UNIT-I

Large-Scale path loss :-

Line of sight: In free space, radio signals propagate as light (ie) they follow a straight line. If such a straight line exists btwn a sender and receiver it is called Los.

* The transmission path in mobile communication is severely obstructed by buildings, mountains and foliage.

Propagation Models: → To predict the average received signal strength at a given distance from the transmitter. As well as the variability of signal strength in close spatial proximity to a particular location → (Radio coverage area).

Large-Scale Propagation Models: Characterize the signal strength over large T-R separation distances.

Small-Scale or Fading Models: Characterize the rapid fluctuations of the received signal strength over very short travel distances.

Free Space Propagation Model :-

→ This model is used to predict received signal strength when unobstructed Los between tnx & Rx.

a) Los Propagation

* The free space power is, (received by receiver antenna):

$$\boxed{P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^2 L}} \rightarrow (1)$$

where

$P_r(d) \rightarrow$ Received power which is a function of T-R separation distance d

$P_t \rightarrow$ transmitted power

$G_t \rightarrow$ transmitter antenna gain

$G_r \rightarrow$ Receiver antenna gain

$d \rightarrow$ T-R separation distance in meters.

$L \rightarrow$ system loss factor $(L \geq 1)$

$\lambda \rightarrow$ wavelength in meters.

* $L=1$ indicates no loss in the system hardware.

Effective Area (or) Effective Aperture (or) capture Area:

* The effective area of an antenna can be defined as,

$$\boxed{A_{eff} = \frac{P_r}{P_D}} \rightarrow (2)$$

$A_{eff} \rightarrow$ Effective area of the antenna in m^2.

$P_r \rightarrow$ Power delivered to the receiver in watts

$P_D \rightarrow$ power density of the wave in W/m^2.

From (2), $P_r = P_D A_{eff} \rightarrow (3)$

Power density P_D is given by,

$$P_D = \frac{P_t G_t}{4\pi d^2} \rightarrow (4)$$

Sub. 4 in 3, we get,

$$P_r = \frac{A_{eff} P_t G_t}{4\pi d^2} \rightarrow 5$$

~~Sub. 5 in 2,~~

$$\cancel{A_{eff} = \frac{A_{eff} P_t G_t}{4\pi d^2 \, P_D}}$$

The effective area of a receiving antenna is,

$$A_{eff} = \frac{\lambda^2 G_r}{4\pi} \rightarrow 6$$

(The gain of an antenna is related to its Aeff by,

$$G_r = \frac{4\pi A_{eff}}{\lambda^2} \rightarrow 7$$

Also,

$$\lambda = \frac{c}{f} = \frac{2\pi c}{\omega_c} \rightarrow 8$$

where $\omega_c \Rightarrow$ carrier frequency in radians per second) X

Isotrophic Radiator: Its an ideal antenna Radiates power ~~uniformly~~ with unit gain uniformly in all directions. Used as reference antenna.

EIRP: Effective Isotropic Radiated Power of a transmitting system in a given direction is,

$$\boxed{EIRP = P_t G_t} \rightarrow 9$$

It represents the maximum radiated power available from a transmitter in the direction of maximum antenna gain, as compared to an isotropic radiator.

Attenuation (or)

<u>Path loss:</u> The path loss is defined as the difference (in dB) btwn the effective transmitted power and received power and may or may not include antenna gains.

Sub. (6) in (5)

$$\text{(5)} \Rightarrow P_r = \frac{A_{eff} P_t G_t}{4\pi d^2} \qquad \text{(6)} \Rightarrow A_{eff} = \frac{\lambda^2 G_r}{4\pi}$$

$$\therefore \quad P_r = \frac{\lambda^2 G_r P_t G_t}{(4\pi)^2 d^2}$$

$$\boxed{P_r = \frac{\lambda^2 P_t G_t G_r}{16\pi^2 d^2}} \rightarrow (10)$$

The path loss for free space model when antenna gains are included is given by,

$$PL\,(dB) = \log \frac{P_t}{P_r}$$

$$PL\,(dB) = \log \left[\frac{\cancel{P_t} (16\pi^2 d^2)}{\lambda^2 \cancel{P_t} G_t G_r} \right] \qquad (\text{on Sub. } (10))$$

$$= \log \left[\frac{1}{\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2}} \right]$$

$\log\left(\frac{1}{N}\right) = -10\log(N)$

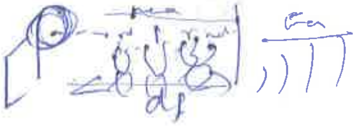
$$\boxed{PL\,(dB) = -10 \log \left(\frac{G_t G_r \lambda^2}{(4\pi)^2 d^2} \right)} \rightarrow (11)$$

when antenna gains are excluded, $G_t = G_r = 1$, then

$$\cancel{PL\,(dB) = 10 \log \frac{P_t}{P_r}}$$

$$\boxed{PL\,(dB) = -10 \log \left(\frac{\lambda^2}{(4\pi)^2 d^2} \right)} \rightarrow (12).$$

Far-field (or) Fraunhofer Region :-



* The far-field of a transmitting antenna is defined as the region beyond the far-field distance d_f, which is related to the largest linear dimension of the transmitter antenna aperture and carrier wavelength.

* The fraunhofer distance is,

$$d_f = \frac{2D^2}{\lambda} \longrightarrow (13)$$

where $D \Rightarrow$ largest physical linear dimension of the antenna.

* Far-field region, d_f must satisfy,

$$d_f \gg D \rightarrow (14.a)$$

$$d_f \gg \lambda \rightarrow (14.b)$$

Let d_o be the received power reference point.

$$d_o \geq d_f$$

* d_o is chosen in far-field region and it should be smaller than any practical distance used in mobile comm. system.

