# Mobile Radio Propagation

## Small-scale Path loss

# Small-Scale Fading and Multipath

- The term fading is used to describe rapid fluctuation of the amplitude of a radio signal over a short period of time or travel distance
- Fading is caused by destructive interference between two or more versions of the transmitted signal being slightly out of phase due to the different propagation time
- This is also called multipath propagation
- The different components are due to reflection and scattering form trees buildings and hills etc.

# Small-Scale Fading and Multipath

- At a receiver the radio waves generated by same transmitted signal may come

  From Different direction

  With Different propagation delays,

  With Different amplitudes

  With Different phases

- Each of the factor given above is random

- The multipath components combine vectorially at the receiver and produce a fade or distortion.

# Effects of Fading/Multipath

- Multipath propagation creates small-scale fading effects. The three most important effects are:
  - Rapid changes in signal strength over a small travel distance or time interval;
  - Random frequency modulation due to varying Doppler shifts on different multipath signals; and
  - Time dispersion (echoes) caused by multipath propagation delays.
- Even when a mobile receiver is stationary, the received signal may fade due to a non-stationary nature of the channel (reflecting objects can be moving)

# Factors influencing small-scale fading

- **Multipath propagation**
  - **The presence of reflecting** objects and scatterers in the space between transmitter and receiver creates a constantly changing channel environment
  - Causes the signal at receiver to fade or distort

- **Speed of mobile receiver**
  - **The relative motion** between the transmitter and receiver results in a random frequency modulation due to different Doppler shifts on each of the multipath signals
  - Doppler shift may be positive or negative depending on direction of movement of mobile

# Factors influencing small-scale fading

- **Speed of surrounding objects:**
  - If the speed of surrounding objects is greater than mobile, the fading is dominated by those objects
  - If the surrounding objects are slower than the mobile, then their effect can be ignored
- **The transmission bandwidth:**
  - Depending on the relation between the signal bandwidth and the coherence bandwidth of the channel, the signal is either distorted or faded
  - If the signal bandwidth is greater than coherence bandwidth it creates distortion
  - If the signal bandwidth is smaller than coherence bandwidth it create small scale fading

The coherence bandwidth of a wireless channel is the range of frequencies that are allowed to pass through the channel without distortion. **This is the bandwidth over which the channel transfer function remains virtually constant.**

# Some Terminologies

- Level Crossing Rate

  Average number of times per sec that the signal crosses a certain level going in positive going direction

- Fading Rate

  Number of times the signal envelop crosses middle value in positive going direction per unit time

- Depth of Fading

  Ratio of mean square value and minimum value of fading

- Fading Duration

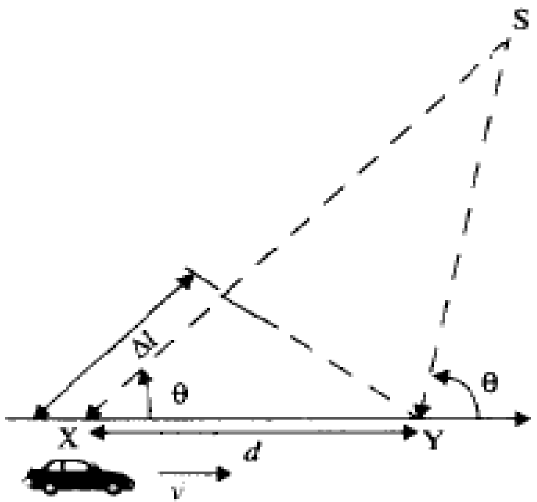
  Time for which signal remain below a certain threshold

# Doppler shift

- Change in the apparent frequency of a signal as Tx and Rx move toward or away from each other
- If mobile is moving towards the direction of arrival of the signal, the Doppler shift is positive(apparent received frequency is increased i.e. fc+fd) and vice versa
- Mathematically

$$\Delta\phi = \frac{2\pi\Delta l}{\lambda} = \frac{2\pi v\Delta t}{\lambda}\cos\theta$$

$$f_d = \frac{1}{2\pi}\cdot\frac{\Delta\phi}{\Delta t} = \frac{v}{\lambda}\cdot\cos\theta$$



# Parameters of Mobile Multipath Channels

- Time Dispersion Parameters
  - Grossly quantifies the multipath channel
  - Determined from Power Delay Profile
  - Parameters include
    - Mean Access Delay
    - RMS Delay Spread
    - Excess Delay Spread (X dB)
- Coherence Bandwidth
- Doppler Spread and Coherence Time

# Timer Dispersion Parameters

- Determined from a power delay profile

Mean excess delay( $\bar{\tau}$ ):

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)(\tau_k)}{\sum_k P(\tau_k)}$$

