CHAPTER

3 Signal Fading and Multipath Propagation

ACRONYMS

- FCC : Federal Communications Commissions
- IDFT : Inverse Discrete Fourier Transforms
- LTI : Linear Time Invarient
- SIRCIM : Simulation of Indoor Radio Channel Impulse Presponse Modal
- SMRCIM : Simulation of Mobile Radio Channel Impulse Response Model
- PDF : Probability Density Function

Small scale fading and multipath propagation and measurements, impulse response model and parameters of multipath channels, types of fading, theory of multipath shape factor for fading wireless channels.

3.1 INTRODUCTION

The focus of this chapter is to identify the parameters that distort the information signal as it penetrates the propagation medium. The corruptive elements are in the form of multipath delay, signal fading and distortion due to time dispersion.

The multipath components can add constructively or destructively depending on the carrier frequency and delay differences. The over all effect is that received signal level fluctuates with time, which leads a phenomenon called '**fading**'. Fading refers to the time variation of received signal power caused by changes in the transmission medium or traveling paths. In a mobile environment, where one is moving relative to the other, the relative location of various obstacles changes over time which leads to path loss and fading.

3.2 SMALL-SCALE FADING

Small scale fading is used to described the rapid fluctuations of the amplitudes, phases, or multipath delays of a radio signal over a short period of time or travel distance so that the large scale path loss effects may be ignored. These rapid changes occur because the signal is received at receiver from many directions. Depending on the different paths the signals take, each signal may have a different phase and cancel each other.

However, if these changes are too fast, such as driving on a highway, through a city, the signal level fluctuates rapidly and increases fading on that channel.

3.3 FACTORS AFFECTING SMALL-SCALE FADING

Following factors in the radio propagation channel may affect small scale fading:

1. Speed of the mobile
2. Speed of surround objects
3. Bandwidth of the transmitted signal
4. Multipath propagation
5. Dopper shift

3.4 REASONS OF SIGNAL FADING

There are three basic reasons of fading of wireless signals

1. Absorption
2. Free-space loss
3. Multipath propagation

3.4.1 Absorption

Absorption simply describes how a radio signal is absorbed by objects. When a radio wave strikes on object, there is possibility that it can be absorbed. Radio frequencies can be absorbed by buildings, trees or hills. It is usually seen that the objects made from organic materials tend to absorb more RF signal than the objects made from inorganic materials.

Absorption can be compensated by using higher gain antennas and higher power levels in order to cover the same geographic area. The greater the amount of absorption of an RF signal, the higher the fading and the less geographic area covered.

3.4.2 Free-Space Loss

It is also known as path-loss It describes the attenuation of a radio signal over a given distance. It is directly proportional to the radio frequency. As the frequency of a radio signal increases, free space path loss also increases.

3.4.3 Multipath Propagation

In multipath propagation, multiple signal paths are established between the base station and the user terminal (mobile phone). The fading due to multipath propagation is known as 'Multipath fading' or 'Rayleigh fading'.

One signal path arrives at an antenna (either mobile or base station) as a direct signal, while other signals are multipath or indirect signals. Indirect signal generated due to reflection; refraction or diffraction of signals from any or all objects lie in the path of transmitting antenna and receiving antenna.

These indirect signals can add to or subtract from the direct signal arriving at the antenna This depends on whether or not the indirect signals are in-phase or out-of-phase with the direct signal.

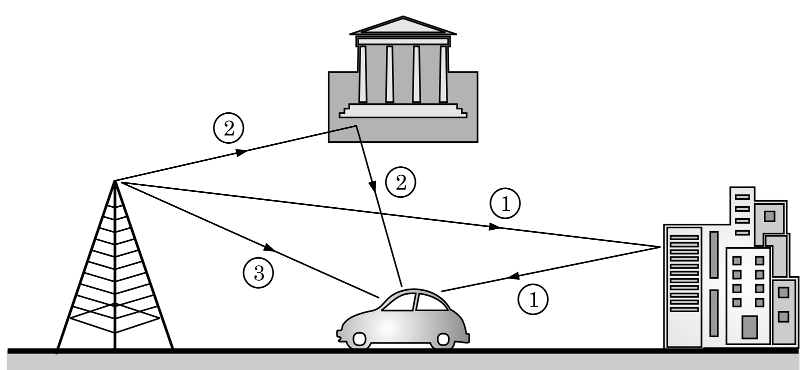


Fig. 3.1 *Multipath Propagation.*

If the signals are in-phase then overall signal strength increases and if the signals are out-of-phase then over all signal strength decreases.

Note: Reflection, Diffraction and scattering effects system performance through various ways depending on local conditions and the mobile unit movement. If clear line-of-sight occurs between mobile unit and transmitter then diffraction and scattering effects are very less while reflection have a significant impact. If there is no clear LOS (that may be the case of urban area or metropolitan cities), then primary means of signal reception is diffraction and scattering [See Fig. 3.2]

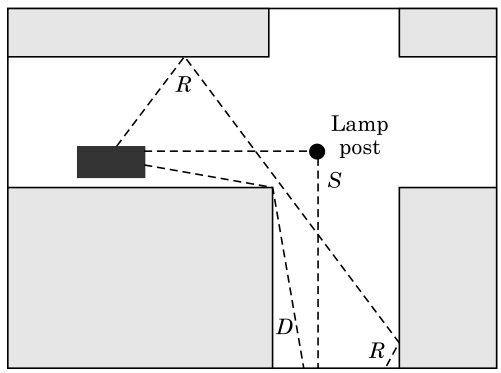


Fig. 3.2 *Three Important Propagation Mechanism: Reflection (R), Scattering (S), Diffraction (D)*

- *Reflection* occurs when the surface is large relative to the wavelength of the signal.
- *Diffraction* occurs at the edge of the surface that is large compared to the wavelength of radio wave.
- An incoming signal *scattered* into several weaker outgoing signals if the size of an obstacle is on the order of the wavelength of the signal or less.

3.5 DOPPLER SHIFT IN MULTIPATH RECEPTION

If the mobile and base station have relative motion between them then there is an apparent shift in frequency of each multipath wave. The shift in received signal frequency due to motion is called the doppler shift. Doppler shift is directly proportional to the velocity and direction of motion of the mobile with respect to the direction of arrival of received multipath wave.