* The received power in free space at a distance greater than d_o is given by,

$$\boxed{P_r(d) = P_r(d_o)\left(\frac{d_o}{d}\right)^2 \quad d \geq d_o \geq d_f} \longrightarrow (15)$$

$10 \log \frac{P(mW)}{1mW} = P(dBm)$

(15) may be expressed in units of dBm or dBW. If P_r is in units of dBm,

$$\boxed{P_r(d)\,dBm = 10 \log\left[\frac{P_r(d_o)}{0.001W}\right] + 20 \log\left(\frac{d_o}{d}\right) \quad d \geq d_o \geq d_f} \rightarrow (16)$$

Three basic propagation Mechanisms :-

* Reflection * Diffraction * scattering.

Reflection:

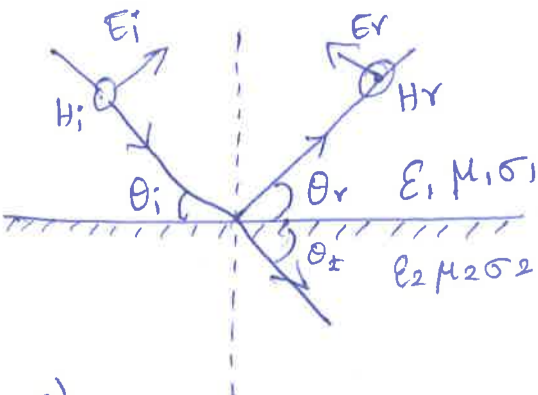
→ Object > wavelength of signal.

→ object with electrical properties – Partially reflect

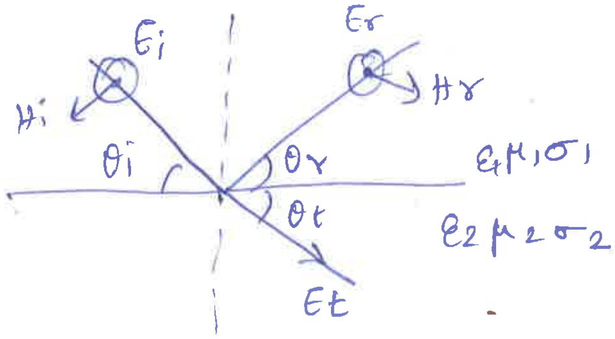
→ Perfect dielectric → no loss

→ Reflection co-efficient is a function of material properties and generally depends on the wave polarization, angle of incidence and the frequency of propagating wave.

Reflection from dielectrics:



a) E-field in the Plane of incidence.



b) E-field normal to the plane of incidence.

$$\Gamma_{\parallel} = \frac{E_r}{E_i} = \frac{\eta_2 \sin\theta_t - \eta_1 \sin\theta_i}{\eta_2 \sin\theta_t + \eta_1 \sin\theta_i}$$

$$\Gamma_{\perp} = \frac{E_r}{E_i} = \frac{\eta_2 \sin\theta_i - \eta_1 \sin\theta_t}{\eta_2 \sin\theta_i + \eta_1 \sin\theta_t}$$

Intrinsic Impedance: It is defined by the ratio of electric to magnetic field for a uniform plane wave in the particular medium.

$$\eta_i = \sqrt{\frac{\mu_i}{\varepsilon_i}}$$

By snell's law,

$$\sqrt{\mu_1 \varepsilon_1} \sin(90-\theta_i) = \sqrt{\mu_2 \varepsilon_2} \sin(90-\theta_t)$$

If $\mu_1 = \mu_2$,

$$\Gamma_{\parallel} = \frac{-\varepsilon_r \sin\theta_i + \sqrt{\varepsilon_r - \cos^2\theta_i}}{\varepsilon_r \sin\theta_i + \sqrt{\varepsilon_r - \cos^2\theta_i}}$$

$$\Gamma_{\perp} = \frac{\sin\theta_i - \sqrt{\varepsilon_r - \cos^2\theta_i}}{\sin\theta_i + \sqrt{\varepsilon_r - \cos^2\theta_i}}$$

Brewster Angle: Angle at which no reflection occurs in the medium of origin. It occurs when the incident angle θ_B is such that the reflection co-efficient $\Gamma_{\parallel}$ is equal to zero.

$$\sin(\theta_B) = \sqrt{\frac{\varepsilon_1}{\varepsilon_1 + \varepsilon_2}}$$

* when the first medium is free space and second medium has a relative permittivity ε_r,

$$\sin(\theta_B) = \sqrt{\frac{\varepsilon_r - 1}{\varepsilon_r^2 - 1}}$$

* Brewster angle occurs only for vertical polarization.

Reflection from perfect conductors:

$$\theta_i = \theta_r$$

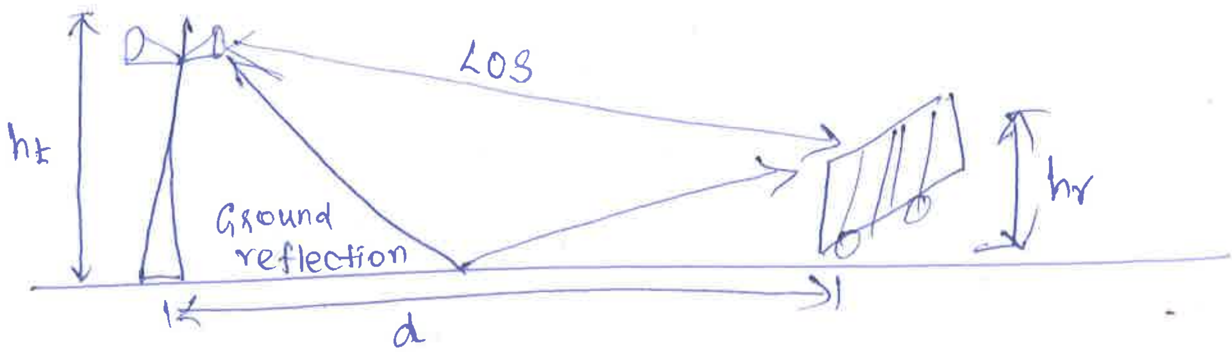
$$E_i = E_r$$

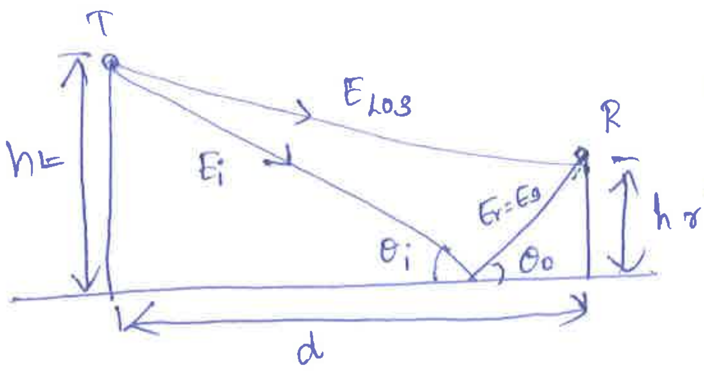
$$E_i = -E_r$$

For perfect conductor, $\Gamma_{\parallel} = 1$ & $\Gamma_{\perp} = -1$ regardless of incident angle.

Ground Reflection (Two-Ray) Model:

* The two-ray ground reflection model ~~that~~ is a useful Propagation model that is based on geometric optics and considers both the direct path and a ~~group~~ ground reflected Propagation path btwn transmitter and receiver.





$$\boxed{E_{TOT} = E_{LOS} + E_g}$$

where

$E_g \rightarrow$ Ground reflected component.

Here $h_t \rightarrow$ height of transmitter

$h_r \rightarrow$ height of receiver

$E_0 \rightarrow$ free space E-field at a reference distance d_0

$d_0 \rightarrow$ reference distance from transmitter.

For $d > d_0$, the free space propagating E-field is,

$$E(d,t) = \frac{E_0 d_0}{d} \cos\left(w_c\left(t - \frac{d}{c}\right)\right)$$

where, $|E(d,t)| = \frac{E_0 d_0}{d}$ represents the envelope of E-field at d meters from the transmitter.

* Two propagating waves arrive at the receiver :
  - → direct wave that travels a distance d'
  - → reflected wave that travels a distance d".

* The E-field due LOS component at the receiver can be expressed as,

$$E_{LOS}(d',t) = \frac{E_0 d_0}{d'} \cos\left(w_c\left(t - \frac{d'}{c}\right)\right)$$

* The E-field for ground reflected wave, which has a propagation distance of d", can be expressed as,

$$E_g(d'',t) = \Gamma \frac{E_0 d_0}{d''} \cos\left(w_c\left(t - \frac{d''}{c}\right)\right)$$

According to laws of reflection in dielectric,

$$\boxed{\theta_i = \theta_0 \;;\quad E_g = \Gamma E_i \;;\quad E_t = (1+\Gamma) E_i}$$

For small values of θ_i, $\Gamma_\perp = -1$ and $E_t = 0$;

$$\therefore |E_{TOT}| = |E_{LOS} + E_g|$$

$$\therefore E_{TOT}(d,t) = E_{LOS}(d',t) + E_g(d'',t)$$

$$\therefore E_{TOT}(d,t) = \frac{E_0 d_0}{d'} \cos\left(w_c\left(t - \frac{d'}{c}\right)\right) + \Gamma \frac{E_0 d_0}{d''} \cos\left(w_c\left(t - \frac{d''}{c}\right)\right)$$

$$= \frac{E_0 d_0}{d'} \cos\left(w_c\left(t - \frac{d'}{c}\right)\right) + (-1) \frac{E_0 d_0}{d''} \cos\left(w_c\left(t - \frac{d''}{c}\right)\right)$$

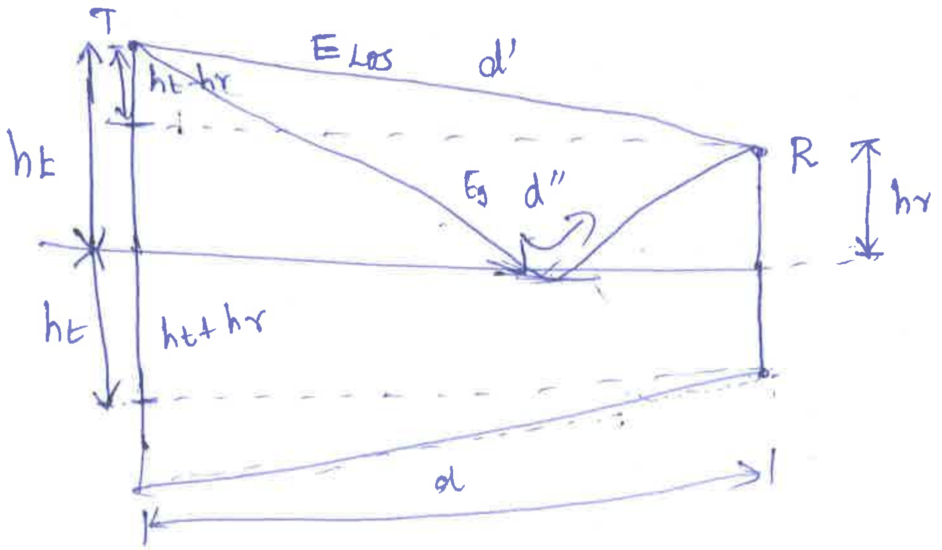
↳ (X)

Method of Images:

→ To find the path difference btwn LOS & ground reflected paths.