Rms delay spread ($\sigma_\tau$):

$$\sigma_\tau = \sqrt{\overline{\tau^2} - \bar{\tau}^2}$$

$$\overline{\tau^2} = \frac{\sum_k a_k^2 \tau_k^2}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)(\tau_k^2)}{\sum_k P(\tau_k)}$$

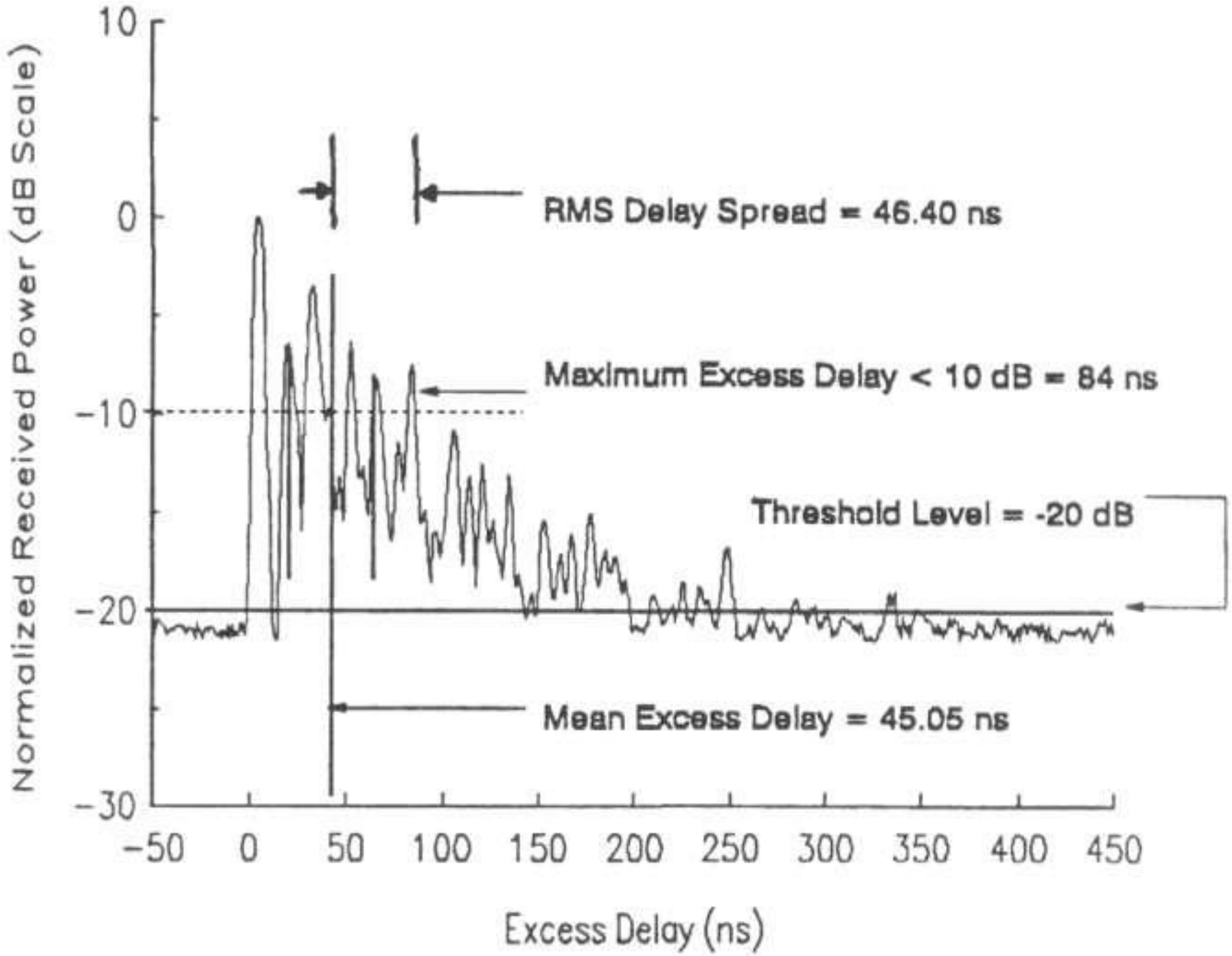
# Timer Dispersion Parameters

Maximum Excess Delay (X dB):

- Defined as the time delay value after which the multipath energy falls to X dB below the maximum multipath energy (not necessarily belonging to the first arriving component).

It is also called *excess delay spread*.

# RMS Delay Spread



# Noise Threshold

- The values of time dispersion parameters also depend on the noise threshold (the level of power below which the signal is considered as noise).

