Chapter 4

Basics of Wireless Communications

4.1 Signals

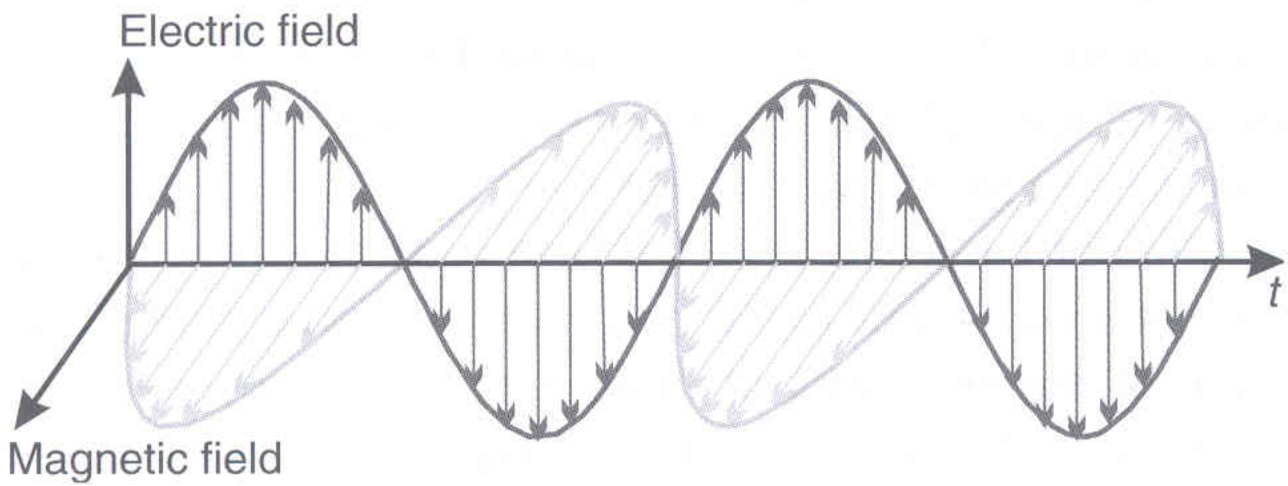

Figure 4.1 Composition of an electromagnetic wave.

$$g(t) = A_t \sin(2\pi f_t t + \varphi_t) \tag{4.1}$$

$$\lambda = \frac{v}{f} \tag{4.2}$$

4.1.1 Modulation

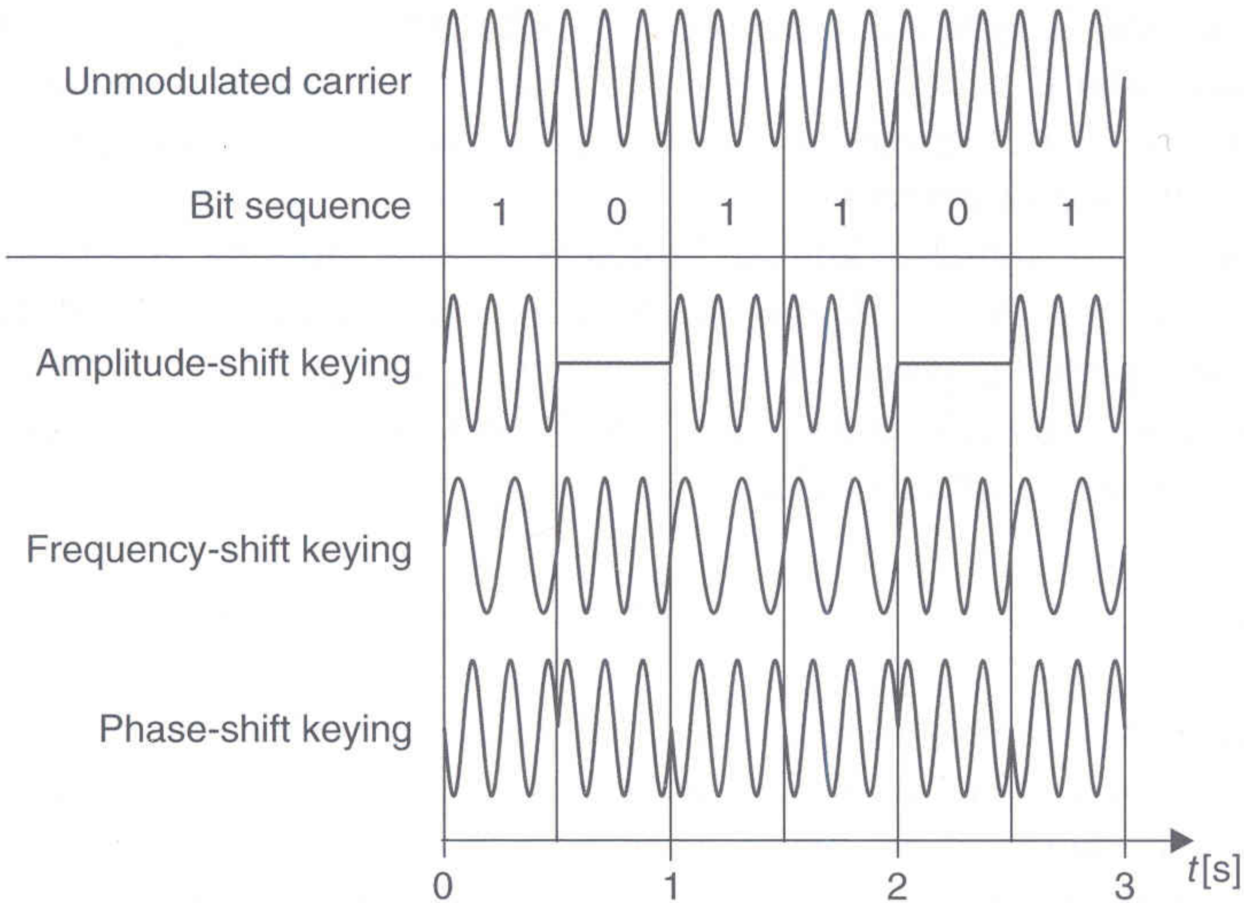

Figure 4.2 Digital modulation schemes.

4.1.2 Representing Signals in the Frequency Domain

$$g(t) = \frac{A_0}{2} + \sum_{n=1}^{\infty} [A_n \cos(2\pi n f_0 t) + B_n \sin(2\pi n f_0 t)] \qquad (4.3)$$

$$\begin{aligned} A_0 &= \frac{2}{T}\int_0^T g(t)\,dt \\ A_n &= \frac{2}{T}\int_0^T g(t)\cos(2\pi n f_0 t)\,dt \qquad (4.4) \\ B_n &= \frac{2}{T}\int_0^T g(t)\sin(2\pi n f_0 t)\,dt \end{aligned}$$