$$\therefore \quad \Delta = d'' - d'$$

$$\Delta = \sqrt{(h_t + h_r)^2 + d^2} - \sqrt{(h_t - h_r)^2 + d^2}$$



* When T-R separation distance d is very large compared to $h_t + h_r$, then by taylor series approximation,

$$\boxed{\Delta = d'' - d' \simeq \frac{2h_t h_r}{d}}$$

The phase difference $\theta_\Delta = \frac{2\pi\Delta}{\lambda} = \frac{\Delta w_c}{c}$ (or) $\Delta = \frac{\theta_\Delta c}{w_c}$ ↳ (1)

The time delay $\tau_d = \frac{\Delta}{c}$; → (2)

∴ Sub. 1 in 2,

$$\tau_d = \frac{\theta_\Delta \cancel{c}}{w_c \cancel{c}}$$

$$\boxed{\tau_d = \frac{\theta_\Delta}{2\pi f_c}}$$

when 'd' becomes larger,

$$\left|\frac{E_o d_o}{d}\right| \simeq \left|\frac{E_o d_o}{d'}\right| \simeq \left|\frac{E_o d_o}{d''}\right|$$

Sub. $t = \frac{d''}{c}$ in (*),

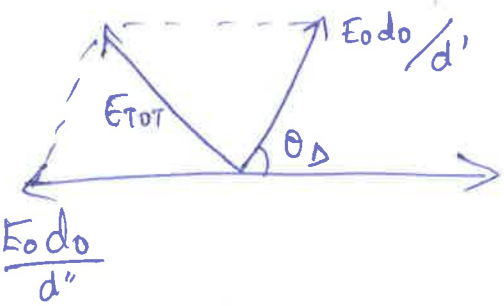
$$\therefore E_{TOT}\left(d, t = \frac{d''}{c}\right) = \frac{E_o d_o}{d'} \cos\left(w_c\left(\frac{d''-d'}{c}\right)\right) - \frac{E_o d_o}{d''} \cos 0^\circ$$

$$= \frac{E_o d_o}{d'} \angle\theta_\Delta - \frac{E_o d_o}{d''}$$

when $d \simeq d' \simeq d''$,

$$E_{TOT}\left(d, t = \frac{d''}{c}\right) \simeq \frac{E_o d_o}{d}\left[\angle\theta_\Delta - 1\right] \quad \& \quad \angle\theta_\Delta = \cos\left(w_c\left(\frac{d''-d'}{c}\right)\right)$$

The electric field at a distance 'd' from the transmitter is,



a) Phasor diag. showing total received E-fields.

$$|E_{TOT}(d)| = \sqrt{\left(\frac{E_o d_o}{d}\right)^2 (\cos\theta_\Delta - 1)^2 + \left(\frac{E_o d_o}{d}\right)^2 \sin^2\theta_\Delta}$$

$$\Rightarrow \frac{E_o d_o}{d}\sqrt{(\cos\theta_\Delta - 1)^2 + \sin^2\theta_\Delta}$$

$$\Rightarrow \frac{E_o d_o}{d}\sqrt{\cos^2\theta_\Delta + 1 - 2\cos\theta_\Delta + (1-\cos^2\theta_\Delta)}$$

$$= \frac{E_o d_o}{d}\sqrt{2 - 2\cos\theta_\Delta}$$

$$= \frac{E_o d_o}{d}\sqrt{2(1-\cos\theta_\Delta)}$$

$$\frac{1-\cos\theta}{2} = \sin^2\frac{\theta}{2}$$

$$= \frac{E_o d_o}{d}\sqrt{4\sin^2\frac{\theta_\Delta}{2}}$$

$$\boxed{|E_{TOT}(d)| = \frac{2E_o d_o}{d}\sin\left(\frac{\theta_\Delta}{2}\right)}$$

$\Rightarrow$ Provides exact received E-field for two way ground reflection model.

For simplification, $\sin\frac{\theta_\Delta}{2} \simeq \frac{\theta_\Delta}{2}$;

$$\therefore |E_{TOT}| = \frac{2E_o d_o}{d}\left(\frac{\theta_\Delta}{2}\right)$$

But $\frac{\theta_\Delta}{2} = \frac{2\pi h_t h_r}{\lambda d}$

$$\therefore \boxed{|E_{TOT}| = \frac{2E_o d_o}{d} \times \frac{2\pi h_t h_r}{\lambda d}}$$

$$E_{TOT} \approx \frac{K}{d^2}\ \frac{V}{m}$$ where $K = \frac{4\pi E_o d_o h_t h_r}{\lambda}$; (constant)

$\therefore$ The free space power received at d is related to the square of the electric field.

$\therefore$ The received power is,

$$\boxed{P_r = P_t G_t G_r \frac{h_t^2 h_r^2}{d^4}}$$

* For large distances ($d >> \sqrt{h_t h_r}$), the received power falls off with distance raised to the fourth power or at a rate of 40 dB/decade.

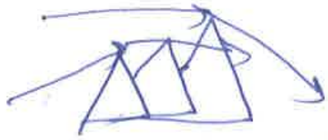
* The Path loss for two-ray model can be expressed in dB as,

$$\boxed{PL(dB) = 40 \log d - (10 \log G_t + 10 \log G_r + 20 \log h_t + 20 \log h_r)}$$

Diffraction:

* Diffraction occurs when the radio path between the transmitter and receiver is obstructed by a surface that has sharp irregularities (edges) and propagates in different directions.

→ ~~Fresnel zone geometry~~
→ Knife-edge diffraction Model
→ Multiple knife-edge diffraction.



Diffraction.

Scattering:

→ If the size of obstacles is in the order of the wavelength or less, then waves can be scattered.

→ Radar cross section Model.

Two main channel design issues:

1) Link budget design: It determines fundamental quantities such as transmit power requirements, coverage areas and battery life. It is determined by the amount of received power that may be expected at a particular distance (or) location from a transmitter.

Practical linkbudget design using path loss models:-

→ Radio propagation models can be derived by use of

i) Empirical Method :- collect measurement, fit curves.

ii) Analytical method :- Model the propagation mechanisms mathematically & derive equations for path loss.