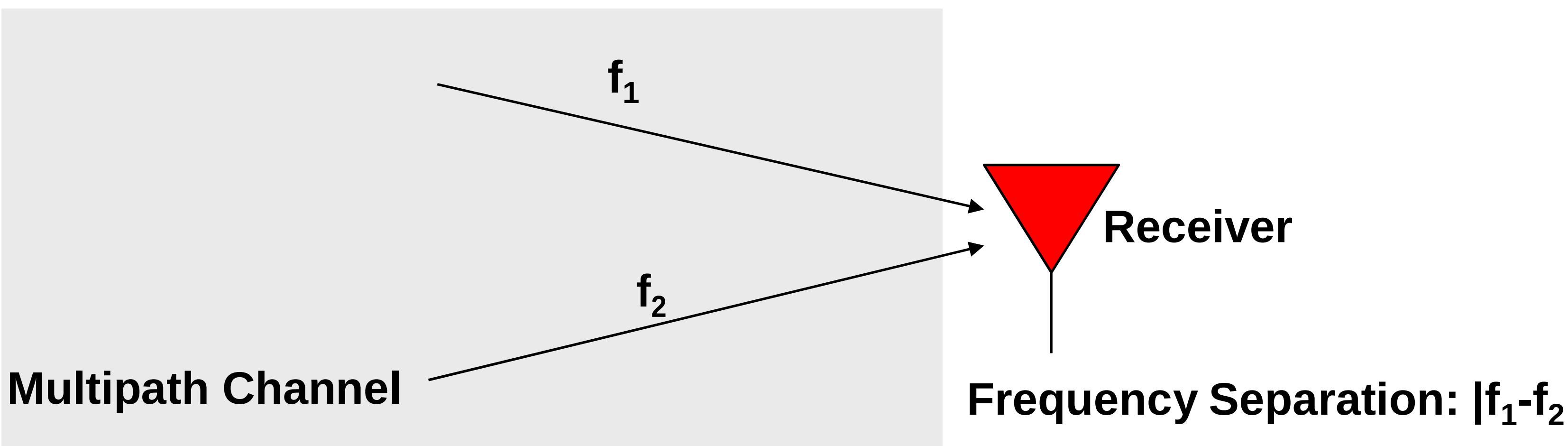
- If noise threshold is set too low, then the noise will be processed as multipath and thus causing the parameters to be higher.

# Delay Spread, Coherence BW

- Describes the time dispersive nature of a channel in a local area
- A received signal suffers spreading in time compared to the transmitted signal
- Delay spread can range from a few hundred nanoseconds for indoor scenario up to some microseconds in urban areas
- The coherence bandwidth $B_c$ translates time dispersion into the language of the frequency domain.
- It specifies the frequency range over which a channel affects the signal spectrum nearly in the same way, causing an approximately constant attenuation and linear change in phase
- The rms delay spread and coherence bandwidth are inversely proportional to each other.

# Coherence Bandwidth ($B_C$)

- Range of frequencies over which the channel can be considered flat (i.e. channel passes all spectral components with equal gain and linear phase).
  - It is a definition that depends on RMS Delay Spread.
- Two sinusoids with frequency separation greater than $B_c$ are affected quite differently by the channel.



# Coherence Bandwidth

Frequency correlation between two sinusoids: $0 \le C_{r1, r2} \le 1$.

If we define Coherence Bandwidth ($B_C$) as the range of frequencies over which the frequency correlation is above 0.9, then

$$B_C = \frac{1}{50\sigma}$$

$\sigma$ is rms delay spread

If we define Coherence Bandwidth as the range of frequencies over which the frequency correlation is above 0.5, then

$$B_C = \frac{1}{5\sigma}$$

This is called 50% coherence bandwidth.

# Coherence Bandwidth

- Example:
  - For a multipath channel, s is given as 1.37ms.
  - The 50% coherence bandwidth is given as: 1/5s = 146kHz.
    - This means that, for a good transmission from a transmitter to a receiver, the range of transmission frequency (channel bandwidth) should not exceed 146kHz, so that all frequencies in this band experience the same channel characteristics.
    - Equalizers are needed in order to use transmission frequencies that are separated larger than this value.
    - This coherence bandwidth is enough for an AMPS channel (30kHz band needed for a channel), but is not enough for a GSM channel (200kHz needed per channel).