If a mobile unit takes Δt time to travel from point A to point B with a constant velocity 'v' then the doppler shift (f_d) is

$$f_d = \frac{v}{\lambda} \cdot \cos\theta \qquad \text{...(3.1)}$$

where $v \rightarrow$ Constant velocity of mobile

$\lambda \rightarrow$ Wave length

and $\theta \rightarrow$ angle of mobile unit from the source (base station)

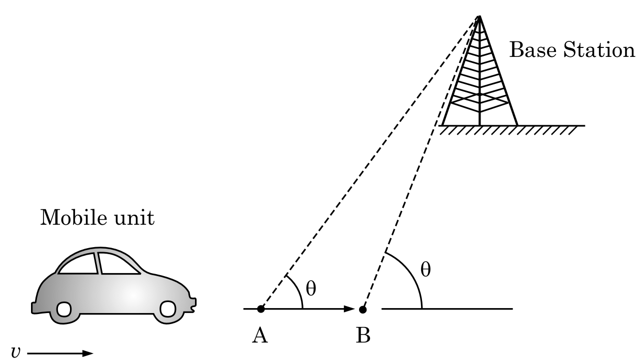


Fig. 3.3 *Illustration of doppler effect.*

Note: θ is assumed same for point A and B since the source (i.e. base station) is assumed to be very far away from Mobile unit.

3.6 MULTIPATH MEASUREMENT TECHNIQUES

Some techniques that are used to measure multipath propagation are given below:

1. Direct pulse measurement

2. Spread spetrum sliding Correlator measurement

3. Swept frequency measurement

These techniques are also known as sounding techniques.

3.6.1 Direct Pulse Measurement Technique

This technique permits the measurement of multipath phase and therefore determines the power delay profile of any channel.

Working Detail

The basic principle of this technique is that a repetitive pulse of width T_b is transmitted from transmitter which is received at receiver through RF link. The receiver section is a combination of band pass filter, amplifier, detector and digital storage oscilloscope.

Band pass filter bandwidth ($2/T_b\ Hz$) is twice of transmission bandwidt ($1/T_b$). This signal is then amplified and detected and finally displayed at CRO. If the CRO is set on averaging mode, then this system can provide a local average power delay profile. Fig. 3.4 shows a simplified block diagram of direct pulse measurement technique. The minimum delay between multipath components is equal to the pulse width (T_b).

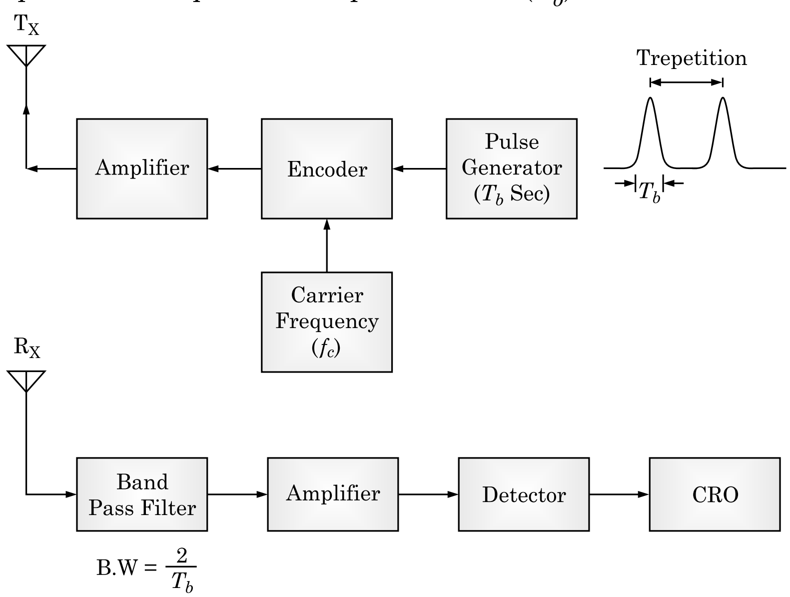


Fig. 3.4 *Direct Pulse Measuremet techique.*

Advantages:

1. Lack of Complexity

2. Determines rapidly the power delay profile of any channel.

Disadvantages:

1. Subjected to interference and noise

2. Phase of the individual multipath components are not received due to envelope detector.

3.6.2 Spread Spectrum Sliding Correlator Measurement Technique

This measurement technique (or sounding technique) of multipath measurement improves the dynamic range of the system as compared to the direct pulse system. This system uses the advantages of spread spectrum techniques (will be discussed in chapter 4).

Working Detail

In this measurement technique, a carrier signal is spread 'over' a large bandwidth. This spreacled signal is generated by mixing the carrier signal (f_C) with a binary pseudo-noise sequence (PN sequence). It is then amplified and transmitted.

This spreaded signal is received, filtered and despreaded using the same PN sequence that was used to transmit the signal. Fig. 3.5 shows the block representation of spread spectrum technique.

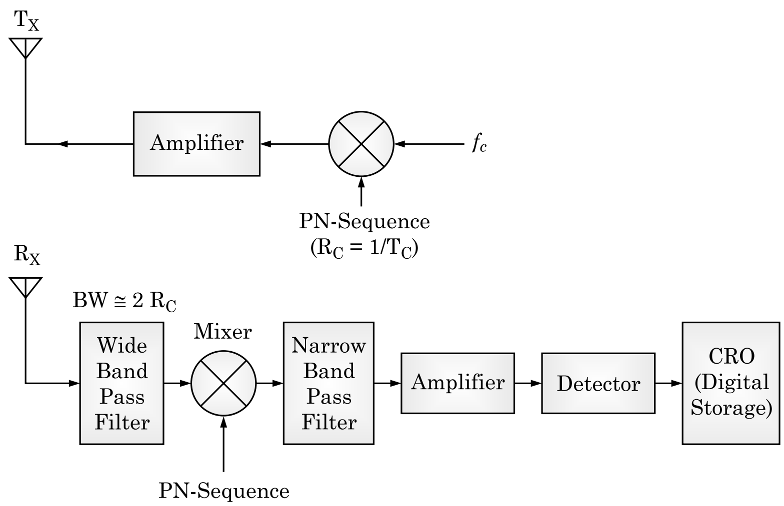


Fig. 3.5 *Block representation of spread spectrum shielding correlator measurement technique.*

The time resolution ($\Delta\tau$) of multipath components using a spread spectrum system with sliding correlation is

$$\Delta\tau = 2T_C = \frac{2}{R_C}$$

We can conclude, that the system can resolve two multipath components as long as they are equal to or greater than two chip durations, ($2T_C$ seconds apart).