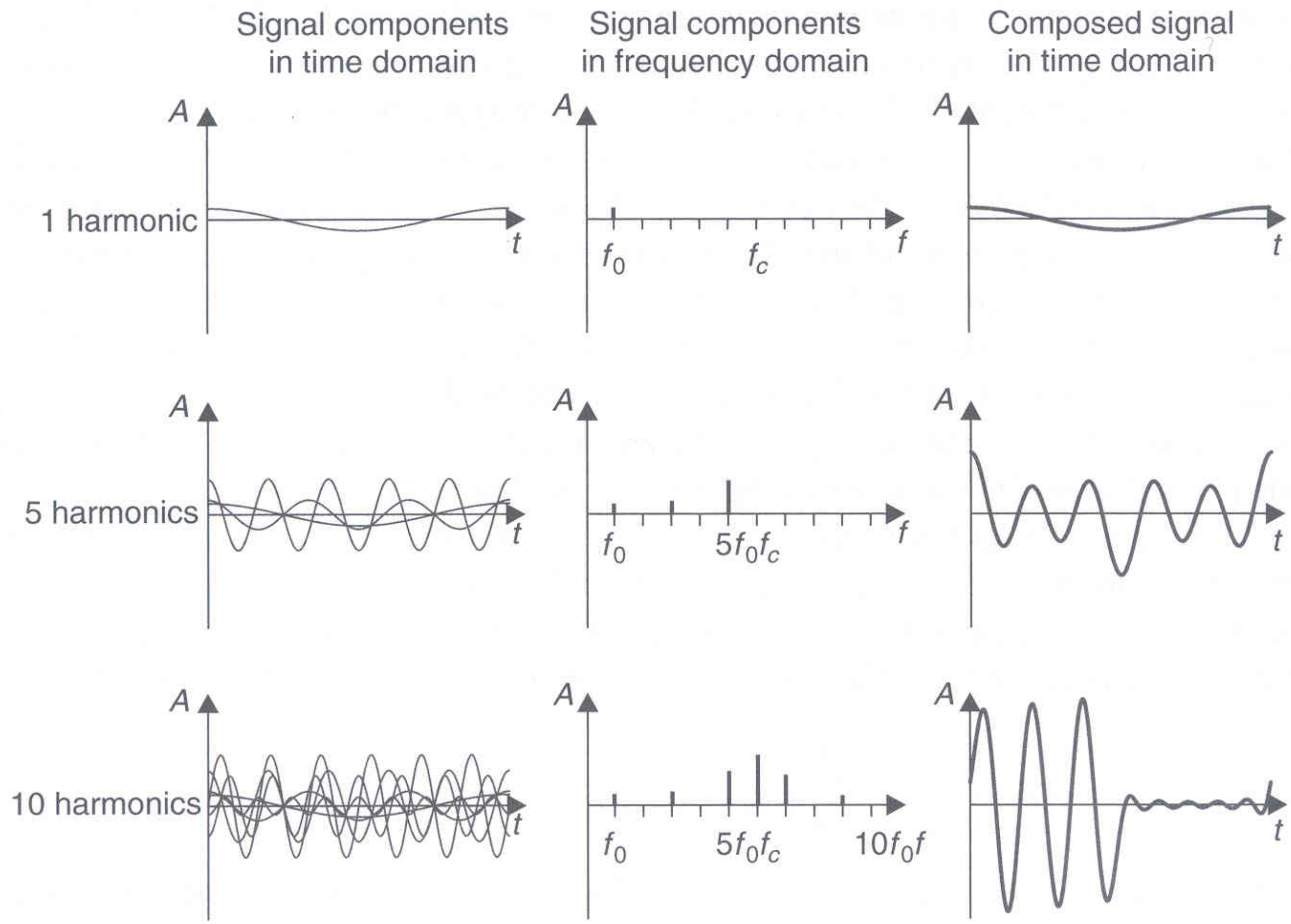

Figure 4.3 Frequency versus time domain.

4.1.3 Signal Spectrum and Bandwidth

$$C = 2B\log_2 M[bits/s] \quad (4.5)$$

$$C = B\log_2(1+SNR) \quad (4.6)$$

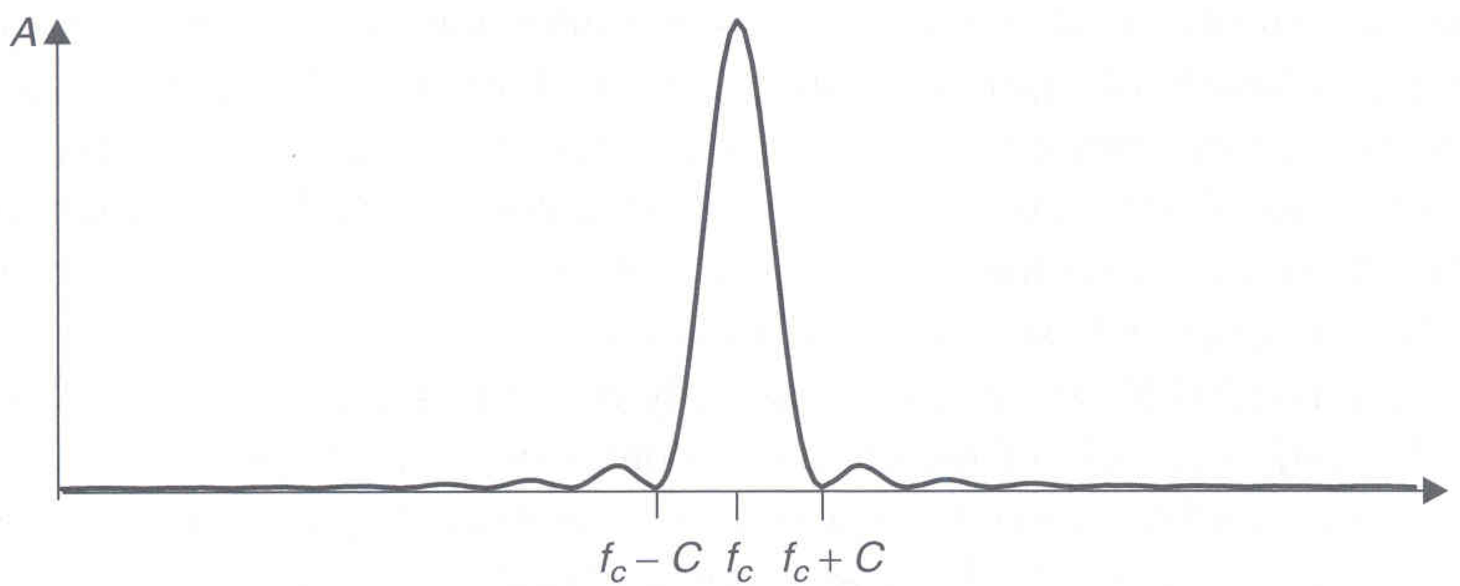

Figure 4.4 Bandwidth of a signal.

