# System Architecture 2018 Fall　Intro LTE Chap3:Digital Wireless Communication

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# Carrier Signal

### *3.1.1 Carrier Signal*

A key part of any radio communication system is the creation and transmission of a radio wave, also known as a *carrier signal*. Mathematically, we can express the carrier signal as follows:

$$I(t) = a\cos(2\pi ft + \phi) \tag{3.1}$$

Here, $a$ is the amplitude of the radio wave, $f$ is its frequency and $\phi$ is its initial phase angle. The angles are measured in radians, with $\pi$ radians equal to 180°.

Carrier

# Digital Signal Processing for wireless uses Complex Exponential signal

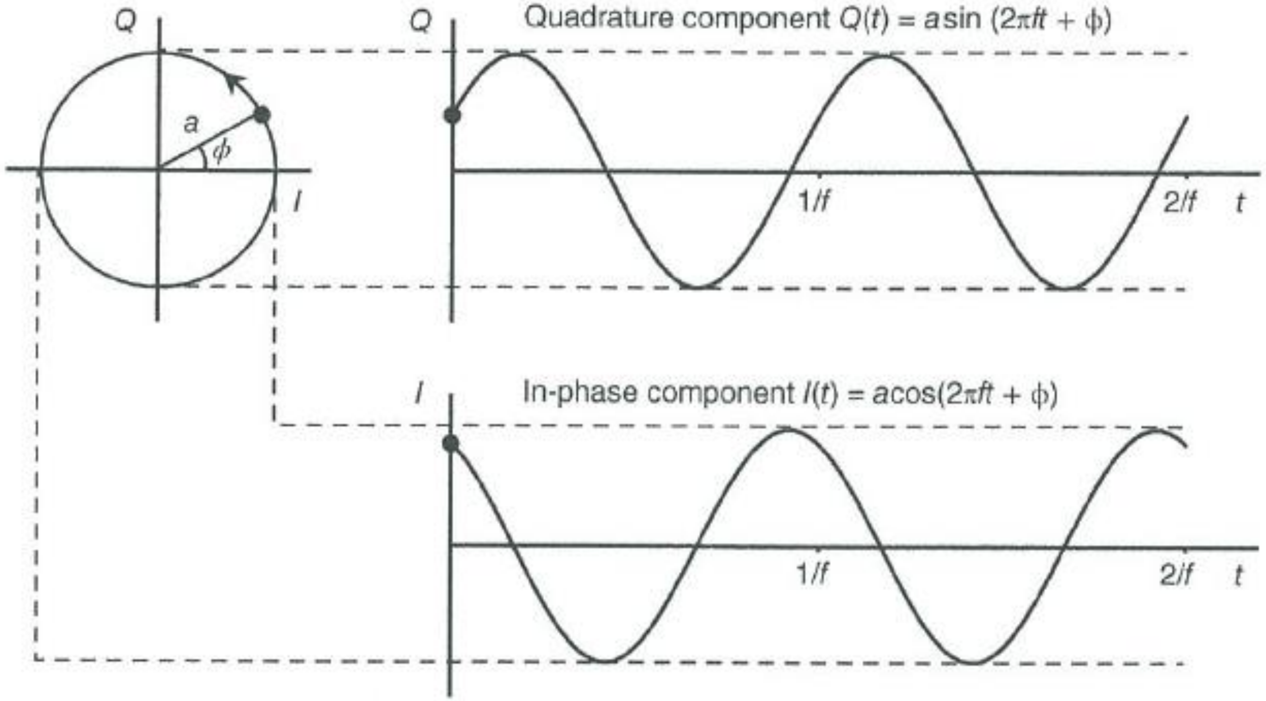



**Figure 3.1** Generation of the in-phase and quadrature components of a carrier signal

which is the object's position along the vertical axis and is shown at the top right:

$$Q(t) = a\sin(2\pi ft + \phi) \tag{3.2}$$

# 1. Complex Exponential Function

- We will shift from SIN and COS to Complex Exponential Function.

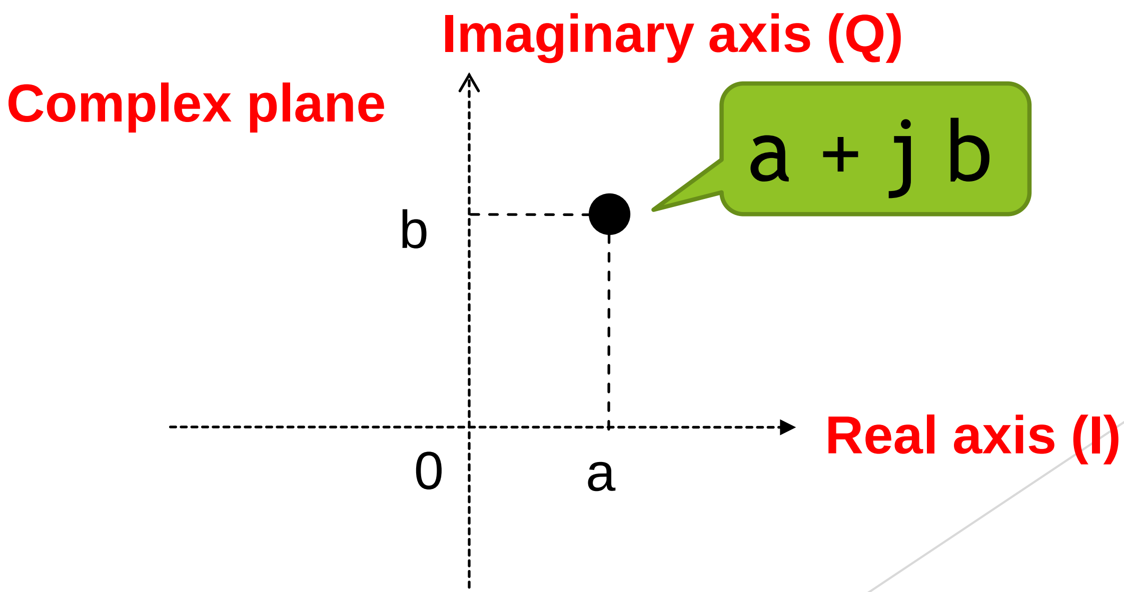
$$\tilde{x}(t) = Ae^{j(2\pi ft+\phi)}$$

$$= \underbrace{A\cos(2\pi ft+\phi)}_{\textbf{Real part}} + \underbrace{j \cdot A\sin(2\pi ft+\phi)}_{\textbf{Imaginary part}}$$

- Real and Imaginary =complex number
- Real part is same as previous cosine wave.