# Doppler Spread and Coherence time

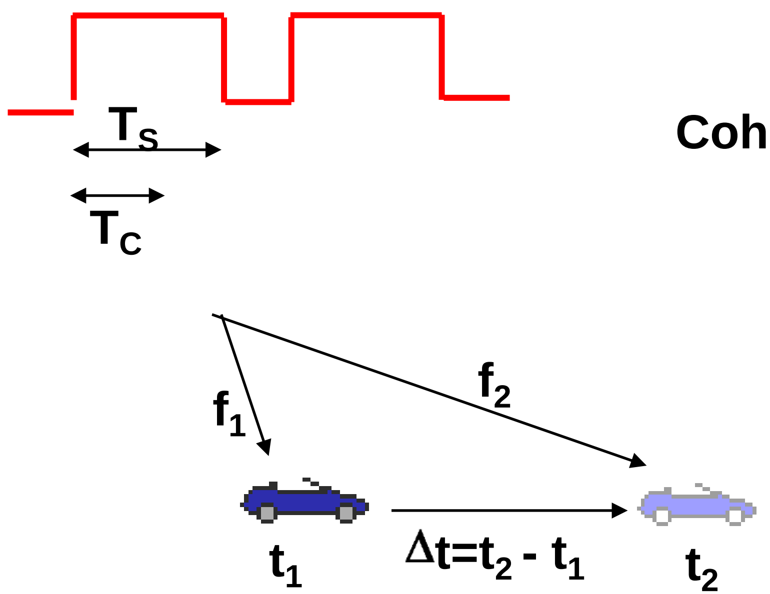
- Delay spread and Coherence bandwidth describe the time dispersive nature of the channel in a local area. They don't offer information about the time varying nature of the channel caused by relative motion of transmitter and receiver.
- Doppler Spread and Coherence time are parameters which describe the time varying nature of the channel in a small-scale region.
- Time varying nature of channel caused either by relative motion between BS and mobile or by motions of objects in channel are categorized by $B_{D \text{ and}}$ $T_c$

# Doppler Spread

- Measure of spectral broadening caused by motion
- We know how to compute Doppler shift: $f_d$
- Doppler spread, $B_D$, is defined as the maximum Doppler shift: $f_m = v/\lambda$
- if Tx signal bandwidth ($B_s$) is large such that $B_s >> B_D$ then effects of Doppler spread are **NOT** Important so Doppler spread is only important For low bps (data rate) applications (e.g. paging), slow fading channel

# Coherence Time

- Coherence time is the time duration over which the channel impulse response is essentially invariant.
- If the symbol period of the baseband signal (reciprocal of the baseband signal bandwidth) is greater the coherence time, than the signal will distort, since channel will change during the transmission of the signal .




**Coherence time ($T_C$) is defined as:**

$$T_C \approx \frac{1}{f_m}$$

# Coherence Time

- Coherence time is also defined as:

$$T_C \approx \sqrt{\frac{9}{16\pi f_m^2}} = \frac{0.423}{f_m}$$

- Coherence time definition implies that two signals arriving with a time separation greater than $T_C$ are affected differently by the channel.

**Small-Scale Fading**
(Based on multipath time delay spread)

**Flat Fading**
1. BW of signal < BW of channel
2. Delay spread < Symbol period

**Frequency Selective Fading**
1. BW of signal > BW of channel
2. Delay spread > Symbol period

**Small-Scale Fading**
(Based on Doppler spread)

**Fast Fading**
1. High Doppler spread
2. Coherence time < Symbol period
3. Channel variations faster than base-band signal variations

**Slow Fading**
1. Low Doppler spread
2. Coherence time > Symbol period
3. Channel variations slower than baseband signal variations