It must be ensured that the sequence length has a period which is greater than the longest multipath propagation delay. It is denoted as τ_{PN}

$$\tau_{PN} = T_C \cdot l \quad ...(3.2)$$

where T_C = Chip period in seconds

and l = PN sequence length (chips)

The PN sequence period provides an estimate of the maximum unambiguous range (MUR) of incoming multipath signal components

$$MUR = \tau_{PN} \times C \quad ...(3.3)$$

where C denotes to the speed of light.

Advantages:

1. Able to reject band pass noise.
2. Coverage range improved for a given power.
3. Adjustable sensitivity
4. Less power requirement

Disadvatnages:

1. Measurements are not made in real time.
2. Unable to measure the phases of multipath components due to the use of noncoherent detector.

3.6.3 Swept Frequency Measurement

In this technique the channel impulse response is measured in frequency domain. Therefore, it is also known as frequency domain channel sounding technique. This technique is useful only for very short range measurements (e.g. indoor channel sounding). Basic block diagram of this sounding system is shown in Fig. 3.6.

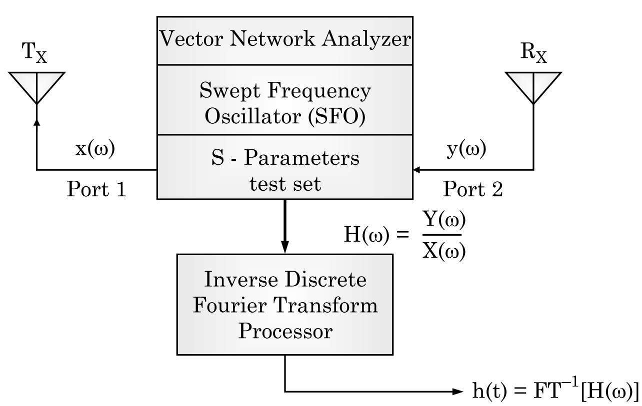


Fig. 3.6 *Swept frequency measurement technique to measure channel impulse response in frequency domain.*

Working Detail

A SFO is used to generate a particular frequency band (centered on the carrier) by stepping through discrete frequencies. SFO is controlled by vector network analyzer (VNA). An S-parameter test set is used to monitor the frequency response of the channel.

A known signal level at port-1 is transmitted by S-parameter test set of each frequency step. The received output is monitored against this step at port-2. These signal levels allow the analyzer to determine the complex channel impulse response [$H(\omega)$].

This response is then converted into time domain using inverse discrete fourier transform (IDFT) processor. As a result, the amplitude and phase information will be received in time domain.

Advantages:

1. Works in time domain.

2. Accurate in measurement

Disadvantages:

1. Successful for indoor propagation studies only.

3.7 IMPULSE RESPONSE MODEL OF A MULTIPATH CHANNEL

Impulse response of multipath channel is very important parameter of mobile radio because it is directly related to small-scale variations of a mobile radio signal. Impulse response contains all information necessary to simulate or analyze any type of radio transmission through channel.

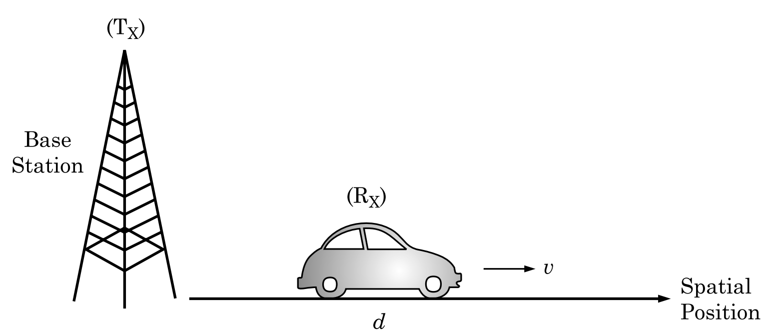


Fig. 3.7 *The mobile radio channel as a functioin of time and space.*

This response is a useful characterization of the channel, because it may be used to predict and compare the performance of many different mobile communication systems and transmission bandwidths for a particular mobile channel condition.

As shown in Fig. 3.7, the receiver moves at some constant velocity v away from the transmitter. At different positions of the receiver, propagation delay varies due to different multipath waves. Here, the impulse response of linear time invarient (LTI) channel may be a function of position of receiver. Therefore, the received signal at position 'd', $y(d, t)$ will be a convolution product of the transmitted signal $x(t)$ and channel impulse response $h(d, t)$.

$$y(d, t) = x(t) \otimes h(d, t) \quad \text{...(3.4)}$$

$$= \int_{-\infty}^{\infty} x(\tau) \cdot h(d, t-\tau)\, d\tau \quad \text{...(3.5)}$$

For a casual system, $h(d, t) = 0$ for $t < 0$, thus

$$y(d, t) = \int_{-\infty}^{t} x(\tau) \cdot h(d, t-\tau) \cdot d\tau \quad \text{...(3.6)}$$

But, distance (d) can be represented as

$$d = v \cdot t \quad \text{...(3.7)}$$

Substituting the value of d from equation (3.7) in equation (3.6), we get

$$y(vt, t) = \int_{-\infty}^{t} x(\tau) \cdot h(vt, t-\tau) \cdot d\tau \quad \text{...(3.8)}$$

Since velocity (v) is a constant, therefore $y(vt, t)$ is just a function of time t.

$$y(t) = \int_{-\infty}^{t} x(\tau) \cdot h(vt, t-\tau)\, d\tau$$

$$= x(t) \otimes h(vt, t)$$

$$y(t) = x(t) \otimes h(d, t) \quad \text{...(3.9)}$$

Hence it is proved from equation (3.9) that the mobile radio channel can be modeled as a linear time varying channel, where the channel changes with time and distance.

After some time velocity (v) may be assumed as constant. Then, the received signal $y(t)$ can be expressed as a convolution of the transmitted signal $x(t)$ and the channel impulse response $h(t,\ \tau)$,

$$y(t) = \int_{-\infty}^{\infty} x(\tau)h(t,\tau)\,d\tau = x(t) \otimes h(t,\ \tau) \qquad ...(3.10)$$

Here, the impulse response completely characterizes the channel and is a function of both t and τ. The variable t represents time variations due to motion and τ represnets the channel multipath delay for a fixed value of t.