4.2 Propagation of Radio Signals

4.2.1 The Electromagnetic Spectrum

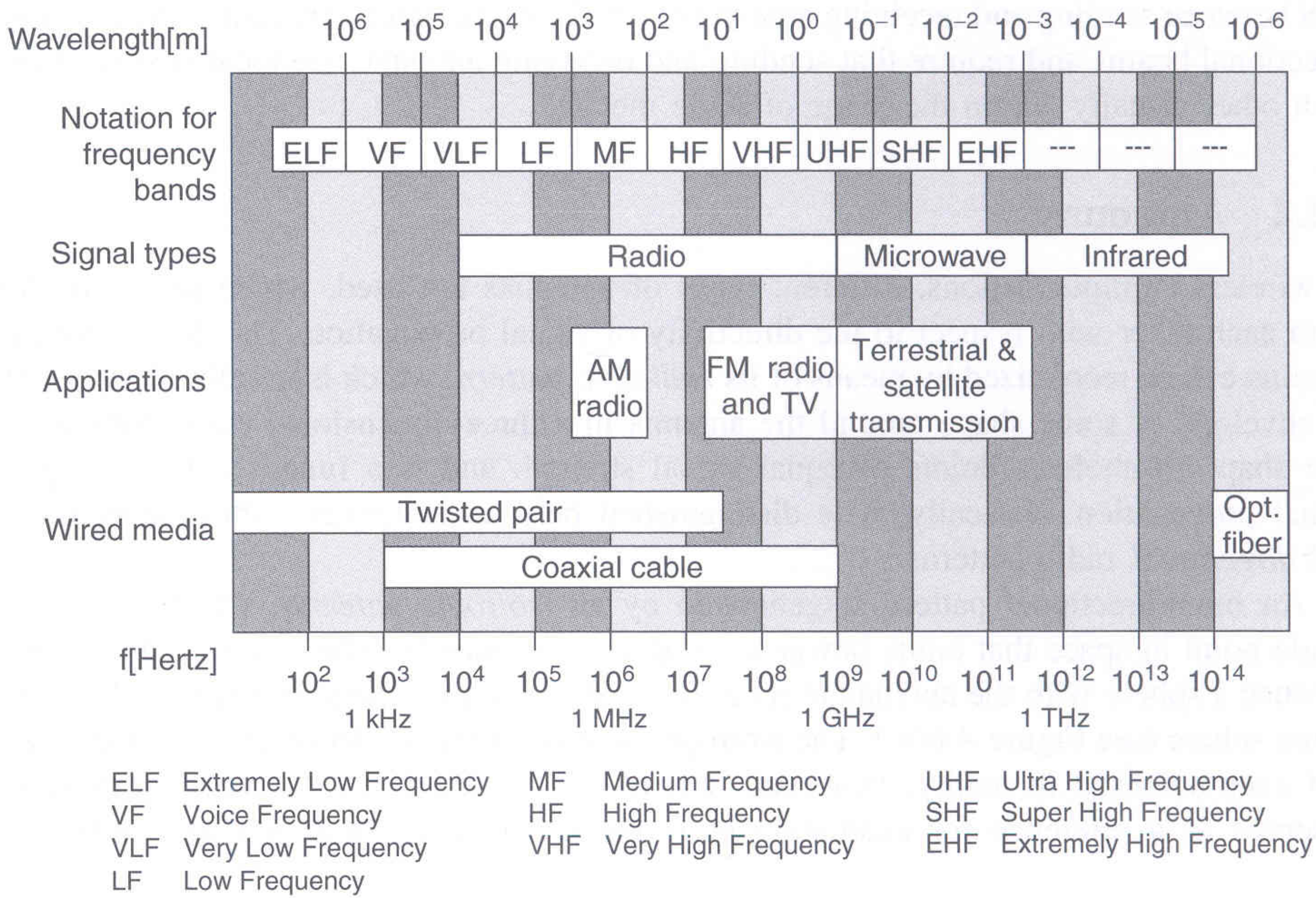

Figure 4.5 The electromagnetic spectrum for telecommunications (Stallings 2002a).

4.2.2 Antennas

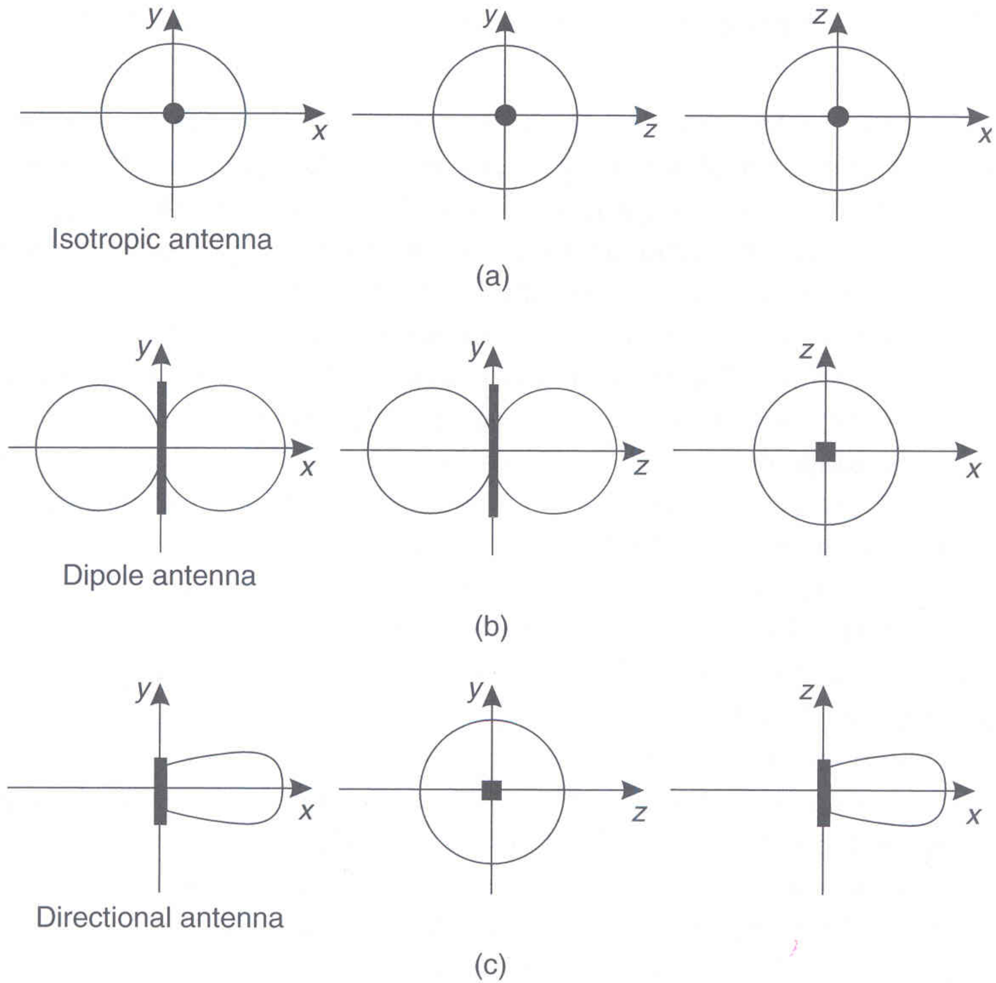

Figure 4.6 Radio patterns of isotropic, dipole, and directional antennas (Schiller 2000).