# 2. Real – Imaginary plane

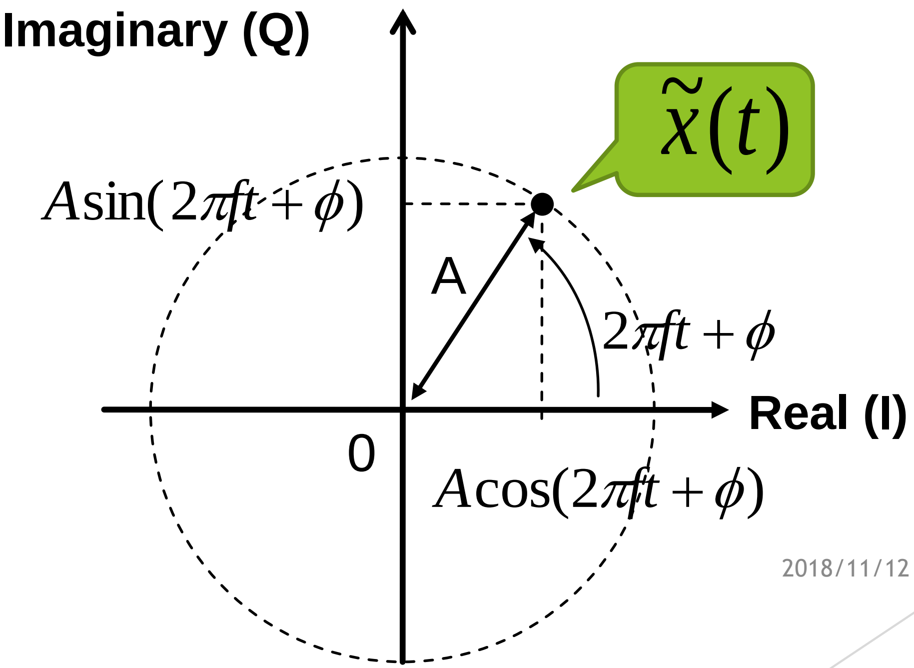
- IQ plane
  - I: In-Phase = Real axis
  - Q: Quadrature-Phase = Imaginary axis
- Real-Imaginary plane (Complex plane)
  - Complex number can be indicated as a point



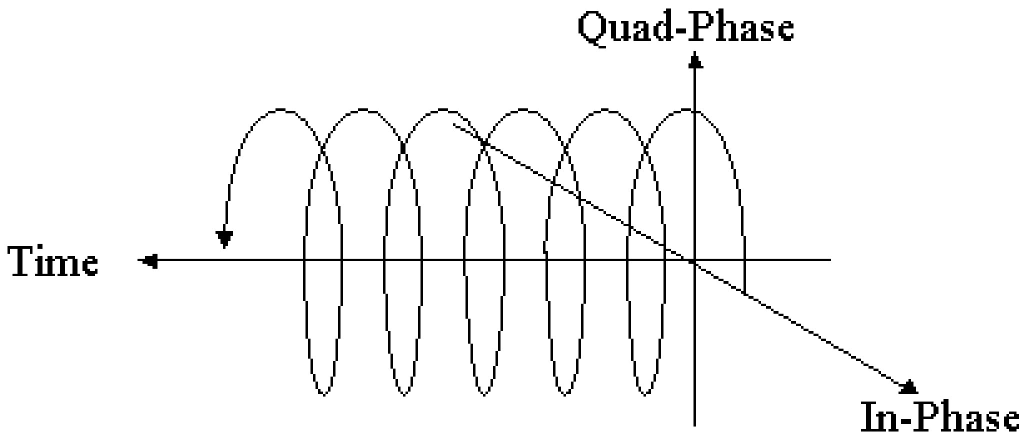
# Complex Exponential Function Shows Rotation in I-Q plane

$$\tilde{x}(t) = Ae^{j(2\pi ft+\phi)}$$

$$= \underbrace{A\cos(2\pi ft+\phi)}_{\textbf{Real part}} + j\cdot \underbrace{A\sin(2\pi ft+\phi)}_{\textbf{Imaginary}}$$