**Figure 5.11** Types of small-scale fading.

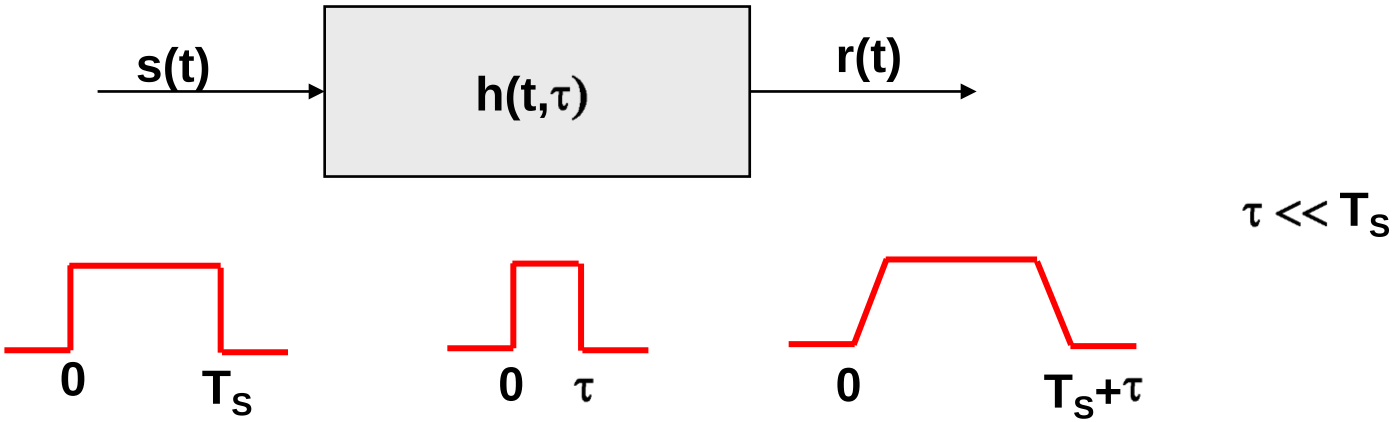
# Classification of Multipath Channels

- Depending on the relation between signal parameters (bandwidth and symbol period) and channel parameters (delay spread and Doppler spread) different signals undergo different types of fading
- Based on delay spread the types of small scale fading are
  - Flat fading
  - Frequency selective fading
- Based on Doppler spread the types of small scale fading are
  - Fast fading
  - Slow fading

# Flat fading:

- Occurs when the amplitude of the received signal changes with time
- Occurs when symbol period of the transmitted signal is much larger than the Delay Spread of the channel
    - Bandwidth of the applied signal is narrow.
- The channel has a flat transfer function with almost linear phase, thus affecting all spectral components of the signal in the same way
- May cause deep fades.
    - Increase the transmit power to combat this situation.

# Flat Fading




**Occurs when:**

$B_S \ll B_C$

and

$T_S \gg \sigma_\tau$

$B_C$: Coherence bandwidth

$B_S$: Signal bandwidth

$T_S$: Symbol period

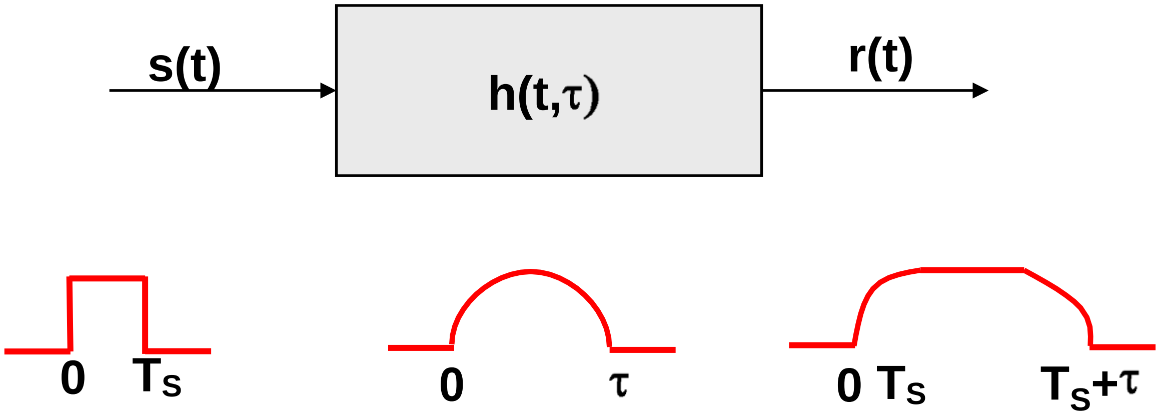
$\sigma_\tau$: Delay Spread

# Frequency selective fading:

A channel that is not a flat fading channel is called *frequency selective fading* because different frequencies within a signal are attenuated differently by the MRC.

- Occurs when channel multipath delay spread is greater than the symbol period.
  - Symbols face time dispersion
  - Channel induces Intersymbol Interference (ISI)
- Bandwidth of the signal s(t) is wider than the channel impulse response.

# Frequency Selective Fading




$\tau >> T_S$

**Causes distortion of the received baseband signal**

**Causes Inter-Symbol Interference (ISI)**

**Occurs when:**

$B_S > B_C$

**and**

$T_S < \sigma_\tau$

**As a rule of thumb** $T_S < \sigma_\tau$

# Fast Fading

- Rate of change of the channel characteristics
  is **larger** than the
  Rate of change of the transmitted signal
- The channel changes during a symbol period.
- The channel changes because of receiver motion.
- Coherence time of the channel is smaller than the symbol period of the transmitter signal

**Occurs when:**

**$B_S < B_D$**
**and**
**$T_S > T_C$**

**$B_S$: Bandwidth of the signal**
**$B_D$: Doppler Spread**
**$T_S$: Symbol Period**
**$T_C$: Coherence Bandwidth**

# Slow Fading

- Rate of change of the <u>channel characteristics</u>
  is **much smaller** than the
  Rate of change of the <u>transmitted signal</u>

