrum Digital Communication System**



**Figure 17.9 Example of Direct Sequence Spread Spectrum**



(a) Transmitter



(b) Receiver

Figure 17.10 Direct Sequence Spread Spectrum System

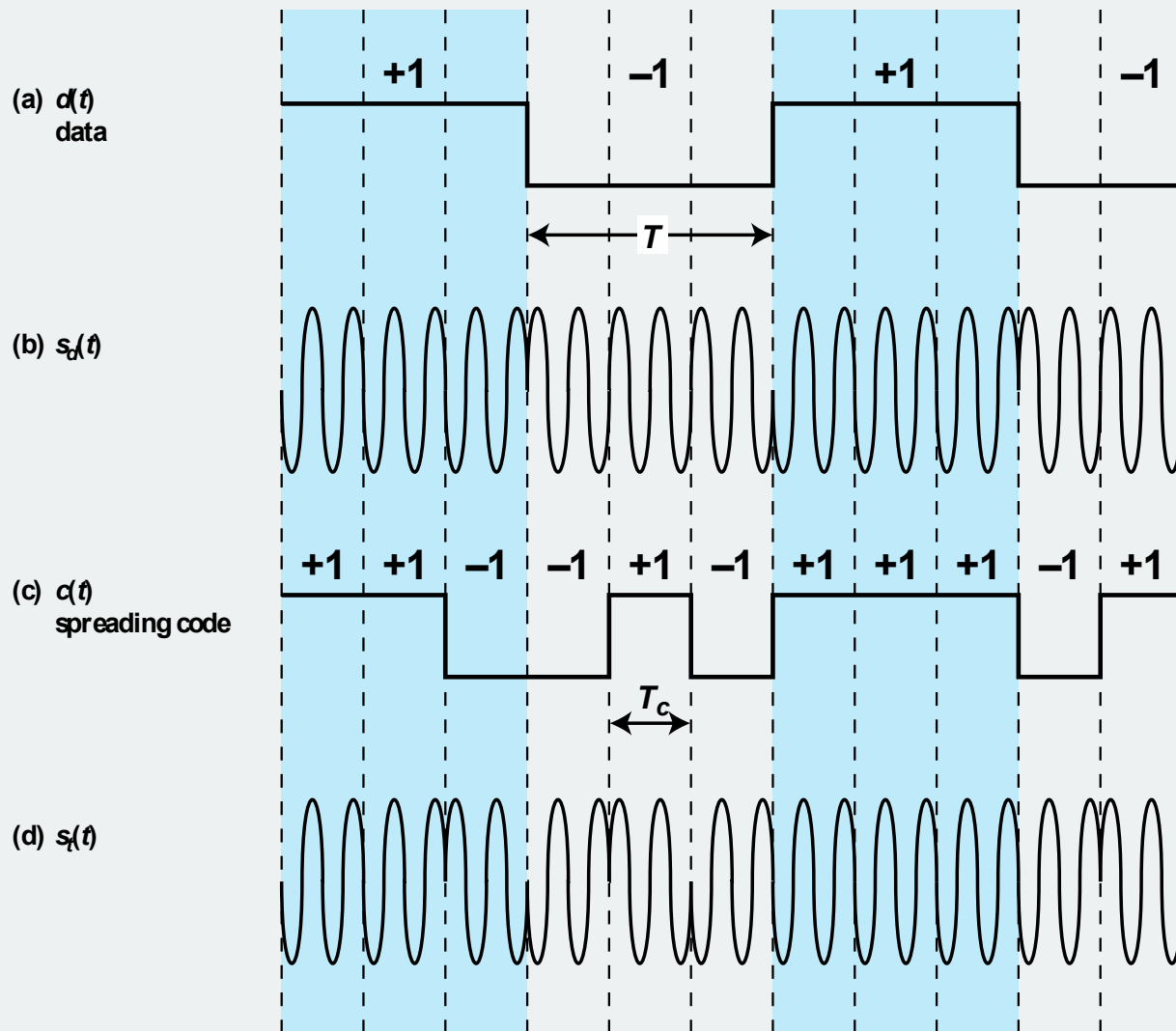
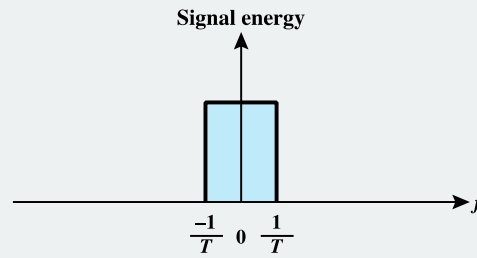
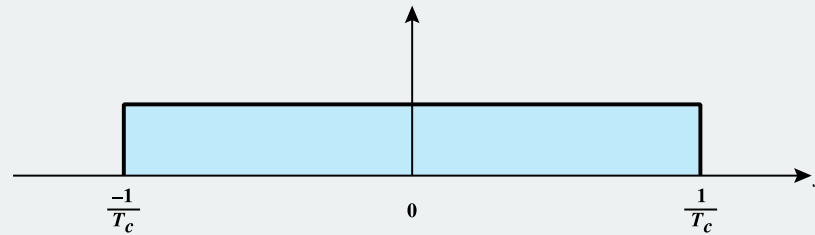