# Complex Exponential Function shows Rotation on TIME!



# Complex Amplitude (Phaser)

$$\tilde{x}(t) = Ae^{j(2\pi ft+\phi)}$$

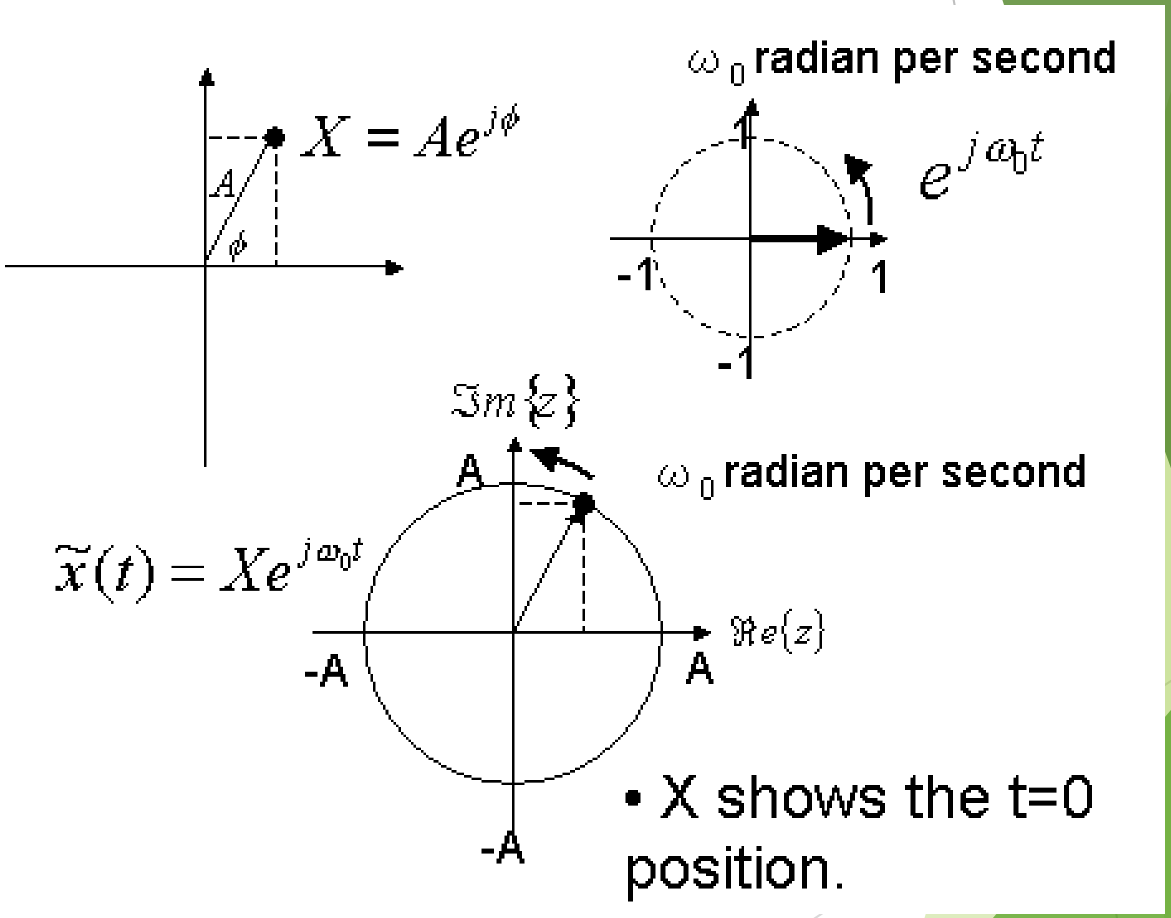
$$= Ae^{j\phi} \cdot e^{j2\pi ft}$$

*assume*

$$X = Ae^{j\phi}$$

$$\omega_0 = 2\pi f$$

$$\tilde{x}(t) = X \cdot e^{j\omega_0 t}$$




- X=x(t=0) shows starting point (t=0) .
- X is called as Complex Amplitude (Phaser)

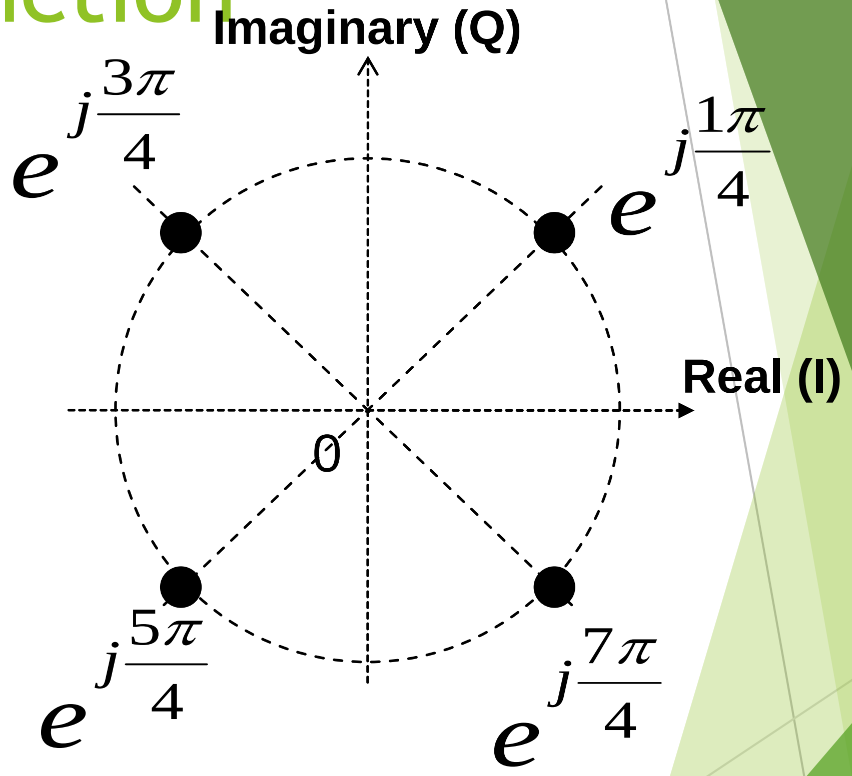
# QPSK
# by Complex Exponential Function

$$\tilde{x}_0(t) = e^{j(2\pi f t + \frac{1\pi}{4})} = e^{j\frac{1\pi}{4}} \cdot e^{j2\pi f t}$$

$$\tilde{x}_1(t) = e^{j(2\pi f t + \frac{3\pi}{4})} = e^{j\frac{3\pi}{4}} \cdot e^{j2\pi f t}$$

$$\tilde{x}_2(t) = e^{j(2\pi f t + \frac{5\pi}{4})} = e^{j\frac{5\pi}{4}} \cdot e^{j2\pi f t}$$

$$\tilde{x}_3(t) = e^{j(2\pi f t + \frac{7\pi}{4})} = e^{j\frac{7\pi}{4}} \cdot e^{j2\pi f t}$$