If the multipath channel is a bandlimited bandpass channel then the transmitted signal, received signal and impulse response will be a complex quantity. Then equation (3.10) will be

$$r(t) = c(t) \otimes \frac{1}{2} h_b(t, \tau) \qquad ...(3.11)$$

Here,

$r(t)$ ⇒ Complex envolve representation of received signal $y(t)$ [See equation (3.12)]

$c(t)$ ⇒ Complex envelope representation of transmitted signal $x(t)$ [See equation (3.13)]

and $h_b(t,\ \tau)$ ⇒ Complex baseband impulse response.

The factor 1/2 in impulse response is due to the properties of complex envolve.

The $r(t)$ and $c(t)$ in terms of $x(t)$ and $y(t)$ respectively are defined as,

$$y(t) = \text{Re}\{r(t)\ \exp\,(j2\pi\tau f_C t)\} \qquad ...(3.12)$$

and

$$x(t) = \text{Re}\{c(t)\ \exp\,(j2\pi f_C t)\} \qquad ...(3.13)$$

Since the received signal in a multipath channel consists of a series of attenuated, time delayed, phase shifted replicas of the transmitted signal. Therefore, the baseband impulse response of a multipath channel can be expressed as,

$$h_b(t,\ \tau) = \sum_{i=0}^{N-1} a_i(t,\tau)\exp[j(2\pi f_c \tau_i(t) + \phi_i(t,\tau))]\,\delta(\tau - \tau_i(t)) \qquad ...(3.14)$$

where $a_i(t,\ \tau)$ = Real amplitude of the ith multipath component at time t.

$\tau_i(t)$ = Excess delay of the ith multipath component at time t.

$[2\pi f_c t_i(t) + \phi_i(t, \tau)]$ = phase shift due to free space propagation of ith multipath component + additional phase shift in channel.

If the channel impulse response is assumed to be time invarient, then it may be simplified as

$$h_b(\tau) = \sum_{i=0}^{N-1} a_i \exp(j\theta_i)\delta(\tau - \tau_i) \qquad \text{...(3.15)}$$

when measuring or predicting $h_b(\tau)$, a probing pulse $p(t)$ is used at transmitter to approximate a delta function,

$$p(t) \approx \delta(t - \tau) \qquad \text{...(3.16)}$$

It makes the channel more sound to determine $h_b(\tau)$.

For small-scale channel modelling, the power delay profile of the channel is found by taking the spatial average of $|h_b(t, \tau)|^2$ over a local area. Then the received power delay profile in a local area, if $p(t)$ has a time duration much smaller than the impulse response of multiplath channel, is given by

$$P(\tau) \approx \overline{k\,|h_b(t, \tau)|^2} \qquad \text{...(3.17)}$$

Where the bar represents the average over the local area to provide a single time invarient multipath power delay profile $p(t)$. Gain k relates the transmitted power in the probing pulse $p(t)$ to the total power received in a multipath delay profile.

3.8 PARAMETERS OF MOBILE MULTIPATH CHANNELS

Parameters of mobile multipath channels are derived in terms of power delay profile. This delay profile represents the plots of relative received power as a function of excess delay. Some multipath channel parameters are given as follows:

3.8.1 Time Dispersion Parameters

The mean excess delay, rms delay spread and excess delay spread are time dispersion parameters that are determined using power delay profile. These parameters are used to characterize the channel in time domain.

The mean excess delay is the first moment of the power delay profile and is defined as:

$$\bar{\tau} = \frac{\sum_k a_k^2 \tau_k}{\sum_k a_k^2} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)} \quad ...(3.18)$$

The rms delay spread (δ_τ) is caused by reflected and scattered propagation paths in radio channel. It is the square root of the second central moment of the power delay profile and defined as:

$$\sigma_\tau = \sqrt{(\overline{\tau^2}) - (\bar{\tau})^2} \quad ...(3.19)$$

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

Note that the mean excess delay ($\bar{\tau}$) and rms delay spread (σ_τ) do not rely on the absolute power level of $P(\tau)$ but only the relative amplitudes of the multipath components within $P(\tau)$.

3.8.2 Coherence Bandwidth

The Coherence bandwidth is inversely proportional to the rms delay spread and used to characterize the channel in frequency domain.

At coherence bandwidth, the channel passes all spectral components with approximately equal gain and linear phase. **In general, coherence bandwidth is also referred as the frequency separation at which the attenuation of two frequency domain samples of the channel becomes decorrelated.**

It is denoted by B_C and defined as,

$$B_C \approx \frac{1}{50\sigma_\tau}; \text{ frequency correlation function} > 0.9$$

and
$$B_C \approx \frac{1}{5\sigma_\tau}; \text{ for frequency correlation function} > 0.5$$

where σ_τ is the rms delay spread.

3.8.3 Doppler Spread and Coherence Time

Both the parameters given above describe the time dispersive nature of the channel in a local area. Doppler spread (B_D) and coherence time (T_C) are the parameters which describe the time varying nature of the channel caused by relative motion between the mobile and base station. Let us assume, the transmitted signal frequency f_C then, the received signal spectrum (or doppler spectrum) = $f_C \pm f_d$

where f_d is doppler shift in transmitted frequency.

It depends on the velocity of mobile and its to and fro motion with base station. At doppler spread (B_D), the received doppler spectrum is essentially non-zero.

The coherence time (T_C) is the time domain dual of doppler spread (B_D). The doppler spread and coherence time are inversely proportional to one another.

$$T_C \propto \frac{1}{B_D}$$

therefore $$T_C \propto \frac{1}{f_D}$$

Basically, coherence time (T_C) represents the time duration over which the channel impulse response is essentially invarient.

It is defined as

$$T_C \approx \frac{9}{16\pi f_D}; \text{ for time correlation function} > 0.5.$$

where f_D is the maximum doppler shift and given by

$$f_D = v/\lambda$$

3.9 TYPES OF SMALL SCALE FADING

Types of small scale fading is highly dependent on nature of speech signal (that is required to be transmitted) and characteristics of the channel. Time dispersion and frequency dispersion mechanisms are also responsible for different effects that occur in signal propagation.

A detailed classification of fading is given in Fig. 3.8.