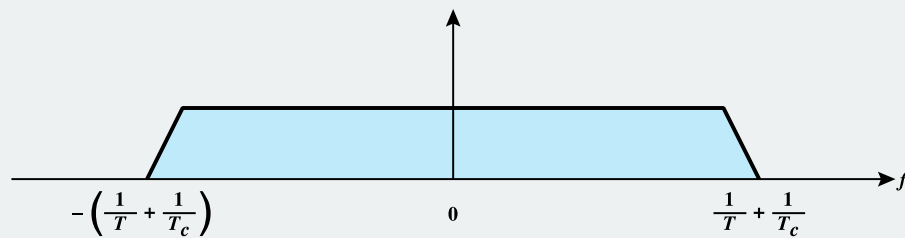
Figure 17.11 Example of Direct-Sequence Spread Spectrum Using BPSK



(a) Spectrum of data signal



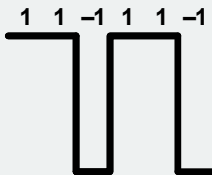
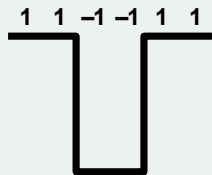
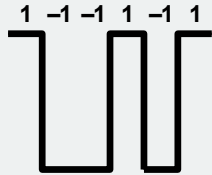
(b) Spectrum of pseudonoise signal



(c) Spectrum of combined signal

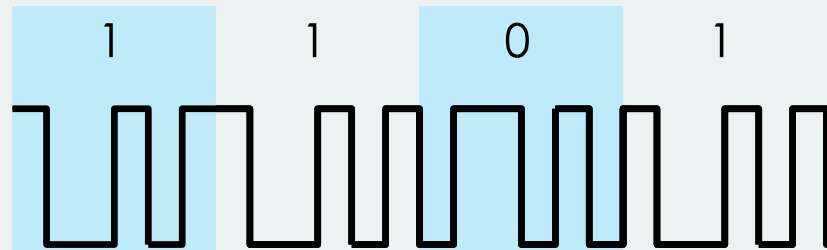
**Figure 17.12 Spectrum of Direct-Sequence Spread Spectrum Signal**

Code

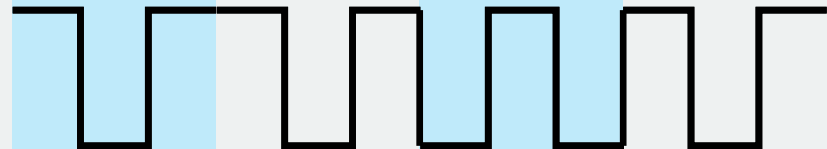


Message "1101" Encoded

User A



User B



User C



Figure 17.13 CDMA Example

(a) User's codes

User A	1	-1	-1	1	-1	1	
User B	1	1	-1	-1	1	1	
User C	1	1	-1	1	1	-1	

(b) Transmission from A

Transmit (data bit = 1)	1	-1	-1	1	-1	1	
Receiver codeword	1	-1	-1	1	-1	1	
Multiplication	1	1	1	1	1	1	= 6

Transmit (data bit = 0)	-1	1	1	-1	1	-1	
Receiver codeword	1	-1	-1	1	-1	1	
Multiplication	-1	-1	-1	-1	-1	-1	= -6

(c) Transmission from B, receiver attempts to recover A's transmission

Transmit (data bit = 1)	1	1	-1	-1	1	1	
Receiver codeword	1	-1	-1	1	-1	1	
Multiplication	1	-1	1	-1	-1	1	= 0

(d) Transmission from C, receiver attempts to recover B's transmission

Transmit (data bit = 1)	1	1	-1	1	1	-1	
Receiver codeword	1	1	-1	-1	1	1	
Multiplication	1	1	1	-1	1	-1	= 2