Types:

Long distance path loss model:-

* As mobile user moves away from its base station, the received signal becomes ~~weakness~~ weaker because of the growing propagation attenuation with the distance.

* Let $\overline{PL}(d)$ denote the long distance path loss, which is a function of the distance 'd' separating the transmitter & receiver.

$$\overline{PL}(d) \propto \left(\frac{d}{d_o}\right)^n, \quad d \geq d_o \quad \longrightarrow (1)$$

or equivalently,

$$\overline{PL}(dB) = \overline{PL}(d_o) + 10 n \log\left(\frac{d}{d_o}\right) dB, \quad d \geq d_o; \quad \rightarrow (2)$$

n - Path loss exponent which indicates the rate at which path loss increases with distance.

d_o - reference distance which is determined from measurements close to the transmitter.

For given d_o, the value of $\overline{PL}(d_o)$ depends on the carrier frequency, antenna heights and gains.

* The bars in (1) & (2), denote the ensemble average of all possible path loss values for a given value of d.

* The value of n depends on the specific propagation environment.

Path loss exponents for different Environments:

Environment	Path loss exponent, n
Free space	2
Urban area cellular radio	2.7 to 3.5
Shadowed urban cellular radio	3 to 5
In building with LOS	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 6

* It is important to select d_0 that is appropriate for the propagation environment. In large cellular systems, 1 km reference distances are commonly used. In microcellular systems, much smaller distances (100m to 1m) are used.

Log-Normal Shadowing Path Model:

* Log-distance path loss model eqn does not consider the fact that the surrounding environmental cluster may be greatly different at two different locations having same T-R separation. This leads to measured signals which are vastly different than the average value predicted by (2).

* The path loss PL(d) at a particular location is random and distributed log-normally (normal in dB) about the mean-distance-dependent value.

$$\text{(ie)}\ PL(d)\,[dB] = \overline{PL}(d) + X_\sigma \Rightarrow \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right) + X_\sigma$$

And, $P_r(d)[dBm] = P_t[dBm] - PL(d)[dB]$

where $X_\sigma \Rightarrow$ zero-mean gaussian distributed random variable (in dB) with standard deviation σ.

Log-Normal Shadowing:- It describes the random shadowing effects which occurs over a large number of measurement locations which have the same T-R separation, but have different levels of cluster on the propagation path. This phenomenon is referred to as log-normal shadowing.

* $PL(d)$ is a random variable with normal distribution in dB about the distance-dependent mean, so is $P_r(d)$ and Q-function (or) error function may be used to determine the probability that the received signal level will exceed a particular level.

* The probability that the received signal level will ~~be~~ exceed a certain value γ can be calculated from the cumulative density function as,

$$P_r[P_r(d) > \gamma] = Q\left[\frac{\gamma - \overline{P_r(d)}}{\sigma}\right]$$

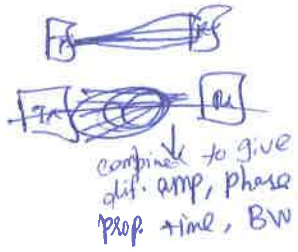
* Similarly the probability that the received signal will be below γ is given by,

$$P_r[P_r(d) < \gamma] = Q\left[\frac{\overline{P_r(d)} - \gamma}{\sigma}\right]$$

Outdoor propagation Models:-

Small-Scale Fading:- * Rapid fluctuations of amp, phase of multipath delays of radio signals over a short period of time.

* Caused by interference b/wn 2 or more versions of the tnx signal which arrive at the receiver at slightly different times. These waves are called multipath waves.



* These multipath waves creates the small-scale fading effects. They are

→ Rapid changes in signal strength over a small travel distance or time interval.

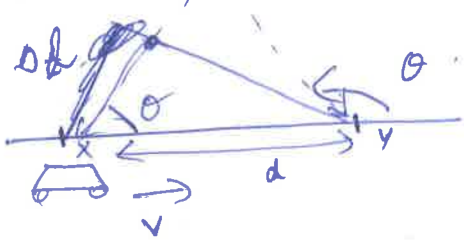
→ Random frequency modulation due to varying Doppler shifts on different multipath signals.

→ Time dispersion (echoes) caused by multipath propagation delays.

Doppler Shift:- Due to relative motion between the mobile and the base station, each multipath wave experiences an apparent shift in frequency. The shift in received signal frequency due to motion is called the doppler shift and is directly proportional to the velocity and direction of motion of the mobile with respect to the direction of arrival of the received multipath wave.

Change in phase due to diff. in path length is

$$\Delta\phi = \frac{2\pi \Delta l}{\lambda}$$



$$\Delta\phi = \frac{2\pi V \Delta t \cos\theta}{\lambda}.$$

$\Delta l = d\cos\theta$.

$\Delta l = V\Delta t\cos\theta$

Hence the apparent change in frequency or Doppler shift is,

$$f_d = \frac{1}{2\pi} \cdot \frac{\Delta\phi}{\Delta t}$$

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

$$\boxed{f_d = \frac{v}{\lambda} \cos\theta}$$

If the mobile is moving towards the source, then fd is positive. (~~fd is in~~ apparent received frequency is increased) & if it is moving away from the source, then fd is negative. ($f \downarrow$)

Parameters of mobile multipath channels:

→ Time dispersion parameters
→ coherence BW
→ Doppler spread & coherence time.

* Delay Profile is the expected Power per unit of time received with a certain excess delay.

Time dispersion Parameters:

* They are determined from power delay profile which gives the intensity of a signal received the MP chan as a func of time delay.

→ Includes mean excess delay, rms delay spread & excess delay spread.

→ Mean excess delay is the first moment of the power delay profile and is defined as,

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

where, $a_k \rightarrow$ amplitude, $\tau_k \rightarrow$ excess delay, $P(\tau_k)$ - Power of the individual multipath signals.