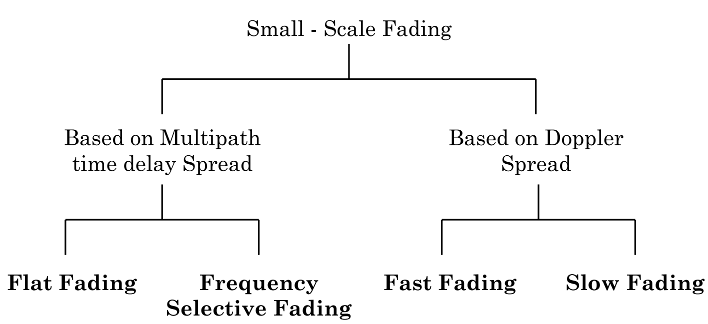


Fig. 3.8 *Types of Fading.*

The generally used signal parameters are bandwidth, symbol period etc. while channel parameters are rms delay spread, doppler spread etc. Different type of fadings depend on the relation of signal parameters and channel parameters.

The **multipath delay spread** is responsible for time dispersion and frequency selective fading while **doppler spread** is responsible for frequency dispersion and time selective fading.

The fading due to multipath time delay spread is divided into two parts

1. Flat fading or non-selective fading

2. Frequency selective fading

In **Flat fading,** all frequency components of the received signal fluctuate in the same proportions simultaneously. While **Frequency selective fading** affects unequally the different spectra components of a radio signal.

Few important parameters for various fadings are–

1. Flat fading

(*a*) Bandwidth of signal (B_S) < Bandwidth of channel (B_C)

(*b*) Delay spread (σ_t) < Symbol period (T_S)

2. Frequency Selective Fading

(*a*) Bandwidth signal (B_S) > Bandwidth of channel (B_C)

(*b*) Delay spread (σ_t) > symbol Perid (T_S)

3. Fast Fading

(*a*) Coherence time of channel (T_S) < symbol period of transmitted signal (T_S)

(*b*) Doppler spread (B_D) > Bandwidth of transmitted signal (B_S)

4. Slow Fading

(*a*) Coherence time of channel (T_C) > Symbol of period of transmitted signal (T_S)

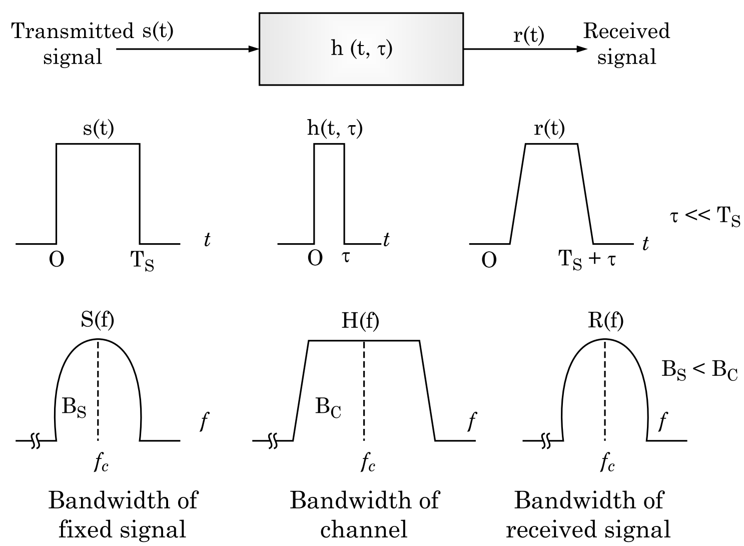
(*b*) Doppler spread (B_D) << Bandwidth of transmitted signal (B_S)

Note: A channel goes under fast fading or slow fading depending on the rapid change of transmitted baseband signal compared to the rate of change of channel. In fast fading, channel impulse response changes at a rate much faster than the transmitted base band signal while vice versa is also true for slow fading. These fadings in mobile environment affects the mobiles in motion.

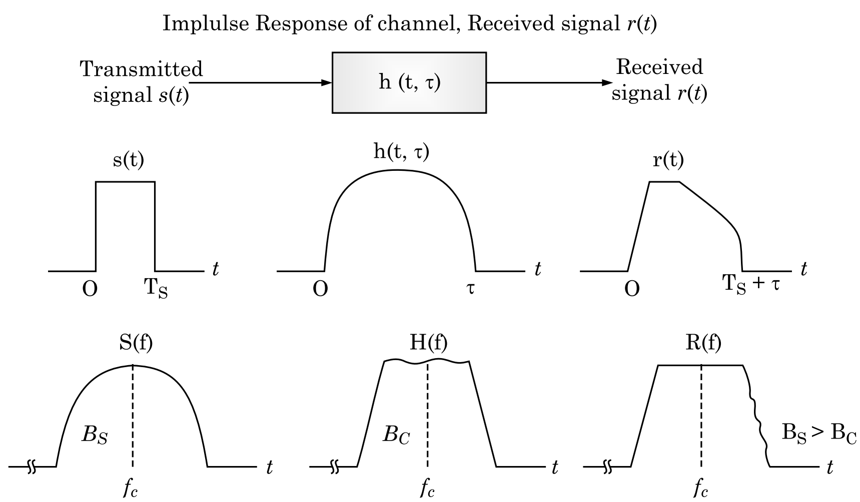
3.9.1 Comparision between Flat Fading and Frequency Selective Fading

S.No.	*Parameters*	*Flat Fading*	*Frequency Slective Fading*
1.	Channel characteristics	Based on multipath time delay spread.	Same as flat fading.
2.	Bandwidth	Bandwidth of signal is less than the bandwidth of channel ($B_S < B_C$)	Bandwidth of signal is greater than bandwidth of the channel ($B_S > B_C$)
3.	Delay vs. symbol period	Rms delay spread is much less than the symbol period ($\sigma_t << T_s$)	Rms delay spread is larger than the Symbol period ($\sigma_t > T_s$)
4.	Other names	Flat fading channels are also known as *amplitude varying channels* or *narrowband channels* because the bandwidth of applied signal is narrow than the band width of channel.	Frequency selective fading channels are also known as *wideband channels* because the bandwidth of applied signal is wider than the bandwidth of the channel.
5.	Modelling	Less difficult to model the multipath signal by channels.	More dificult to model the multipath signal by channels.
6.	Responsible for	Typical flat fading channels causes deep fades and may require 20 to 30 dB more transmitter power (at the time of deep faded) to achieve low bit error rates.	Frequency selective fading channels induces inter-symbol interference (ISI) because it occurs due to time dispersion of the transmitted symbols.
7.	Effect on received signal	In this fading, although the strength (gain) of the received signal changes with time but the spectrum of the transmission is preserved.	In this fading, the received signal gets distorted because it includes multiple versions of the transmitted wave form which are attenuated (faded) and delayed in time.