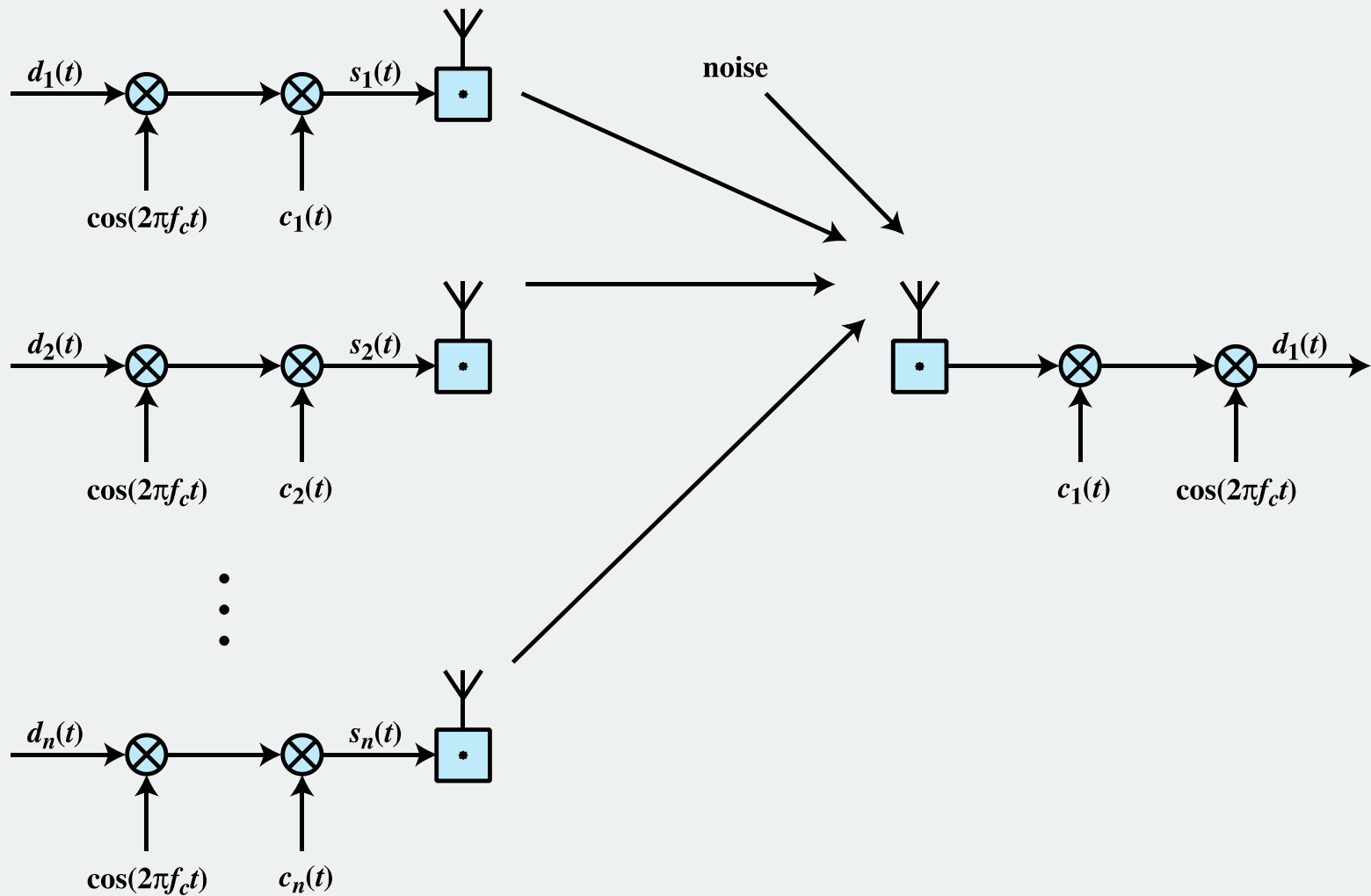
(e) Transmission from B and C, receiver attempts to recover B's transmission

B (data bit = 1)	1	1	-1	-1	1	1	
C (data bit = 1)	1	1	-1	1	1	-1	
Combined signal	2	2	-2	0	2	0	
Receiver codeword	1	1	-1	-1	1	1	
Multiplication	2	2	2	0	2	0	= 8

Table 17.1

# CDMA Example

(Table is on page 576 in textbook)



**Figure 17.14 CDMA in a DSSS Environment for Receiving User 1**





# Summary

- MIMO antennas
  - MIMO principles
  - Multiple-user MIMO
- OFDM
- OFDMA
- SC-FDMA
- Spread spectrum
  - Direct sequence spread spectrum
    - DSSS using BPSK
    - DSSS performance considerations
  - Code division multiple access
    - Basic principles
    - CDMA for DSSS