**Occurs when:**

**$B_S >> B_D$**
**and**
**$T_S << T_C$**

**$B_S$: Bandwidth of the signal**
**$B_D$: Doppler Spread**
**$T_S$: Symbol Period**
**$T_C$: Coherence Bandwidth**

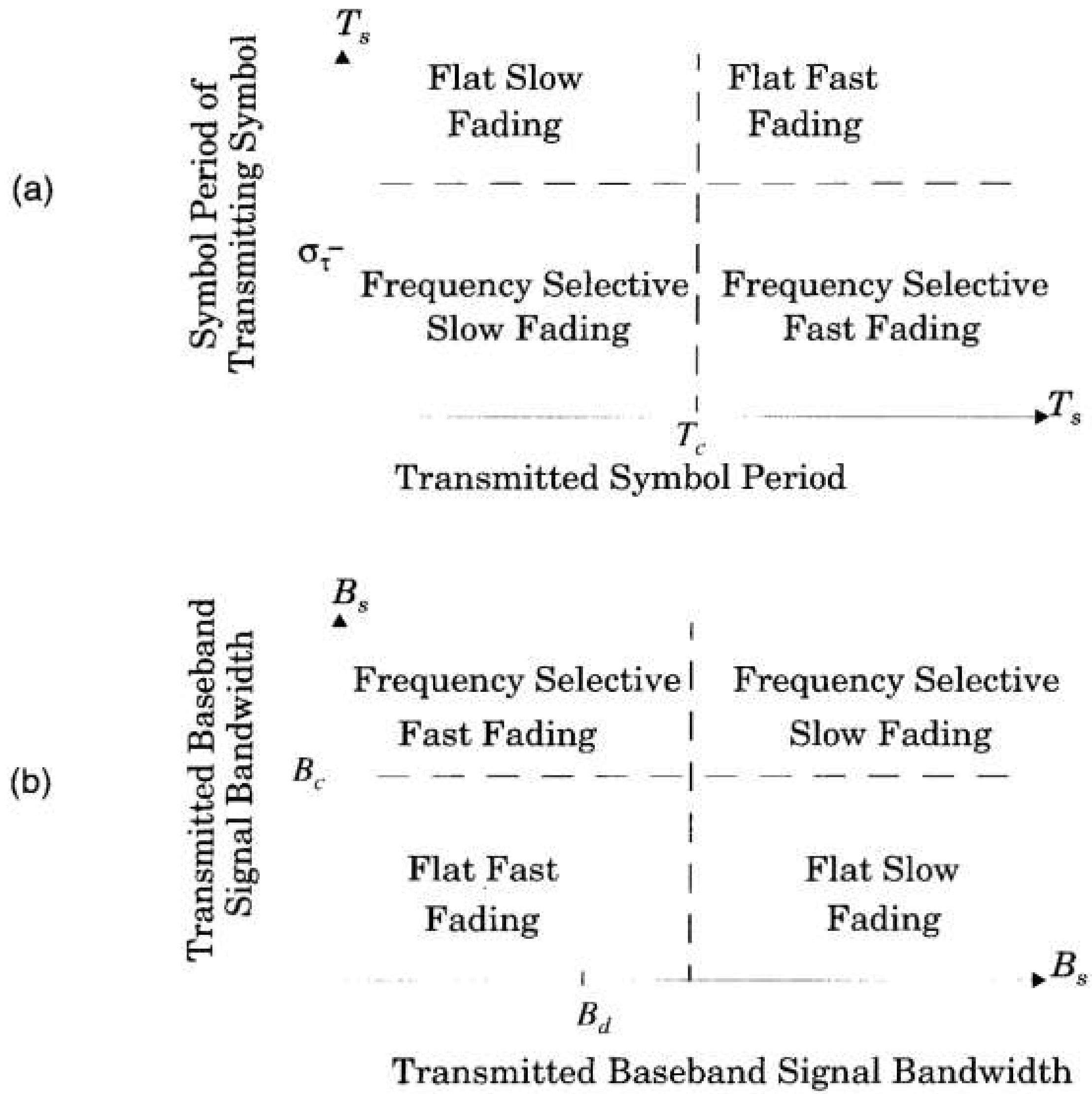



**Figure 5.14** Matrix illustrating type of fading experienced by a signal as a function of: (a) symbol period; and (b) baseband signal bandwidth.

# Fading Distributions

- Describes how the received signal amplitude changes with time.
  - Remember that the received signal is combination of multiple signals arriving from different directions, phases and amplitudes.
  - With the received signal we mean the baseband signal, namely the envelope of the received signal (i.e. r(t)).