Complex Amplitude (Phaser) = Constellation point

# Conversion
# from Complex Exponential Function
# to Real sinusoid.

$$\tilde{x}(t) = Ae^{j(2\pi ft+\phi)}$$
$$= A\cos(2\pi ft + \phi) + j \cdot A\sin(2\pi ft + \phi)$$

Take Real Part
Then
You can convert!

$$\tilde{x}(t) = Ae^{j(2\pi ft+\phi)}$$

$$A\cos(2\pi ft + \phi) = \mathrm{Re}[\tilde{x}(t)] = \mathrm{Re}[Ae^{j(2\pi ft+\phi)}]$$

# Modulation Technique

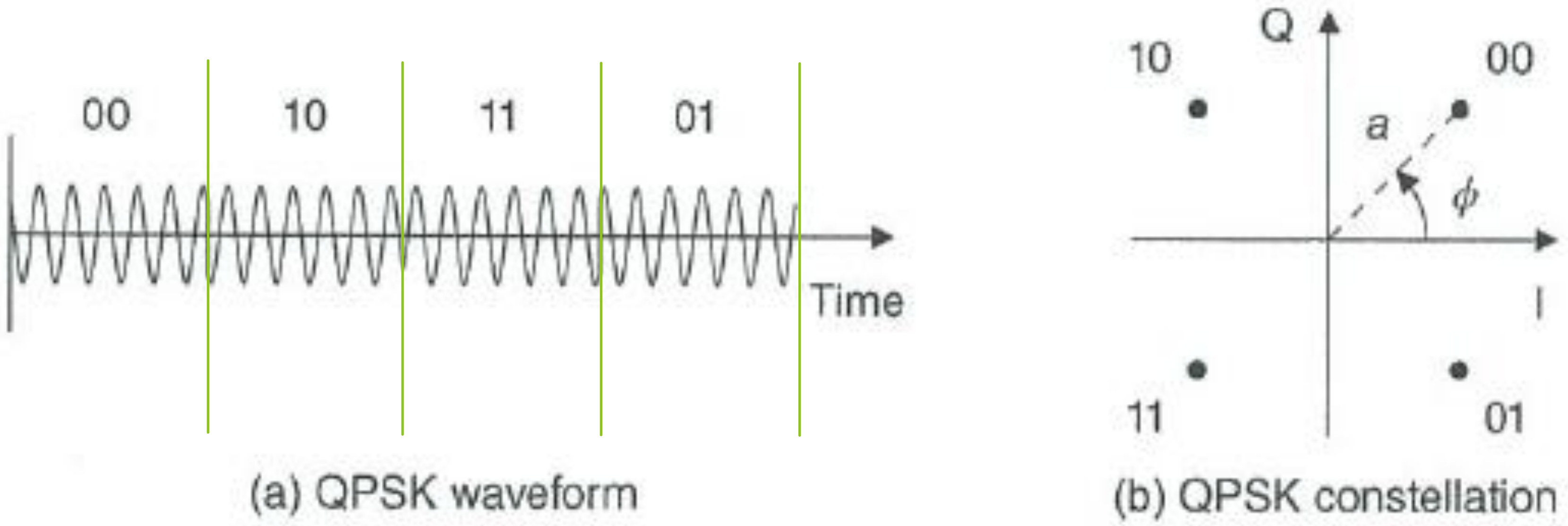



**Figure 3.2** Quadrature phase shift keying. (a) Example QPSK waveform. (b) QPSK constellation diagram

# Modulation schemes used in LTE

Constellation shows Phaser
= Amplitude and Phase at signal starting point

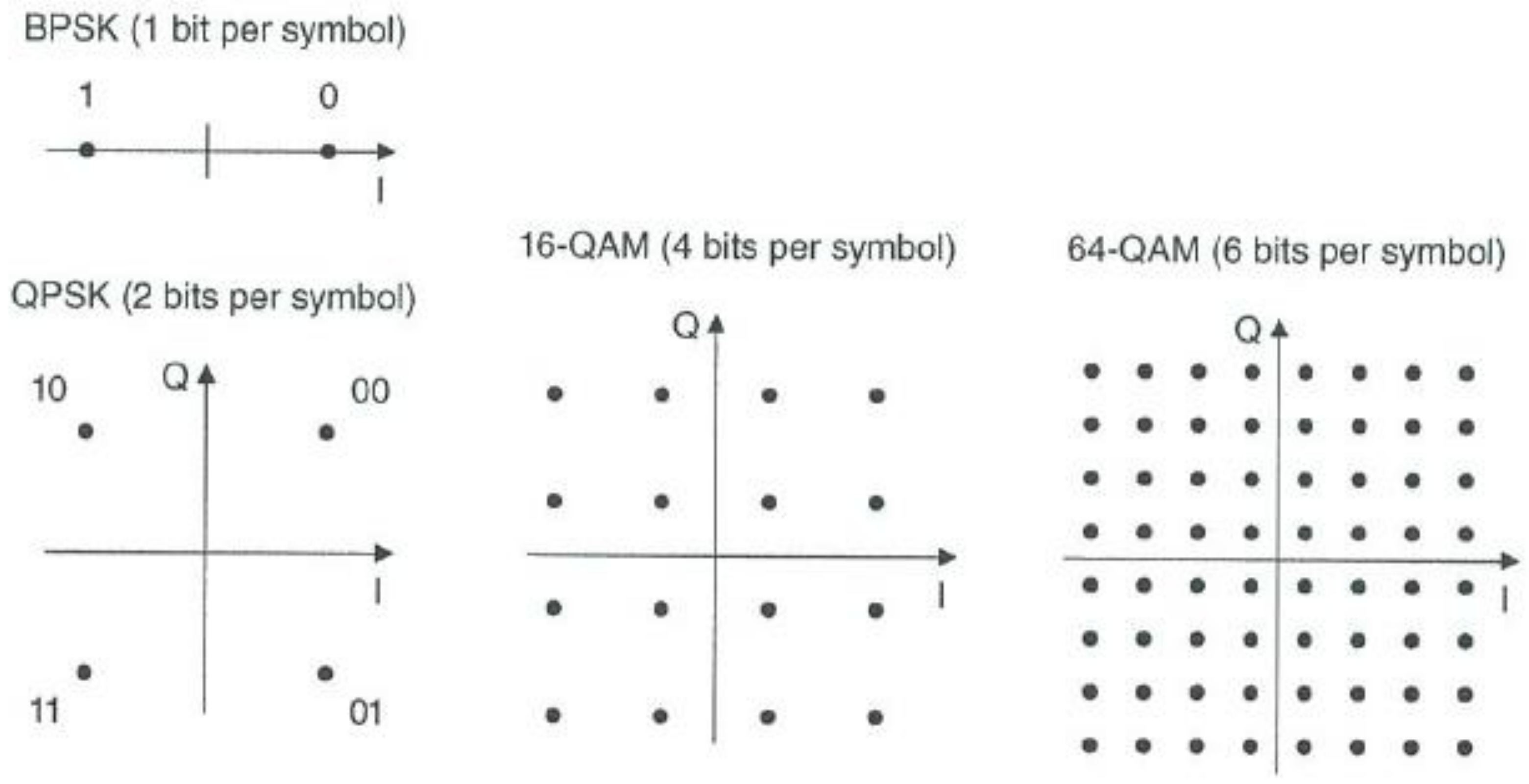
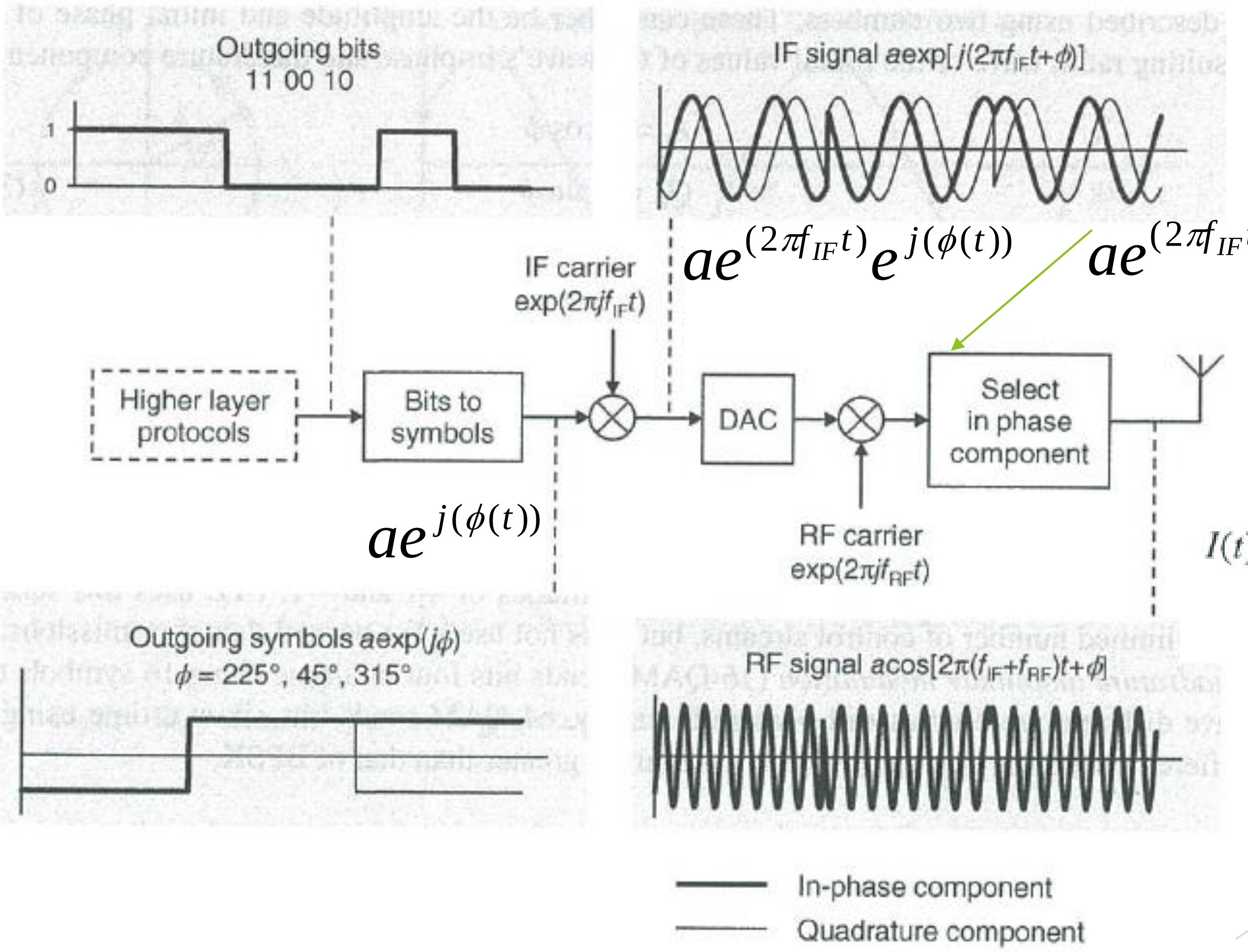