* The mean square excess delay spread is defined as,

$$\overline{\tau^2} = \frac{\sum P(\tau_k)\,\tau_k^2}{\sum P(\tau_k)}$$

* The rms delay spread is the square root of the second central moment of the power delay profile, it can be written as,

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

* As a rule of thumb, for a channel to be flat fading the following condition must be satisfied.

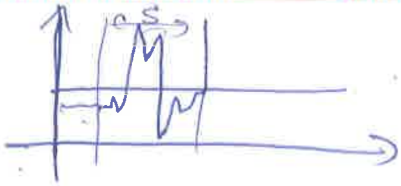
$$\frac{\sigma_\tau}{T_s} \leq 0.1$$

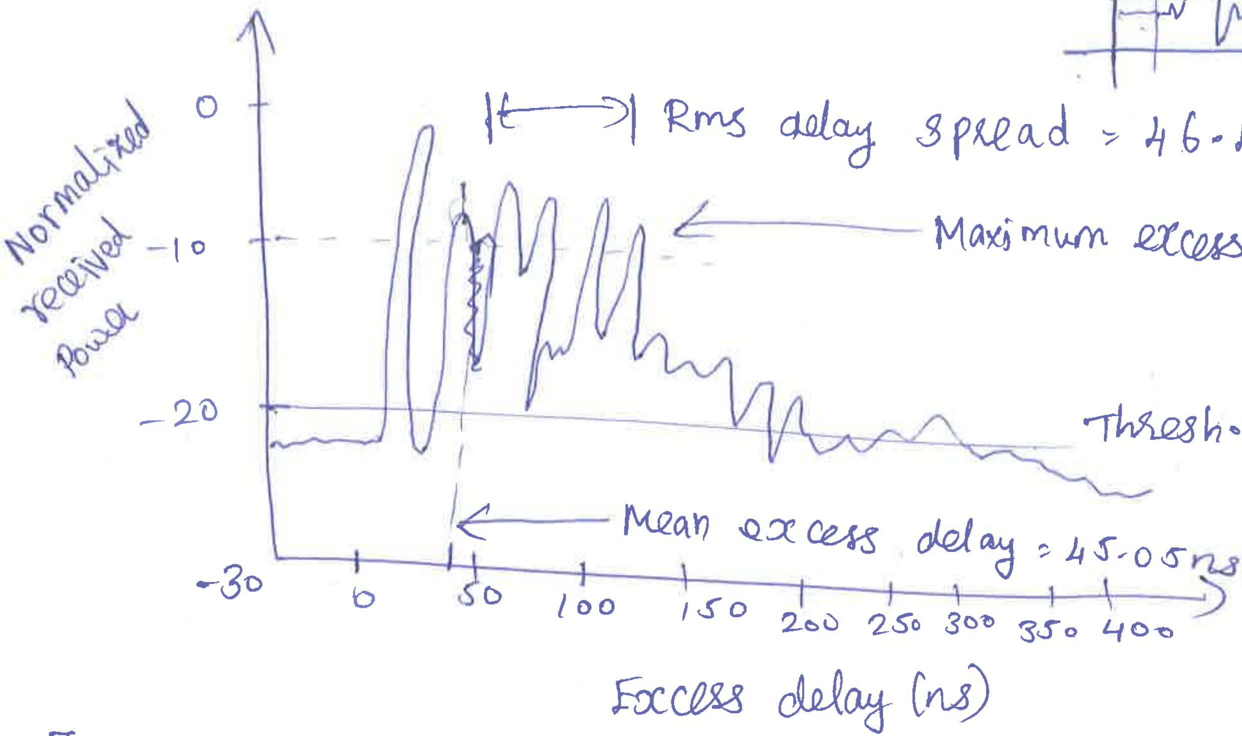
Where T_s is the symbol duration. For this case, no equalizer is required.

* The maximum excess delay (x dB) of power delay profile is defined to be the time delay during which multipath energy falls to x dB below the maximum. $(\tau_x - \tau_0)$

where, $\tau_0 \rightarrow$ first arriving multipath signal.

$\tau_x \rightarrow$ maximum delay at which a multipath component is within x dB of the strongest arriving multipath signal. [Also called excess delay spread]

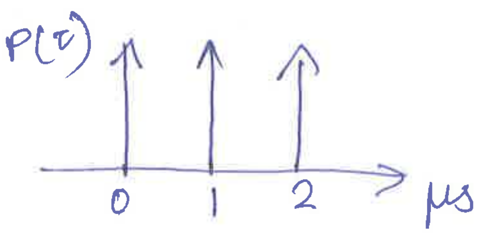




In practice, $\bar{\tau}$, $\overline{\tau^2}$ and σ_τ depends on the noise threshold used to process $P(\tau)$. The noise threshold is used to differentiate btwn received multipath components and thermal noise.

Pblm

Compute the rms delay spread for the following Power delay Profile :-



<u>Soln:</u>

$$\text{RMS delay } (\sigma_\tau) = \sqrt{\overline{\tau^2} - (\bar{\tau})^2}$$

where,

$$\bar{\tau} = \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)} = \frac{(1)(0) + 1(1) + 1(2)}{1+1+1} \Rightarrow \frac{3}{3} \Rightarrow 1\,\mu s.$$

$$\overline{\tau^2} = \frac{(1)(0)^2 + (1)(1)^2 + 1(2)^2}{1+1+1} \Rightarrow \frac{5}{3} \Rightarrow 1.6\,\mu s.$$

$$\sigma_\tau = \sqrt{1.6 - 1} \Rightarrow \sqrt{0.6} \Rightarrow 0.77\,\mu s.$$

Coherence Bandwidth :-

* (It is a statistical measure of the range of frequencies over which the channel can be considered flat. (ie.. a channel which passes all spectral components with approximately equal gain and linear phase)

* In other words, it is the range of frequencies over which two frequency components have a strong potential for amplitude correlation.