Fig. 3.9 shows channel characteristics for flat fading channel and frequency selective fading channel.



(a) Flat Fading Channel Characteristics



(b) Frequency Selective Fading Channel Characteristics

Fig. 3.9 *Different small scale fading characteristics based on multipath time delay spread.*

3.9.2 Comparision between Fast Fading and Slow Fading

S.No.	*Parameters*	*Fast Fading*	*Slow Fading*
1.	Channel characteristics	Based on doppler spread effect.	—Same—
2.	Channel variations	Channel variations are faster than baseband signal variations. Coherence time si time over which two received signals have a strong potential for amplitude correlation. OR Coherence time is statistical measure of time over which the channel response is essentially invariant. It shows the similarity of the channel response at different times.	Channel variations are slower than baseband signal variations.
3.	Coherence time*	Coherence time of the channel is smaller than the symbol period of the transmitted signal. $(T_C < T_S)$	Coherence time of the channel is greater than the symbol period of the transmitted signal. $(T_C > T_S)$
4.	Dispersion	Causes for frequency dispersion due to doppler spreading.	—Same—
5.	Doppler spread	Doppler spread of the channel is higher than the bandwidth of the baseband signal. $(B_D >> B_S)$	Doppler spread of the channel is much less than the bandwidth of the baseband signal. $(B_D << B_S)$
6.	Signal distortion	Signal distortion increases with increasing doppler spread.	Signal distortion decreases with decreased doppler spread.
7.	Data rates	Fast fading only occurs for very low data rates.	Slow fading only occures for very high data rates.

* Coherence time is the time over which two received signals have a strong potential for amplitude correlation or it is a statistical measure of time over which the channel response is essentially invarient. It shows the similarity of the channel response at different times.

3.10 THE FADING CHANNEL

In designing a communication system, the effect of multipath reception, noise and fading etc. is estimated on the mobile channel. In this analysis, the simplest channel model is *additive white gaussian noise* (*AWGN*). This model is good for space communication and coaxial cable transmission but it is not a good choise particularly in the mobile situation.

Rayleigh fading occurs when there are multiple indirect paths between transmitter (BS) to receiver (MS) and no direct line-of-sight path exist.

Rician fading is best characterizes where there is a direct LOS path exist in addition to a number of indirect multiple signal.

In general, the Rician Model is best applicable in an indoor environment whereas the Rayleigh model is for outdoor environment.

The channels can be characterized by a parameter K, which is–

$$K = \frac{\text{Power in dominent path}}{\text{Power in scattend path}}$$

If $K = 0$ (i.e. numerator is zero) $\Rightarrow$ channel is Rayleigh
and $K = \infty$ (i.e. denominator is zero) $\Rightarrow$ channel is AWGN.

3.11 STATISTICAL MODELS FOR MULTIPLE FADING CHANNELS

To observe the fading characteristics in channels, several statistical models are suggested. These are given as below:

1. Ossana's Model
2. Clarke's Model
3. Two-ray Rayleigh Fading Model
4. Saleh and Valenzuela Statistical Model
5. SIRCIM and SMRCIM indoor and outdoor statistical Model

Description of these models is given as follows:

3.11.1 Ossana's Model

- It was the first model to analyze fading characteristics presented by 'Ossana'.
- It was based on interference of wave reflected from randomly located buildings.

- It assumes the existence of direct path between the transmitter and receiver in suburban areas.
- This model is found inappropriate for urban areas where the direct path is always blocked by buildings or other obstacles.

3.11.2 Clarke's Model

- It is based on scattering and is widely used.
- It comprises a fixed transmitter and vertically polarized antenna.
- The field incident on the mobile comprise of 'N' azimuthal plane waves, each having equal average amplitude.
- Equal average amplitude is assumed at receiver (mobile) because the scattered components arriving at receiver will experience similar attenuation over small scale distances, in the absence of direct line-of-sighat (LOS) path.
- For the nth wave arriving at an angle θ_n to the x-axis at receiver, the doppler shift (f_{Dn}) is given by

$$f_{Dn} = \frac{v}{\lambda} \cdot \cos \theta_n \qquad \text{...(3.20)}$$

where v = Receiver (mobile) traveling velocity

λ = Wavelength of the incident wave

- Note that every wave that is incident on mobile undergoes a doppler shift due to the motion of the receiver.

3.11.3 Two-Ray Rayleigh Fading Model

- It is based on flat fading conditions and does no consider multipath time delay.
- A commonly used multipath model is an independent rayleigh fading two-ray model.
- The impulse response of this model,

$$h_b(t) = \alpha_1 \exp(j\phi_1)\ \delta(t) + \alpha_2 \exp(j\phi_2)\delta(t - \delta) \qquad \text{...(3.21)}$$

  where

  α_1 & α_2 = Rayleigh distributed coefficients

  ϕ & ϕ_2 = Independent and uniformly distributed phase over 0 and 2π.

  and τ = time delay between two rays.

- By varying τ, a wide range of frequency selective fading effects can be created.

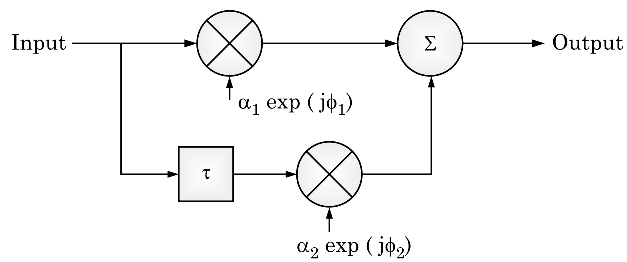


Fig. 3.10 *Two ray rayleigh fading model*

3.11.4 Saleh and Valenzuela Indoor Statistical Model

- This model involves arranging of square law detected pulse response while sweeping the frequency of the transmitted pulse.
- This method is able to resolve the multipath components within 5 ns.
- This model is developed for indoor channels based on multipath measurement.
- This model assumes that multipath components arrive in clusters.
- This formation of cluster is related to building structure while multipath components within the cluster are formed by multiple reflections from narby objects.