**Figure 3.3** Modulation schemes used by LTE

# Modulation Process




$ae^{(2\pi f_{IF}t)}e^{j(\phi(t))}$

$ae^{(2\pi f_{IF}t)}e^{(2\pi f_{RF}t)}e^{j(\phi(t))}$

$ae^{j(\phi(t))}$

$$I(t) = \mathrm{Re}\{a\exp[2\pi j(f_{IF}+f_{RF})t + j\phi]\}$$
$$= a\cos[2\pi(f_{IF}+f_{RF})t+\phi]$$

**Figure 3.4** Block diagram of the modulator in a wireless communication system

# Demodulation Process

$$a \cdot \cos(2\pi(f_{IF} + f_{RF})t + \phi + \psi) + noise$$

$$I(t) = a\cos[2\pi(f_{IF} + f_{RF})t + \phi + \psi]$$
$$= \frac{a\exp\{j[2\pi(f_{IF} + f_{RF})t + \phi + \psi]\} + a\exp\{-j[2\pi(f_{IF} + f_{RF})t + \phi + \psi]\}}{2} \quad (3.8)$$

$$\frac{1}{2} a e^{(2\pi f_{IF} t + \phi + \psi)} + noise'$$

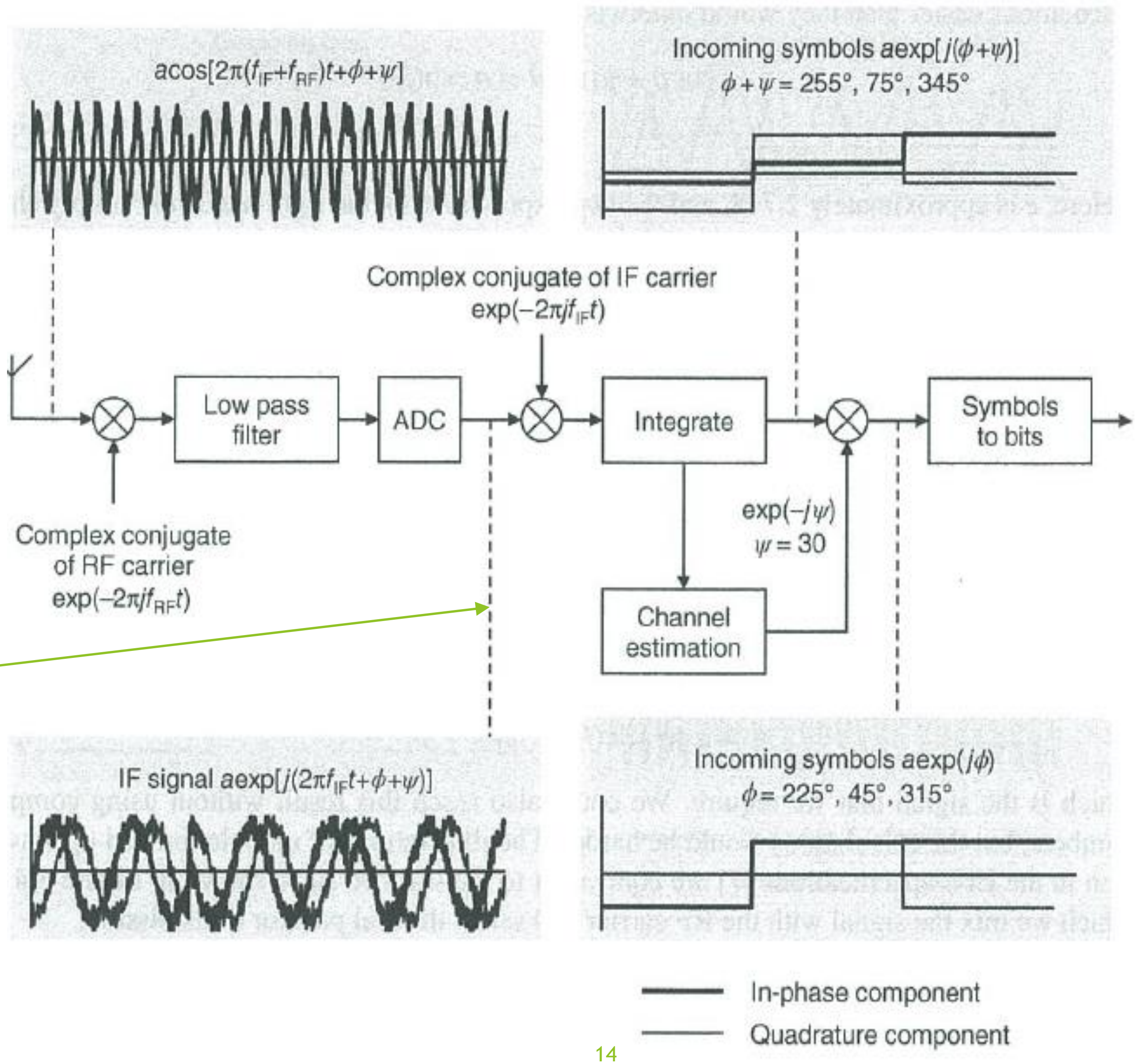



**Figure 3.5** Block diagram of the demodulator in a wireless communication system

# Channel Estimation

### *3.1.5 Channel Estimation*

There is one more complication: the phase of the incoming signal depends not only on the phase of the transmitted signal but also on the receiver's exact position. If the receiver moves through half a wavelength of the carrier signal (a distance of 10 cm at a carrier frequency of 1500 MHz, for example), then the phase of the received signal changes by 180°. When using QPSK, this phase change turns bit pairs of 00 into 11 and vice versa, and completely destroys the received information. We can express this issue by including an arbitrary phase shift $\psi$ in the received signal. In Figure 3.5, the phase shift is 30°.