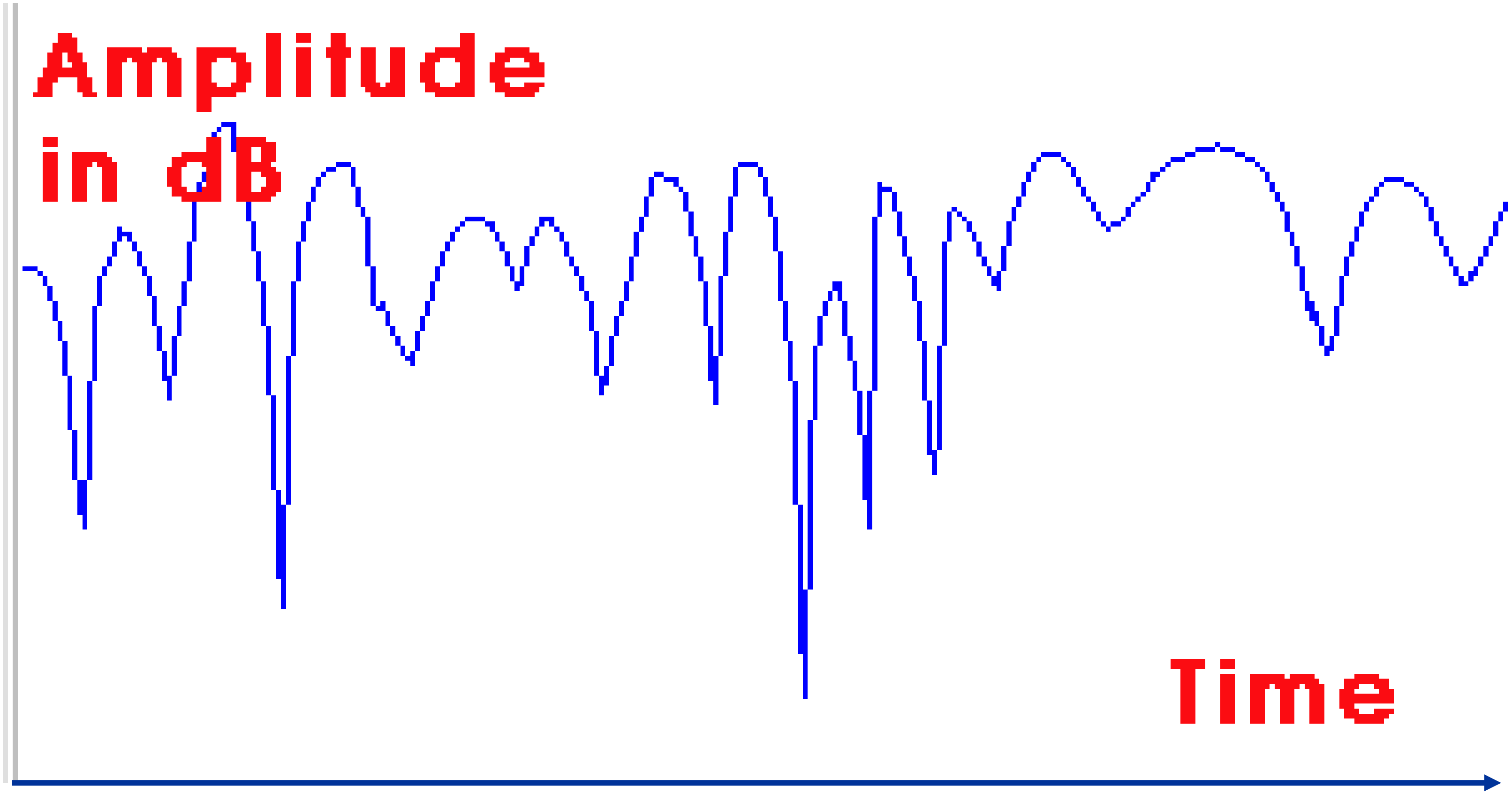
$$r(t) = \sum_{i=0}^{N-1} a_i \exp(j\theta_i(t, \tau))$$

- Its is a statistical characterization of the multipath fading.
- Two distributions
  - Rayleigh Fading
  - Ricean Fading

# Rayleigh and Ricean Distributions

- Describes the received signal envelope distribution for channels, where all the components are non-LOS:
  - i.e. there is no line-of–sight (LOS) component.
- Describes the received signal envelope distribution for channels where one of the multipath components is LOS component.
  - i.e. there is one LOS component.

# Rayleigh Fading



# Rayleigh

❑ **Rayleigh distribution has the probability density function (PDF) given by:**

$$p(r) = \begin{cases} \dfrac{r}{\sigma^2} e^{\left(-\frac{r^2}{2\sigma^2}\right)} & (0 \le r \le \infty) \\ 0 & (r < 0) \end{cases}$$

- **$\sigma^2$ is the time average power of the received signal before envelope detection.**
- **$\sigma$ is the rms value of the received voltage signal before envelope detection**