* Two sinusoids with frequency separation greater than B_c are affected quite differently by the channel.

* If the coherence bandwidth is defined as the bandwidth over which the frequency correlation function is above 0.9, the coherence bandwidth is,

$$\boxed{B_c \simeq \frac{1}{50\sigma_\tau}}$$

* If the frequency correlation function is above 0.5 then,

$$\boxed{B_c \simeq \frac{1}{5\sigma_\tau}}$$

Doppler spread :- (B_D)

* Doppler spread B_D is a measure of the spectral broadening caused by the time rate of change of the mobile radio channel and is defined as the range of frequencies over which the received Doppler spread is essentially non-zero.

* (When a pure sinusoidal tone of frequency f_c is transmitted, the received signal spectrum called the doppler spectrum, will have components in the range $f_c - f_d$ to $f_c + f_d$, where f_d is the doppler shift.)

* (The amount of spectral broadening depends on f_d, which is a function of the realative velocity of the mobile and direction of arrival of the scattered waves.

(ie) $$\boxed{f_d = \frac{v}{d} \cos\theta}$$)

* If the baseband signal bandwidth is much greater than B_D, the effects of doppler spread are negligible at the receiver. This is a slow fading channel.

Coherence Time: (T_c)

* (Coherence time T_c is used to characterize the time varying nature of the frequency dispersiveness of the channel in the time domain.

* The doppler spread and coherence time are inversely proportional to one another.

(ie) $$\boxed{T_c = \frac{1}{f_m}}$$)

* The coherence time is the time duration over which two received signals have a strong potential for amplitude correlation.

* If $\frac{1}{f_m} > T_c$, distortion occurs at the receiver.

* If the coherence time is defined as the time over which the time correlation function is above 0.5, then the coherence time is,

$$\boxed{T_c \simeq \frac{9}{16\pi f_m}}$$

where $f_m \rightarrow$ maximum doppler shift given by $f_m = V/\lambda$.

By the rule of thumb,

$$T_c = \sqrt{\frac{9}{16\pi f_m^2}} = \frac{0.423}{f_m};$$

* This defition implies that two signals arriving with a time separation greater than T_c are affected differently by the channel.

Types of Small scale Fading:

Signal parameters	channel param
BW, symbol period.	rms delay, Doppler spread.

Small Scale Fading
(Based on multipath time delay spread) → Time dispersion & ~~time~~ freq. selective fadding

Flat fading

a) BW of signal < BW of Channel

b) Delay spread < symbol period.

~~Slow fading~~ **Frequency selective Fading**

a) BW of signal > BW of channel

b) Delay spread > symbol period

Small Seal Fading
(Based on Doppler Spread) → (frequency dispersion & time selective fading)

Fast fading

1) High Doppler Spread
2) coherence time < symbol period
3) Channel variations faster than base-band sig. variations.

Slow fading

1) Low doppler spread
2) coherence time > Symbol period
3) Channel variations slower than baseband signal variations.

~~Flat~~ fading effects due to multipath time delay spread:

~~Fast~~ Flat Fading:- $B_S << B_C$, $T_S >> \sigma_\tau$;

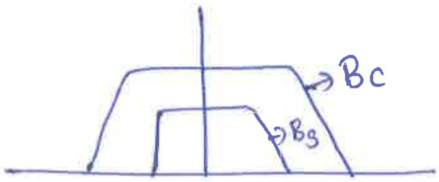
Fading:

Small-Scale Fading

- Based on Multipath time delay Spread
  - Flat Fading
  - Frequency selective Fading
- Based on Doppler Spread
  - Fast Fading
  - Slow Fading

Flat Fading

i) BW of signal < BW of channel.



ii) Delay spread < symbol period

iii) Sometimes called as narrow band channels as $B_s < B_c$.

iv) It causes deep fades and hence high transmitting power is required for non-fading channels.

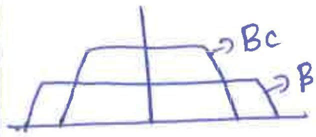
v) It follows Rayleigh distribution. Model.

vi) A signal undergo flat fading if

a) $B_s << B_c$; b) $T_s >> \sigma_\tau$.

Frequency selective Fading

i) BW of signal > BW of channel



ii) Delay spread > Symbol period

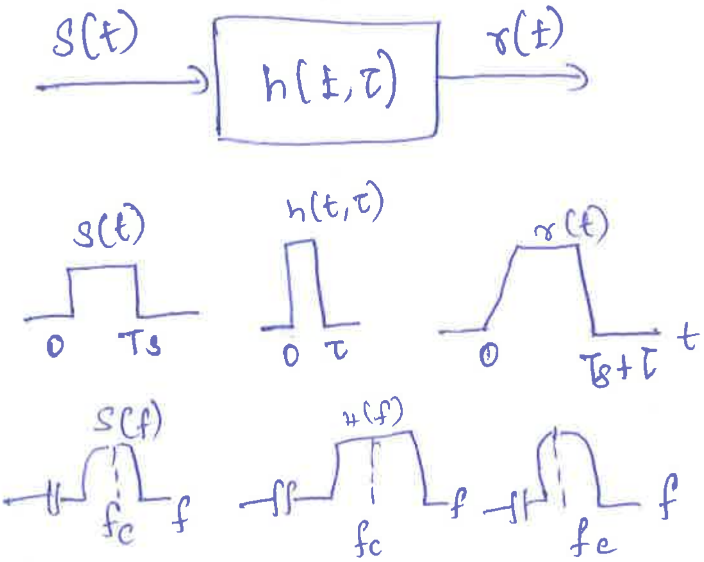
iii) ISI

iv) Also known as wideband channels, as $B_s > B_c$.

v) Distortion occurs in the received signal.