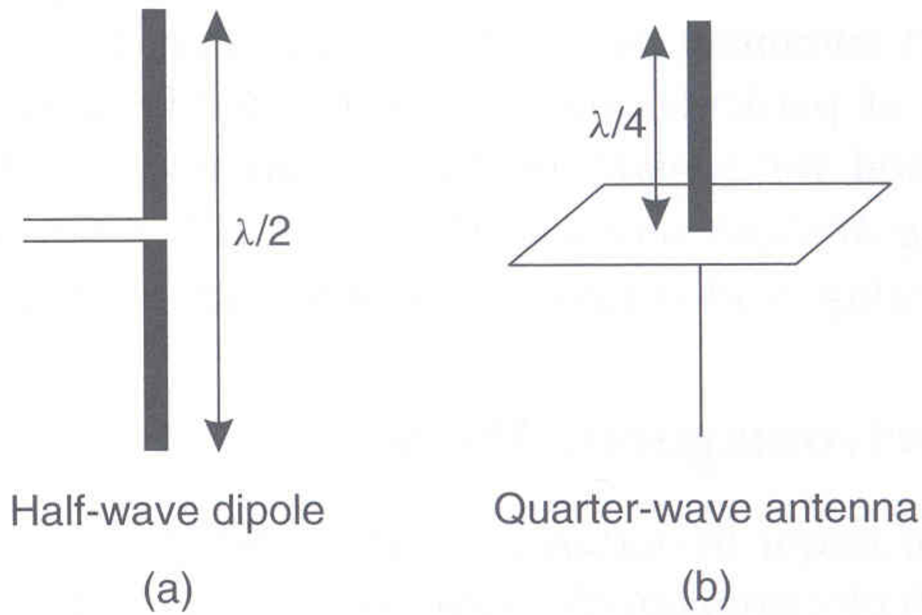

Figure 4.7 Half-wave dipole and quarter-wave antenna.

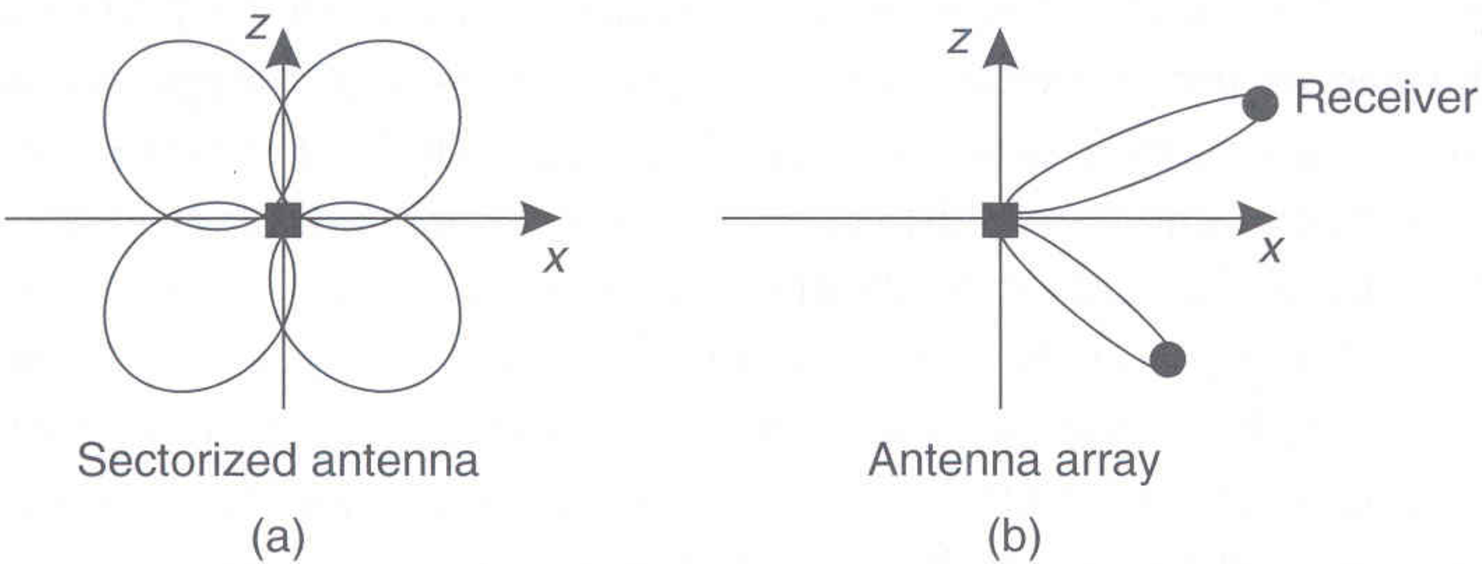

Figure 4.8 Radio patterns of sectorized antennas and antenna arrays.

4.2.3 Speed of Electromagnetic Waves

$$c_0 = 299{,}792{,}458\,\text{m/s} \tag{4.7}$$

$$n = \frac{c_0}{c} \tag{4.8}$$

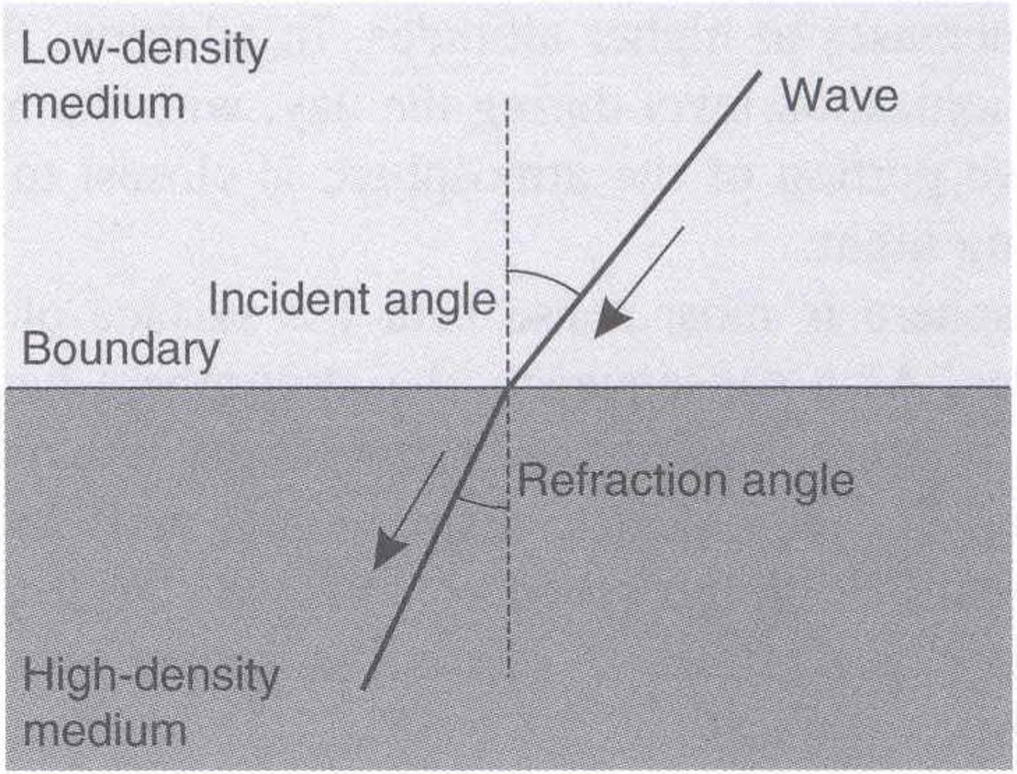

Figure 4.9 Refraction of electromagnetic waves.