To deal with this problem, the transmitter inserts occasional *reference symbols* into the data stream, which have a transmission time, amplitude and phase that are defined in the relevant specifications. In the receiver, a *channel estimation* function measures the incoming reference symbols, compares them with the ones that the specifications defined, and estimates the phase shift $\psi$ that the air interface introduced. It can then remove this phase shift from the incoming symbols by multiplying them by the complex number $\exp(-j\psi)$. The phase shift does not change much from one symbol to the next, so the reference symbols only need to take up a small part of the transmitted data stream. The resulting overhead in LTE is about 10%.

# Bandwidth is proportional to how much information transfered

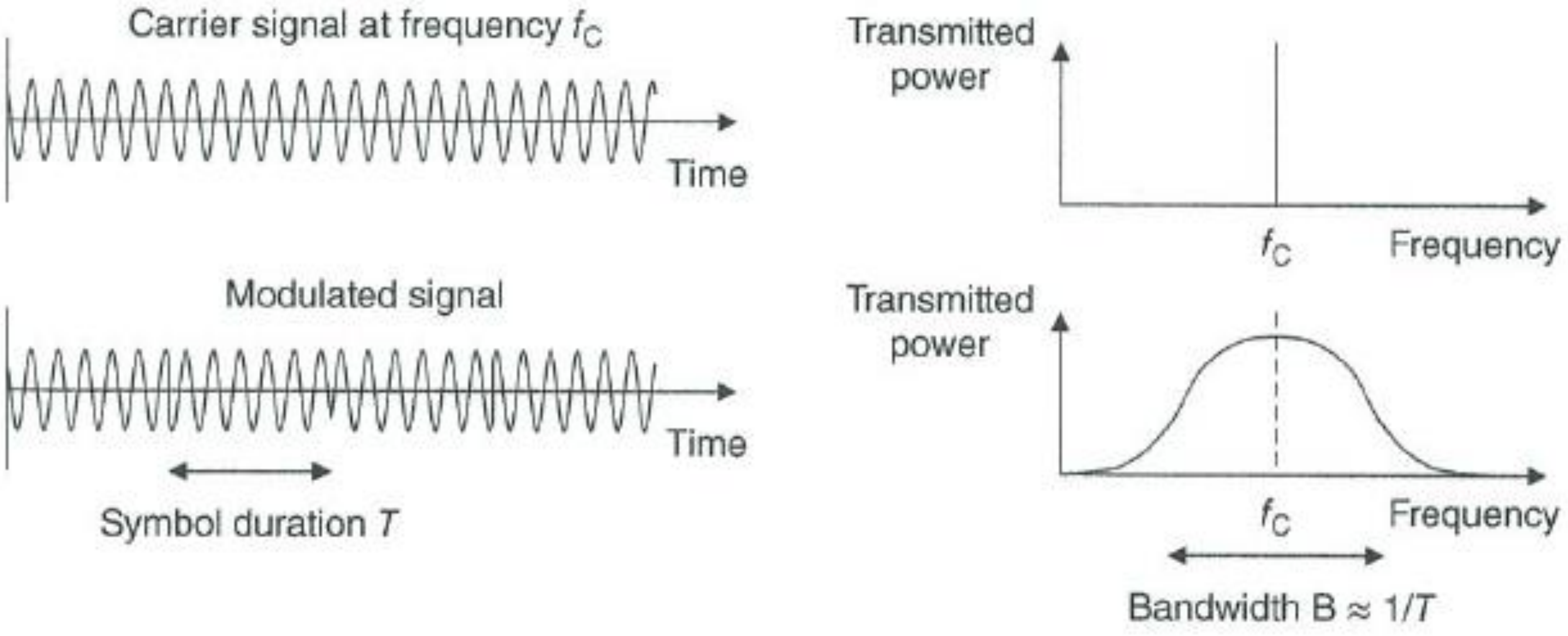



**Figure 3.6** Relationship between the bandwidth and symbol duration of a modulated signal

# Wireless channel always have multipath

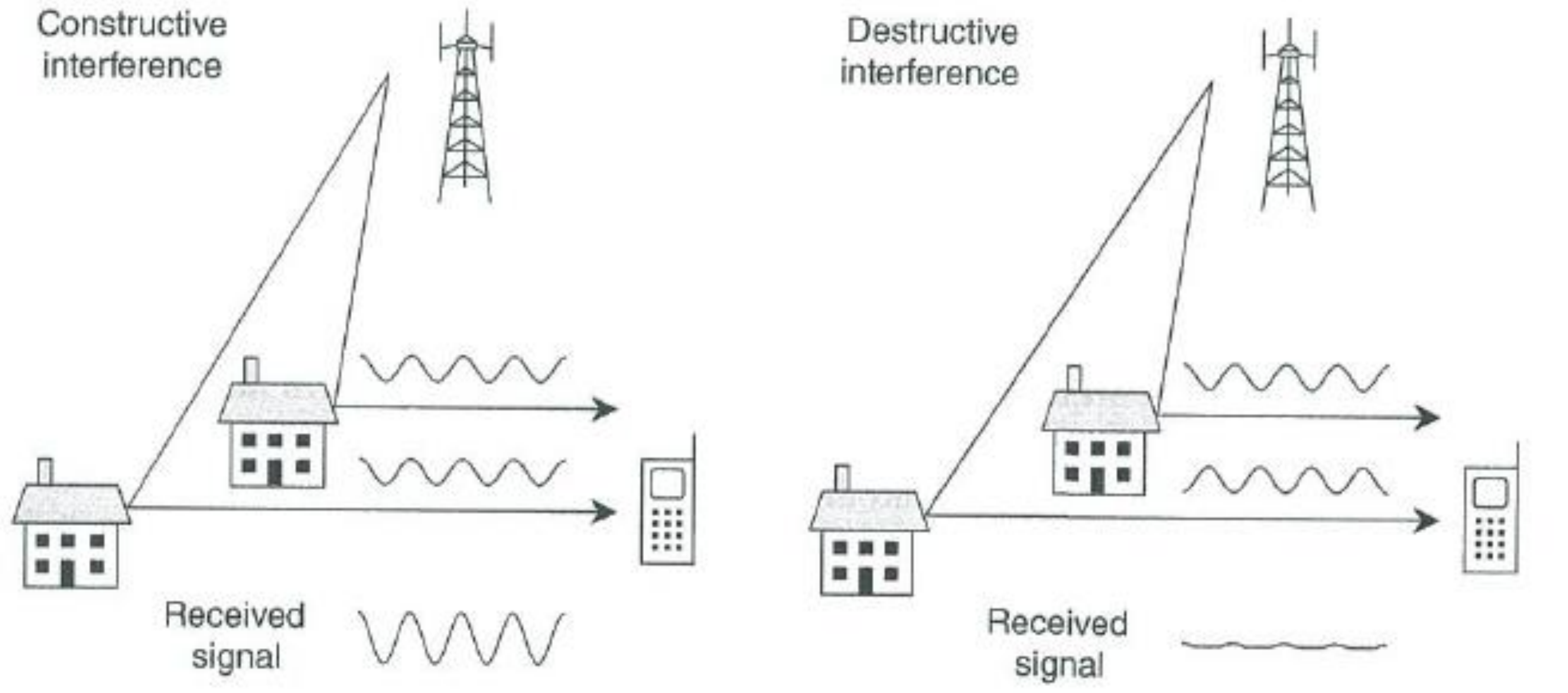



Figure 3.9 Generation of constructive interference, destructive interference and fading in a multipath environment

**Multipath causes delay spread -> frequency selective fading**

**Mobile reception causes Doppler -> time selective fading**

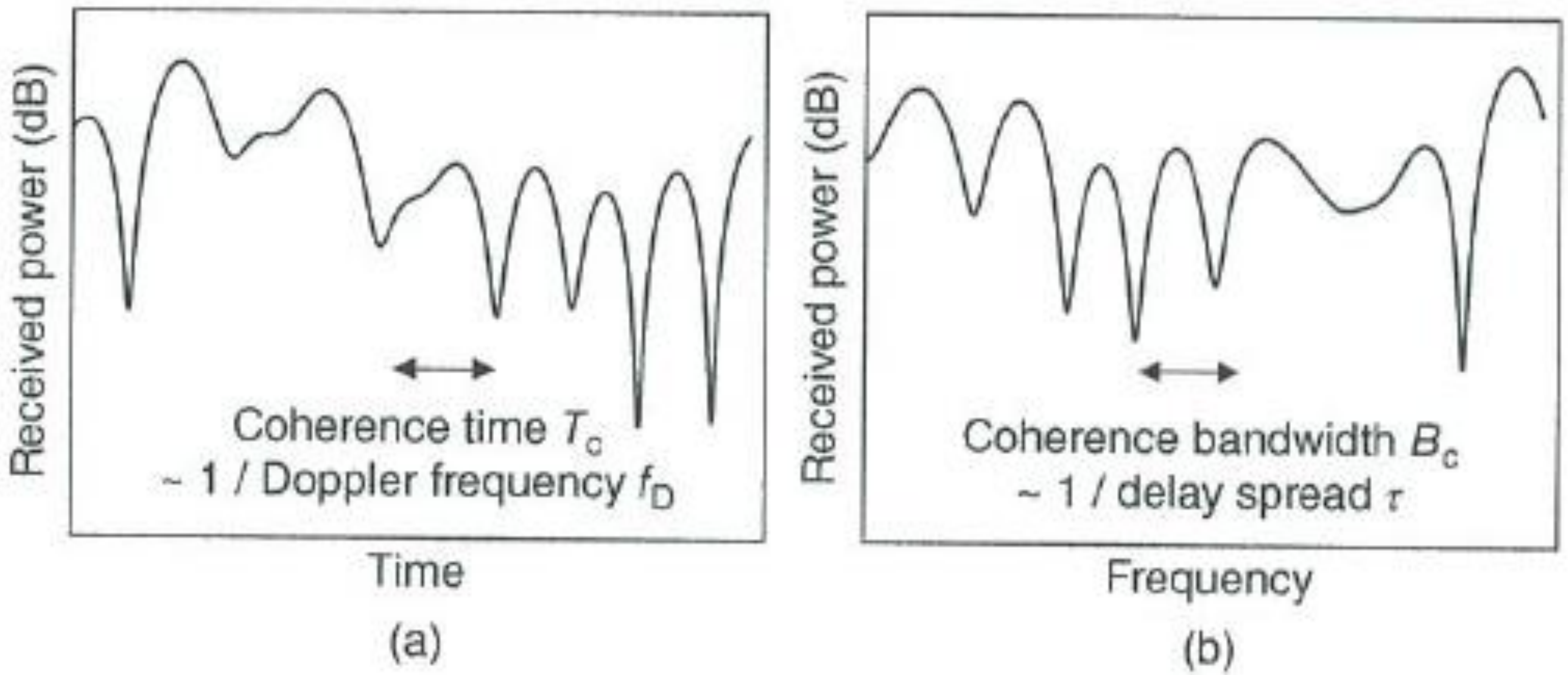



**Figure 3.10** Fading as a function of (a) time and (b) frequency