3.11.5 SIRCIM and SMRCIM Indoor and Outdoor Statistical Models

- This statistical model was developed to geneerate measured channels based on discrete impulse response channel model.
- A computer program is written for SIRCIM (Simulation of Indoor and Radio Channel Impulse response Model).
- SIRCIM generates realistic samples of small-scale indoor channel impulse response measurements.
- In this model by recording power delay profile impulse response at $\lambda/4$ intervals, the small scale fading of individual multipath components can be measured.
- Using similar statistical modeling techniques, urban cellular and microcellular multipath measurement data were used to develop SMRCIM (Simulation of Mobile Radio Channel Impulse response Model).

3.12 THEORY OF MULTIPATH SHAPE FACTORS FOR FADING WIRELESS CHANNELS

Shaping factors are used to characterize fading that occurs at receiver. These factors have simple, intuitive geometrical interpretations and are used to describe the statistics of received signal variatioins in fading conditions.

Due to fading, signal strength fluctuates at receiver side. This fluctuation may affect the receiver parameters such as equaliztion, diversity, dynamic range, modulation, error-correction coding etc. There may be two type of statistics to measure the receiver parameters.

3.12.1 First Order Statistics

It includes the measure of probability density function (pdf). The fading characteristics can be studied by examining the pdfs of the envelope and phase of received signal at any time. The fading characteristics depend on whether the transmitter and receiver are in line-of-sight (LOS) or not. The former case is called LOS scattering and the latter is referred to as NLOS scattering as shown in Fig. 3.11

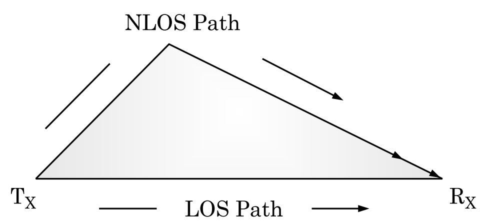


Fig. 3.11 *LOS and NLOS Scattering*

3.12.2 Second Order Statistics

It include the measure of level-crossing rate, average fade duration special autocovariance and coherence distance. All these factors are defined in section 3.13.

3.13 MULTIPATH SHAPE FACTORS

All the four second order statistics (discussed above) of small-scale fading may be described in terms of multipath shape factor theory. The shape factors are used in this theory that are related to the average rate at which a received signal fades. These factors are:

1. The angular spread (Λ)

2. The angular constriction (γ)

3. The azimuthal directioin of maximum fading. (θ_{max})

Detail of these shape factors is given below:

3.13.1 The Angular Spread (Λ)

It is a measure of how multipath concentrates about a single azimuthal direction of arrival.

$$\Lambda = \sqrt{1 - \frac{|F_1|^2}{F_0^2}} \qquad \text{...(3.22)}$$

where F_n is the nth complex fourier coefficient. The main *advantage* of this factor is that it is invarient for any change in transmitted power and for any series of reflective transformation of multipath power $P(\theta)$.

Maximum range of Λ

$$= \begin{cases} 1 \text{ (No clear bias in the angular distribution of received power.)} \\ \uparrow \\ 0 \text{ (Single multipath component from a single direction)} \end{cases}$$

3.13.2 The Angular Construction (γ)

It is a measure of how multipath concentrates about two azimuthal directions of arrival.

$$\gamma = \frac{|F_0 F_2 - F_1^2|}{F_0^2 - |F_1|^2} \qquad \text{...(3.23)}$$

where F_n is the nth complex fourier coefficient. The *advantages* of this factor is same as of angular spread (Λ).

Maximum range of γ

$$= \begin{cases} 1 \text{ (Two multipath components arriving from different directions.)} \\ \uparrow \\ 0 \text{ (No clear bias in two arrival directions)} \end{cases}$$

3.13.3 The Azimuthal Directionn of Maximum Fading (θ_{max})

It may correspond to the direction in which a mobile user would move in order to experience the maximum fading rate in the local area.

$$\theta_{max} = \frac{1}{2} \arg\left(F_0 F_2 - F_1^2\right) \qquad \text{...(3.24)}$$

3.14 SECOND ORDER STATISTICS USING SHAPE FACTORS

Second-order statistical measures may be redefined using different shape factors. Different second order statistics will now be in terms of the angular spread, the angular constriction and the azimwthal direction of maximum fading.

3.14.1 Level Crossing Rate (N_R)

The level crossing rate of flat fading channel is the expected number of times for which the channel amplitude fading level crosses the specified threshold with positive slope.

Level crossing rate incorporating the shape factors is given as:

$$N_R = \frac{\sqrt{2\pi}\, \upsilon \Lambda \rho}{\lambda} \sqrt{1 + \gamma \cos [2(\theta - \theta_{max})]} \exp(-\rho^2) \quad \ldots(3.25)$$

The normalized level crossing rate of flat rayleigh fading channel is shown in Fig. 3.12.

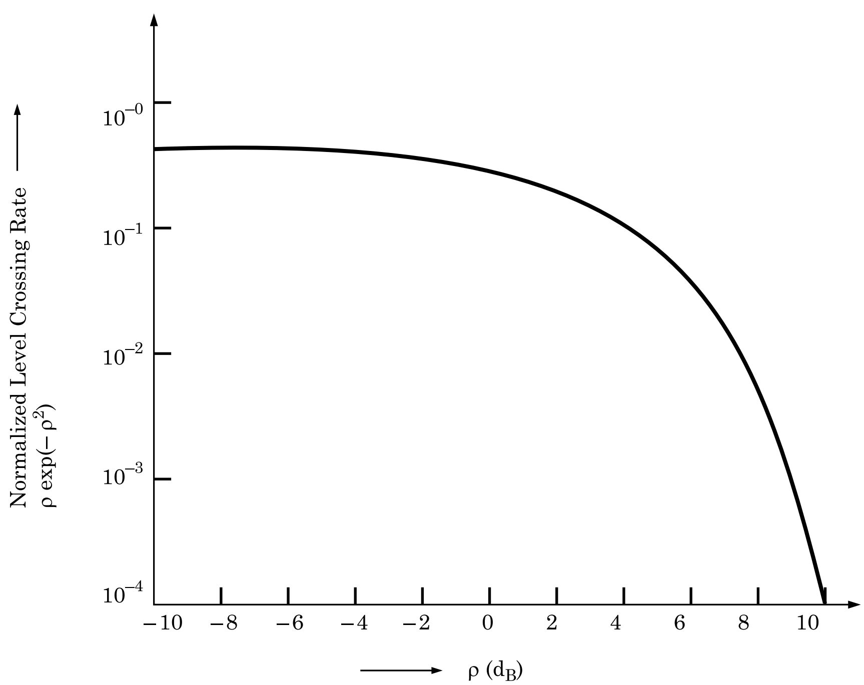


Fig. 3.12 *The normalized level crossing rate of flat Rayleigh Fading channel.*

3.14.2 Average Fade Duration ($\bar{\tau}$)

It is the average period of time for which the channel amplitude fading level is below the threshold level for each fade period. It is denoted as $\bar{\tau}$ and given as follows:

$$\bar{\tau} = \frac{\lambda\,[\exp((\rho^2) - 1]}{\sqrt{2\pi}\, \upsilon\, \Lambda\, \rho\, \sqrt{1 + \gamma \cos[2(\theta - \theta_{max})]}} \qquad ...(3.26)$$