# Rayleigh

**The probability that the envelope of the received signal does not exceed a specified value of R is given by the CDF:**

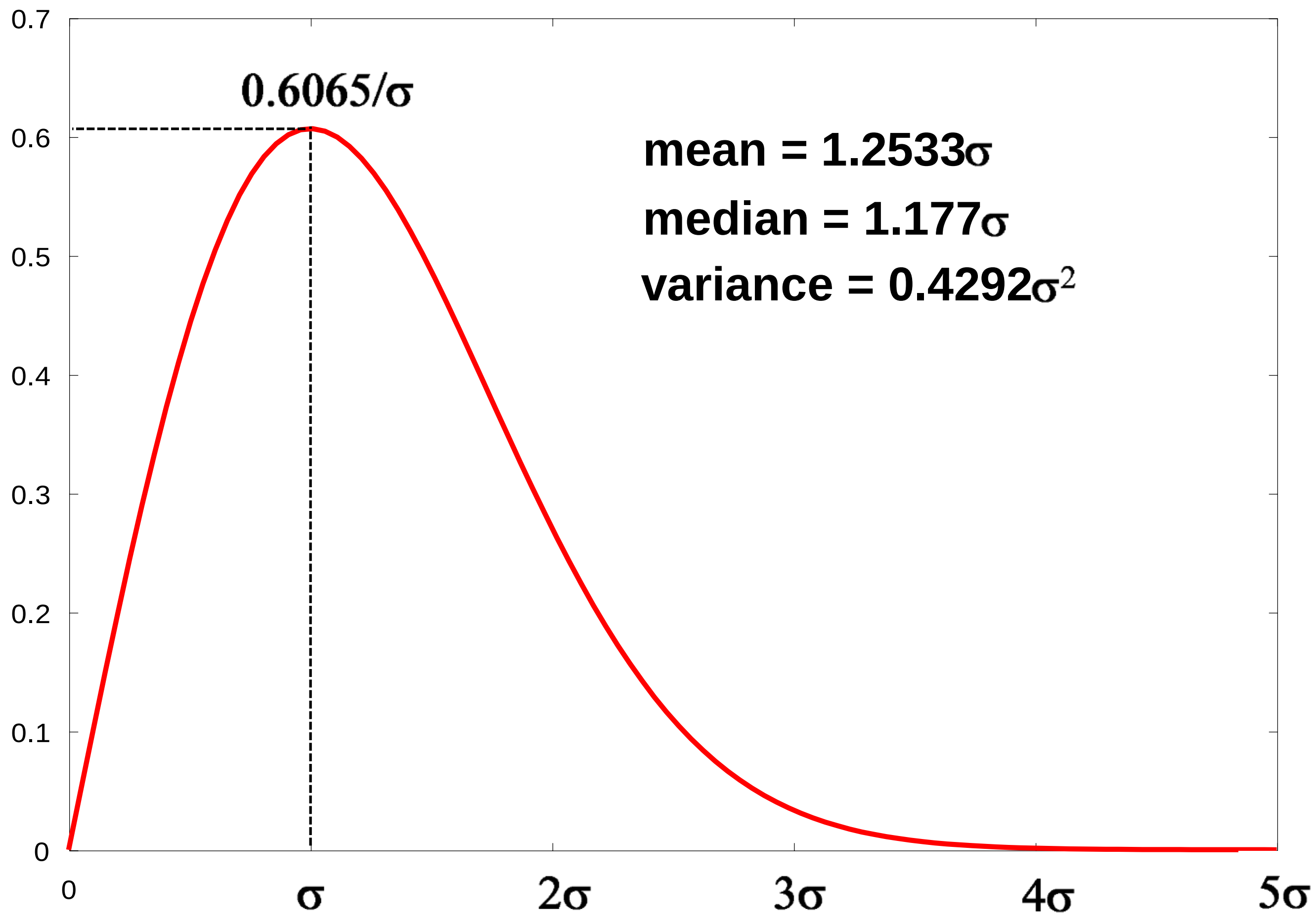
$$P(R) = P_r(r \leq R) = \int_0^R p(r)dr = 1 - e^{-\frac{R^2}{2\sigma^2}}$$

$$r_{mean} = E[r] = \int_0^\infty rp(r)dr = \sigma\sqrt{\frac{\pi}{2}} = 1.2533\,\sigma$$

$$r_{median} = 1.177\,\sigma \quad \text{found by solving} \quad \frac{1}{2} = \int_0^{r_{median}} p(r)dr$$

$$r_{rms} = \sqrt{2}\sigma$$

# Rayleigh PDF



# Ricean Distribution

- When there is a stationary (non-fading) LOS signal present, then the envelope distribution is Ricean.
- The Ricean distribution degenerates to Rayleigh when the dominant component fades away.
- The Pdf of Ricean function is given as

$$f(x \mid \nu, \sigma) = \frac{x}{\sigma^2} \exp\left(\frac{-(x^2 + \nu^2)}{2\sigma^2}\right) I_0\left(\frac{x\nu}{\sigma^2}\right)$$

# Ricean Distribution