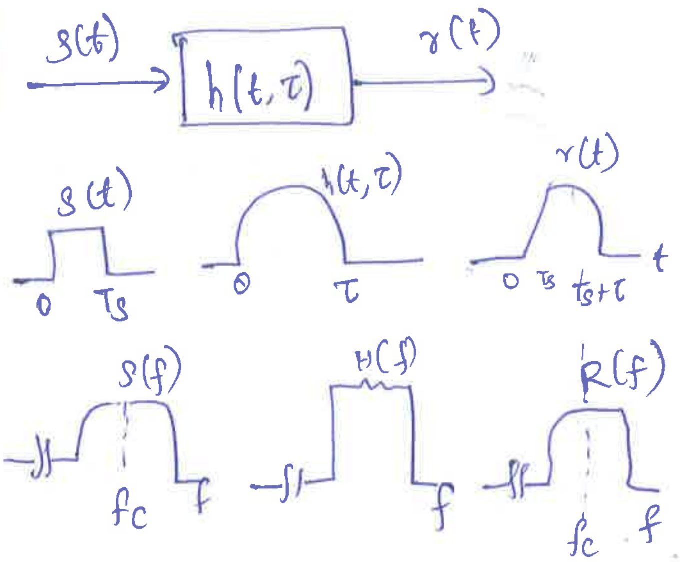
vi) It follows two-ray rayleigh distribution model.

vii) Spectral characteristics of transmitted signal is Preserved.



Condition:

$B_s > B_c$; $T_s < \sigma_T$.



Fast Fading

* The channel impulse response Changes rapidly within symbol duration.

(ie) $T_s > T_c$

* Coherence time of the channel is smaller than the symbol period of the transmitted signal (ie) $T_s > T_c$.

* (This causes frequency dispersion due to doppler spreading which leads to signal distortion)

Slow Fading

* The channel impulse response Changes at a rate much slower than the transmitted signal.

* coherence time larger than sym. period.

$T_s << T_c$

* Doppler spread of the channel is much less than the bw of the baseband signal.

$B_s >> B_D$.

* Signal distortion increases due to fast fading and increase in doppler spread.

(ie) $B_S < B_D$.

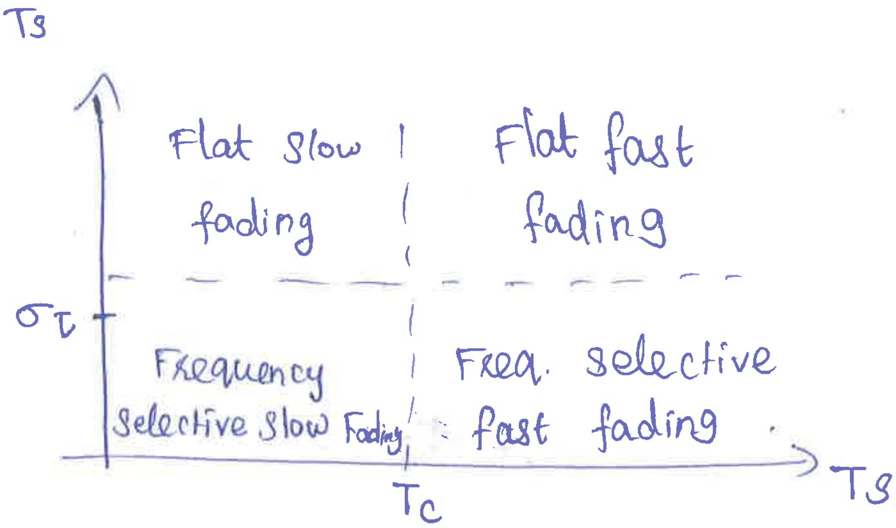
* Fast fading deals with the rate of change of channel due to motion.

* Flat fast fading channel is a channel in which the amplitude of the delta function varies faster than the rate of change of the transmitted baseband signal.

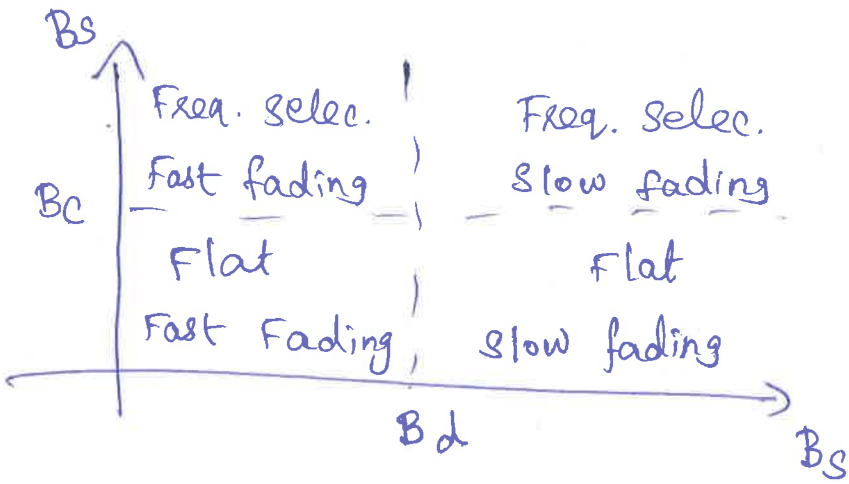
* In frequency selective fast fading channel, the amplitude, phase and time delays of any one of the multipath components vary faster than the rate of change of the transmitted signal.

* In practice, fast fading occurs for low data rates.

* In this case, the channel may be assumed to be static over one or several reciprocal bw intervals.



a) Fading experienced by a signal with respect to time.



b) Fading experienced with respect to BW.

Flat	Freq. selective.
$B_s < B_c$	$B_s > B_c$
$T_s > \sigma_\tau$	$T_s < \sigma_\tau$
Fast	slow.
$T_s > T_c$	$T_s < T_c$
$B_s < B_D$	$B_s > B_D$