The normalized average fade duration of the flat rayleigh fading channel is shown in Fig. 3.13.

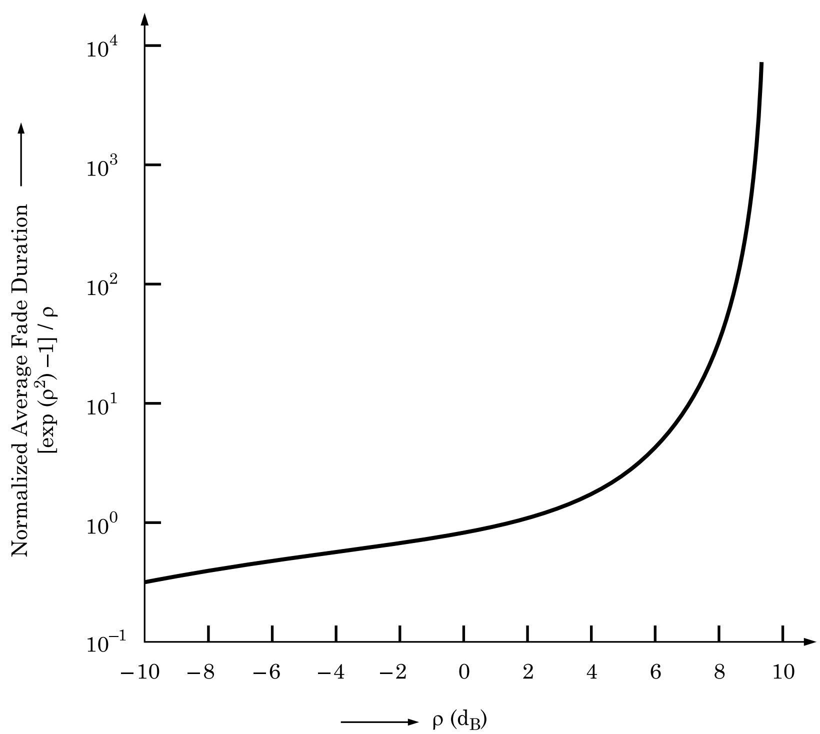


Fig. 3.13 *The normalized average fade duration of the flat Rayleigh Fading channel.*

3.14.3 Spatial Autocovariance ($\rho(r, \theta)$)

It is denoted by ρ and detemines the correlation of received voltage envelope in terms of change in receiver position.

$$\rho(r,\ \theta) \approx \exp\left[-23\Lambda^2\left(1+\gamma\cos\left[2\left(\theta-\theta_{max}\right)\right]\right)\left(\frac{r}{\lambda}\right)^2\right]^2 \quad ...(3.27)$$

where r is the distance two points in space and θ is the azimuthal direction of wave.

3.14.4 Coherence Distance (D_C)

Coherence distance is denoted by D_C and defined as the distance over which a fading channel appeares to be consant. The value of cherence distance in an ammidirectional Rayleigh channel is given by–

$$D_C \approx \frac{9\lambda}{16\pi} \quad ...(3.28)$$

It is used to determine the coherence time (T_C) of a mobile receiver. At T_C, a fading channel appears to be constant.

$$T_C = D_C \cdot v$$

where v is the velocity of the mobile.

SUMMARY

- The amplitude of received signal level fluctuates at receiver due to corruptive elements in propagation medium. This phenomenon is known as fading.
- Multipath fading is the fading that occurs due to multipath propagation.
- Multipath fading is also known as Rayleigh fading.
- The doppler shift depends on the velocity and direction of mobile motion with respect to the direction of arrival of multipath wave.
- Multipath measurement techniques are also known as sounding techniques.
- Impulse response of multipath channels is directly related to the small-scale variatiosn of a mobile radio signal.
- Impulse response is used to predict and compare the performance of many different mobile communication systems and transmission bandwidths.
- Different parameters of mobile multipath channels are derived in terms of power delay profile.
- Time dispersion is leaded by multipath delay.
- Frequency dispersion is leaded by doppler spread.
- First order and second order statistics are used to measure receiver parameters such as pdf, level crossing rate, average fade duration etc.
- Small scale fading is affected by speed of mobile, bandwidth of transmitted signal, multipath propagation and doppler shift.
- Absorption can be compensated by using higher gain antennas.
- The greater the amount of absorption of an RF signal, the higher the fading and the less geographic area covered.
- The PN sequence period provides an estimate of the maximum unambiguous range (MUR) of incoming multipath signal components.

$$\text{MUR} = \tau_{PN} \times C$$

where, C is speed of light.

REVIEW QUESTIONS

1. What are the main problems occured in signal propagation? What is the basic reason behind 'fading'?
2. List several factors that may affect fading. What are three reasons of signal fading in wireless communication?
3. Explain 'Rayleigh fading' in detail. Also mention the basic principle behind this fading.
4. How doppler shift occurs in multipath reception?
5. What are different techniques used for multipath measurement? How spread spectrum sliding correlator sounding technique is advantageous over direct pulse measurement technique?
6. Why, typically, impulse response of multipath channel is find out? Prove the impulse response model of a multipath channel.
7. Explain and derive different parameters of mobile multipath channels?
8. What are the different types of small scale fading? Give a comparision between flat fading and frequency selective fading.
9. Explain different parameters of fast fading. Show fading.
10. Explain two ray Rayleigh fading model in detail.
11. Is the shaping factors useful to characterize a wireless fading channel? What are the two different statistics to measure the receiver parameters?

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