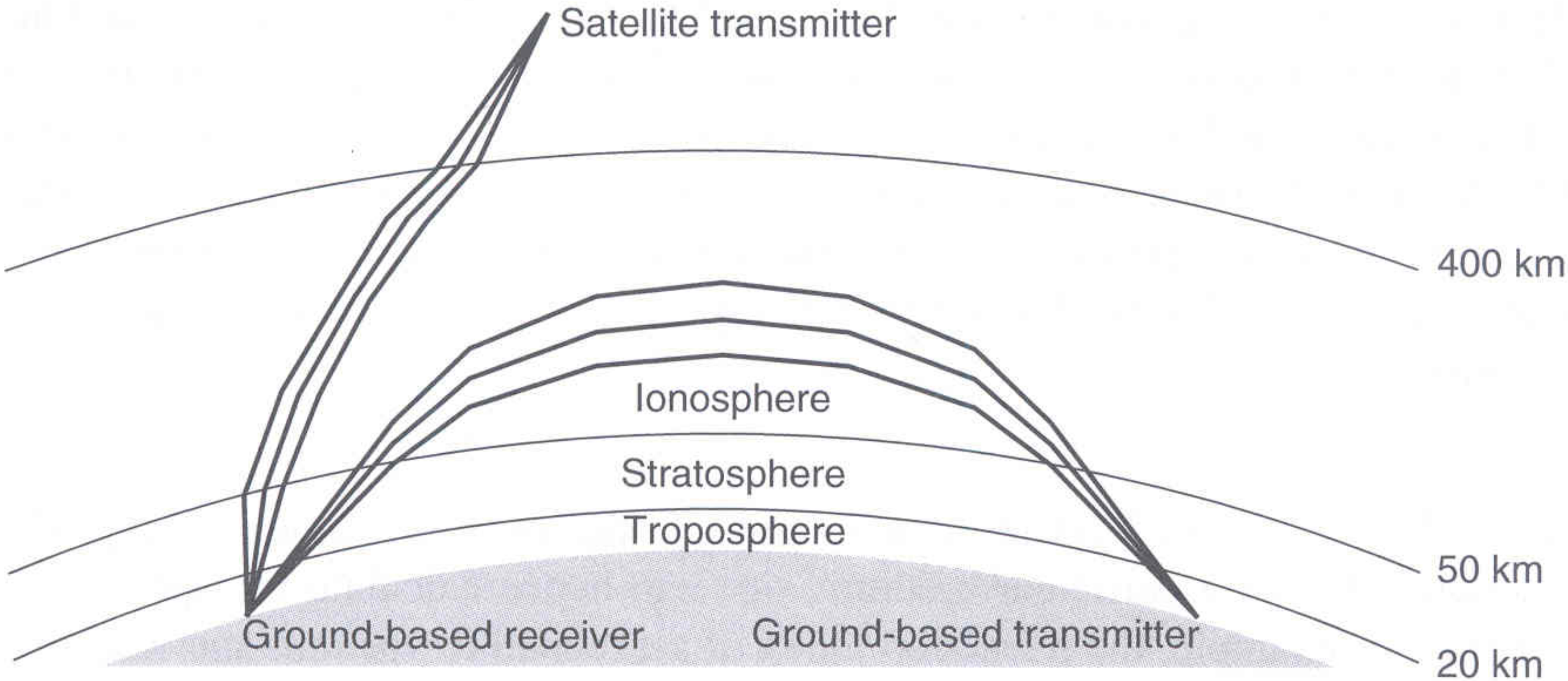

Figure 4.10 Signal propagation in the atmosphere.

$$n = \sqrt{\varepsilon_r} \approx \sqrt{1 - \frac{81 N_e}{f^2}} \qquad (4.9)$$

4.2.4 Attenuation

$$\frac{P_t}{P_r} = \frac{(4\pi \mathrm{d})^2}{\lambda^2} \qquad (4.10)$$

$$P_r(d) = P_r(d_f)\left(\frac{d_0}{d}\right)^2 \qquad (4.11)$$

$$P_r(d) = P_r(d_f)\left(\frac{d_0}{d}\right)^\alpha \qquad (4.12)$$

Table 4.1 Examples for path-loss gradients

α	**Environment**
2	Free space (vacuum)
2.5	Outdoor – rural areas
3–4	Outdoor – urban areas
4–5	Outdoor – dense urban areas
1.6–1.8	Indoor – large open areas and corridors
4–6	Indoor – non-line-of-sight environments

4.2.5 Multipath Propagation

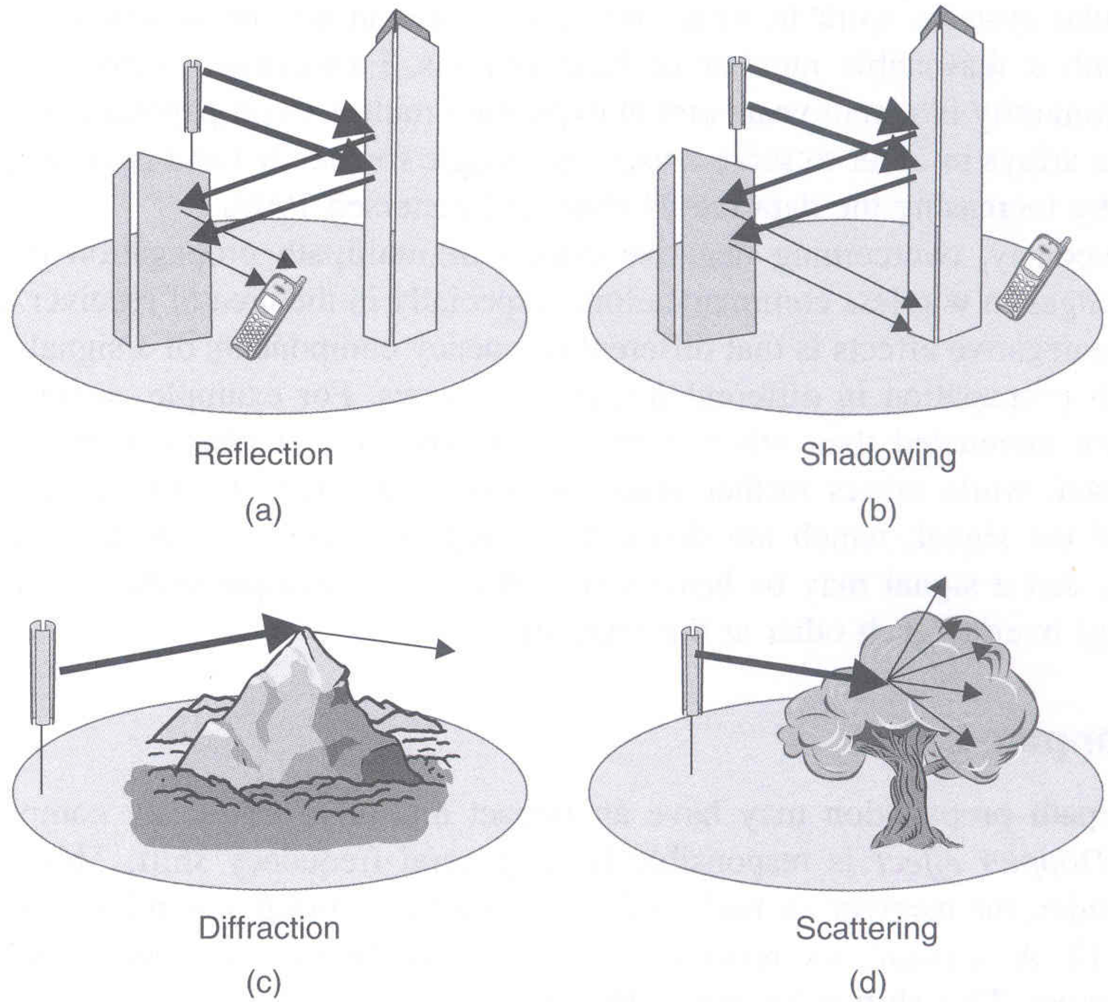

Figure 4.11 Multipath Propagation.

4.2.6 Doppler Effect

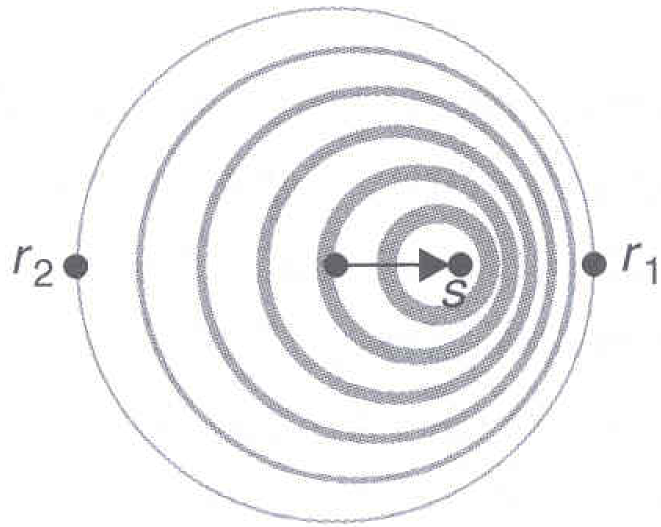

Figure 4.12 Doppler effect.

$$f_d = \frac{v}{\lambda}\cos\alpha \tag{4.13}$$

4.3 Multiplexing and Multiple Access

4.3.1 SDM and SDMA

4.3.2 FDM and FDMA

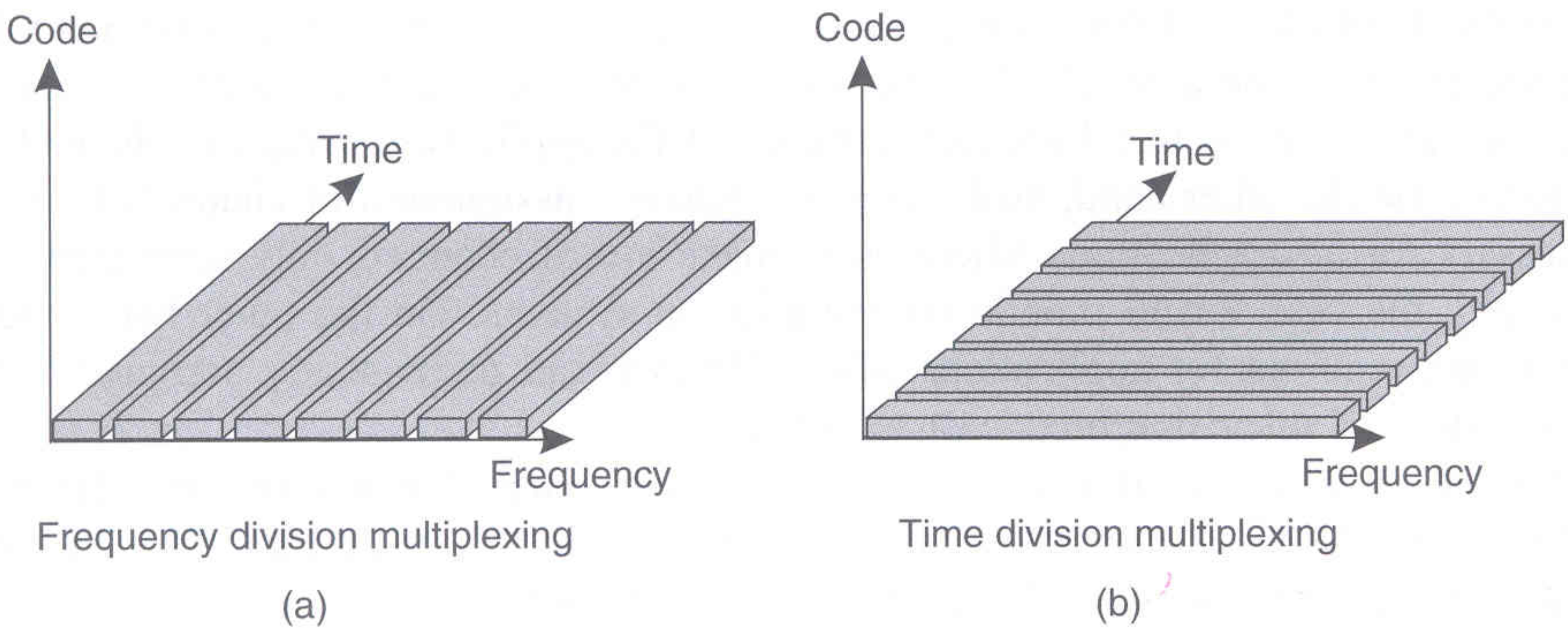

Figure 4.13 FDM and TDM.

4.3.3 TDM and TDMA

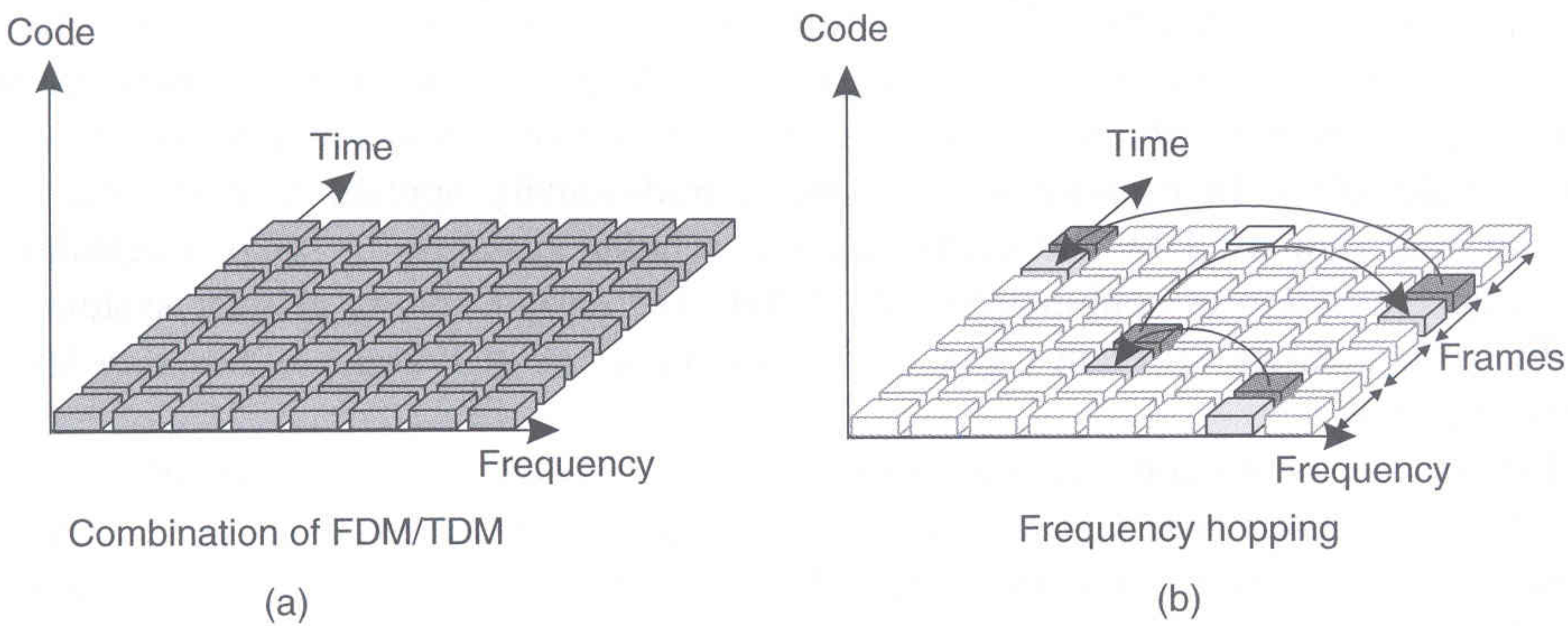

Figure 4.14 Combination of FDM/TDM and frequency hopping.

4.3.4 CDM and CDMA

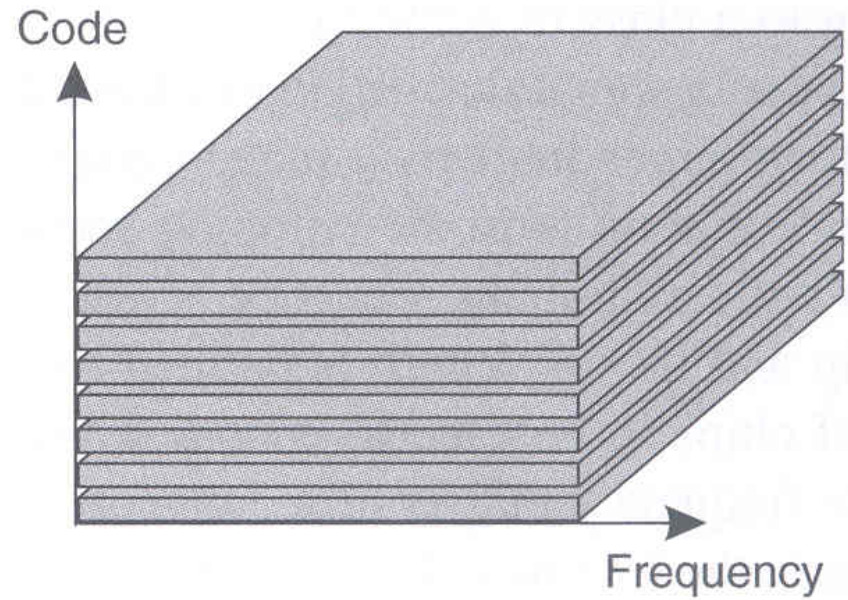

Figure 4.15 CDM.

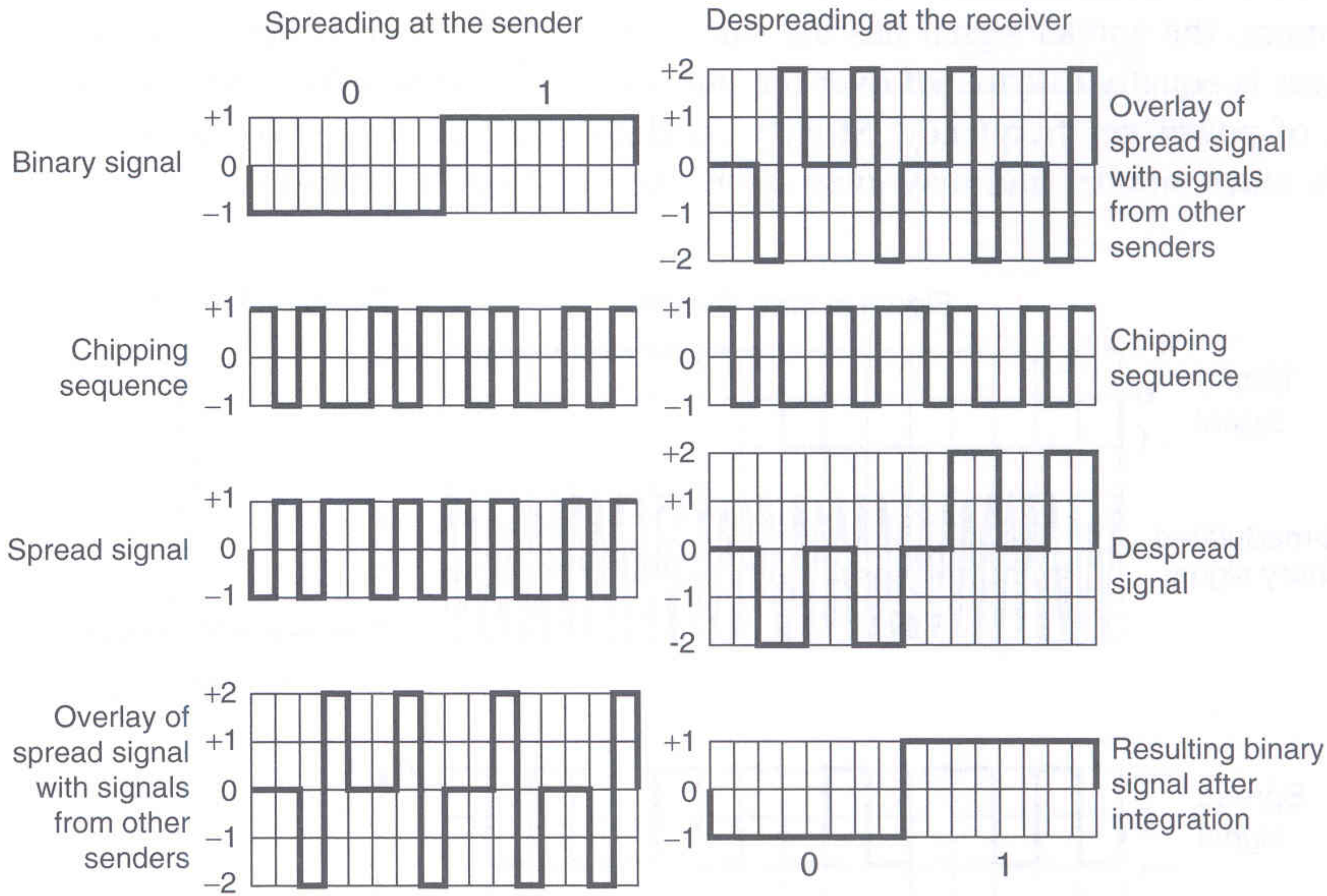

Figure 4.16 Encoding and decoding of data in CDMA. Adapted from (Roth 2002).

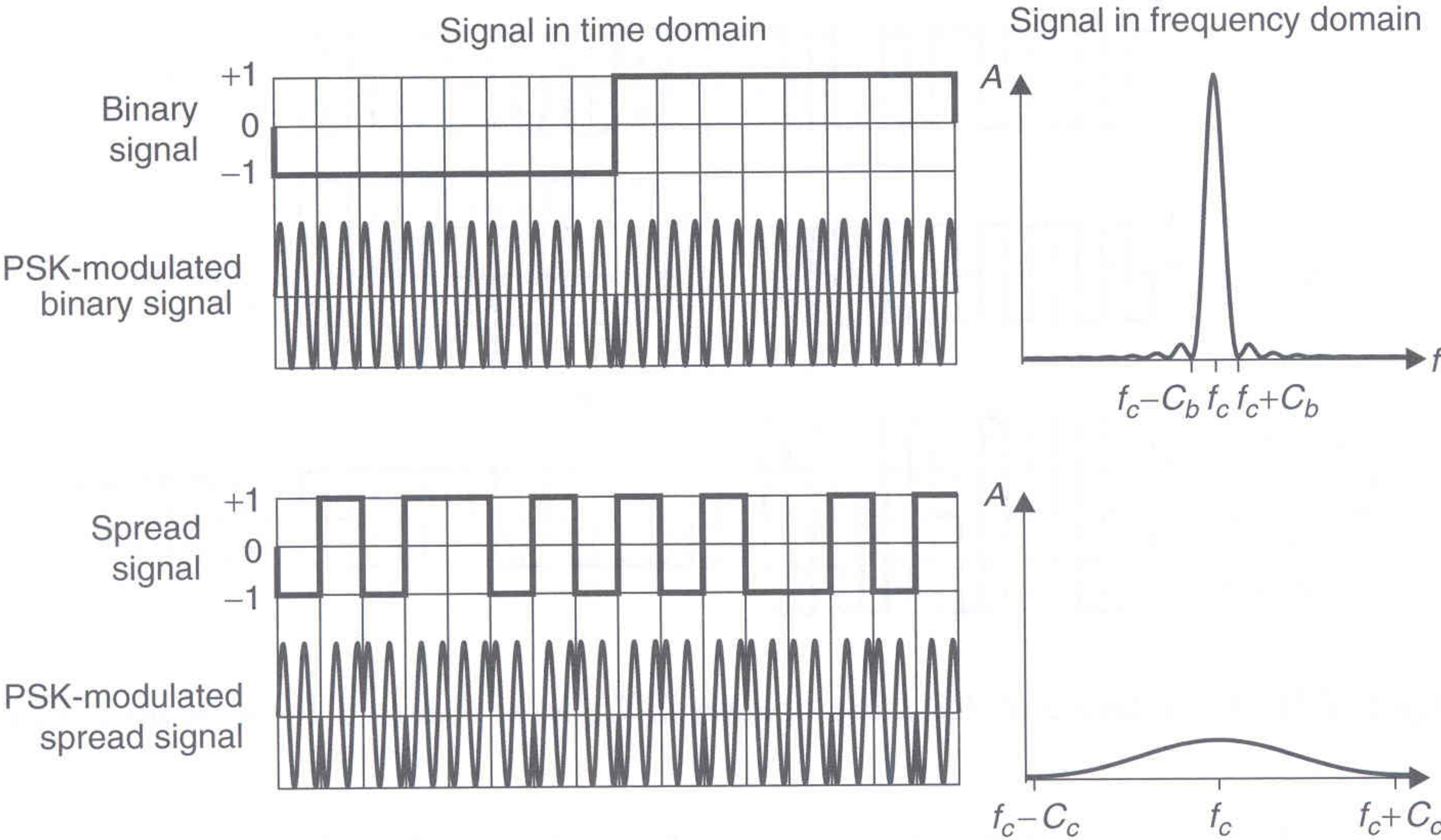

Figure 4.17 Spread and despread signals in time and frequency domain.

$$\Phi_{ii}[n] = \frac{1}{N}\sum_{m=1}^{N} c_i[m]c_i[m+n] \tag{4.14}$$

$$\Phi_{ij}[n] = \frac{1}{N}\sum_{m=1}^{N} c_i[m]c_j[m+n] \tag{4.15}$$

Table 4.2 Interpretation of correlation values

Correlation value	Interpretation
1	Both sequences match exactly.
0	There is no relation between the sequences at all.
–1	The two sequences are inverse to each other.

$$\Phi_{ii}[n] = \begin{cases} 1 & n = 0, N, 2N, \ldots \\ -\dfrac{1}{N} & \text{otherwise} \end{cases} \tag{4.16}$$

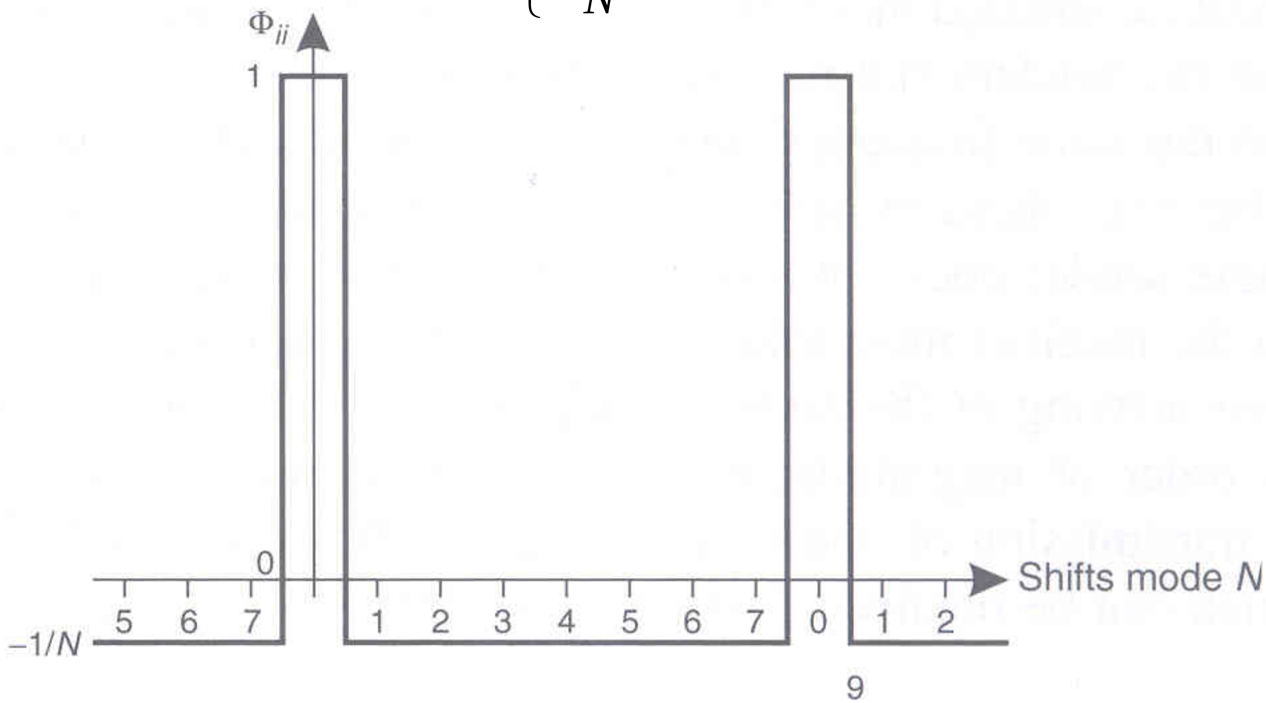

Figure 4.18 Autocorrelation of a chipping sequence.

4.4 Conclusion