Unit III

Fading - rapid fluctuations of amplitudes, Phases or multipath delays of a radio signal over a short period of time or travel distance so that large scale path loss effects may be ignored.

Multipath - Interference betwn two or more versions of the transmitted signal which arrive at the receiver at slightly different times
- multipath waves combine at receiver antenna to give a resultant signal that vary in amplitude & phase, depending on distribution of intensity and relative propagation time of the waves and bandwidth of txd signal.

Small scale Multipath Propagation:

- Rapid changes in signal strength over a small travel distance or time interval
- Random freq modulation due to Varying Doppler shifts on different multipath signals.
- Time dispersion Caused by multipath Propagation delays

In builtup Urban areas fading occurs because the height of the mobile antenna are well below surrounding structures

↳ No LOS - Even if LOS exist multipath still occurs due to reflections from ground & surrounding structures.

- Incoming radio waves arrive from diff directions with diff propagation delays
- received signal - consists of large no. of plane waves having randomly distributed amplitudes, Phases and angle of arrival
- Multipath components combine vectorially at the receiver's antenna - fade
- Even when Ms is stationary, recd signal fade due to movement of surrounding objects.

Objects are static - motion of mobile - fading is purely spatial phenomenon

signal variations of resulting signal are temporal as it moves through multipath field.

Due to constructive & destructive effects of multipath waves summing at various points, receiver moving at high speed pass through several fades in small period of time

receiver may stop at location of deep fade.

Antenna space diversity. prevent deep fading nulls.

Doppler shift: Due to relative motion betwn the mobile and the BS, each multipath wave experiences an apparent shift in frequency. directly $\propto$ to the velocity & direction of mobile with respect to direction of arrival of recd. multipath wave

Factors Influencing Small Scale Fading:

- Multipath Propagation - Presence of reflecting objects & scatterers in the channel
  random phase and amplitudes of diff multipath components cause fluctuations in SS
  Multipath lengthens time required for baseband portion of the signal to reach the receiver - Smearing of signal due ISI
- Speed of Mobile - Doppler shift +ve, -ve moving toward or away from BS. relative motion betwn BS and MS results in random freq mod.
- speed of surrounding objects $\Rightarrow$ induce time varying Doppler shift on multipath components.

  Surrounding objects move at a greater rate than mobile $\rightarrow$ effect dominates

  T_c - Staticness of channel - $\propto$ impacted by DS

- Transmission BW $\rightarrow$ Tx sig BW > BW of multipath channel recd signal will be distorted, but received signal will not fade much over a local area.

  $B_c \rightarrow$ measure of max. freq diff for which signals are still strongly correlated in amplitude

diff in path length traveled by wave from S to mobile at X and Y

$\Delta l = d\cos\theta = v\Delta t\cos\theta$

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

Δt - time reqd to travel from $X \rightarrow Y$

θ - same at X and Y

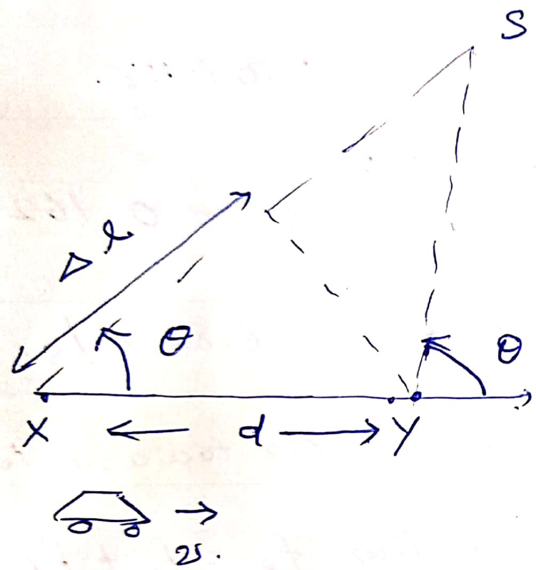
$f_d = \frac{v}{\lambda}\cos\theta$

Doppler Shift :

Consider a mobile moving at a constant Velocity v along a path segment length d between points X and Y, while it receives signal from a remote Source S.

Difference in Path length traveled by the wave from S to the mobile at points X and Y is $\Delta l = d\cos\theta$.

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



$\Delta t \rightarrow$ time required for the mobile to travel from X to Y

$\theta \rightarrow$ assumed to be the same at points X and Y since source is assumed to be very far away.

The Phase change in the received signal due to difference in path length is

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

and hence the apparent change in frequency or Doppler Shift is given by f_d.

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

This relates the doppler shift to the mobile Velocity and the spatial angle between direction of motion of the mobile.

if mobile moving towards the direction of arrival of wave f_d is positive, away it is negative.

Prob 1. Given a transmitter which radiates a sinusoidal carrier frequency of 1850 MHZ. For a vehicle moving at 60 kmph, calculate the received carrier frequency if the mobile is moving (i) directly toward the transmitter (ii) directly away from transmitter and in the direction which is perpendicular to the direction of arrival of the transmitted signal

Given carrier frequency $f_c = 1850\ MHZ$.

wavelength $\lambda = \frac{c}{f_c} = \frac{3\times10^8}{1850\times10^6} = 0.162\ m$.

Vehicle speed $= v = 60\ kmph = 26.82\ m/s$.

(i) The Vehicle is moving directly toward transmitter

f_d is positive received freq $f_0 = f_c + f_d$.

$$1850\times10^6 + \frac{3\times10^8}{1850\times10^6} = 1850.00016\ MHZ$$

(ii) The vehicle is moving directly away from transmitter

$f = f_c - f_d = 1849.99983\ MHZ$.

(iii) Vehicle is moving perpendicular to Angle of Arrival.

$\theta = 90^\circ$. $\cos\theta = 0$. There is no doppler shift.

Small Scale Multipath Measurements

Channel Sounding techniques.
Time / Freq domain

→ Direct pulse measurements – Narrow pulse to Probe
No Post processing Needed / IR is obtained directly

– Spread spectrum sliding Correlator
↳ PN Seq to spread and Correlator to obtain channel IR.

– Swept frequency.

I Direct Pulse :- Direct RF pulse system is used

- Allows to determine power delay Profile of any channel
- a wideband pulse bistatic radar – system transmits a repetitive pulse of width T_{bb} s, and uses a receiver with a wide BPF ($BW = 2/T_{bb}$ Hz)
- Signal is then amplified, detected with an envelope detector and displayed and stored on high speed Oscilloscope.

Recr set on averaging mode

$$|r(t_0)|^2 = \frac{1}{T_{max}} \int_0^{T_{max}} r(t) \times r^*(t)\, dt$$

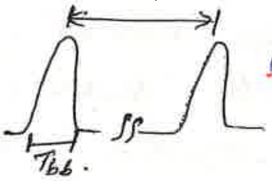
– local avg Power delay profile

↳ Square of channel IR convolved with the probing pulse.

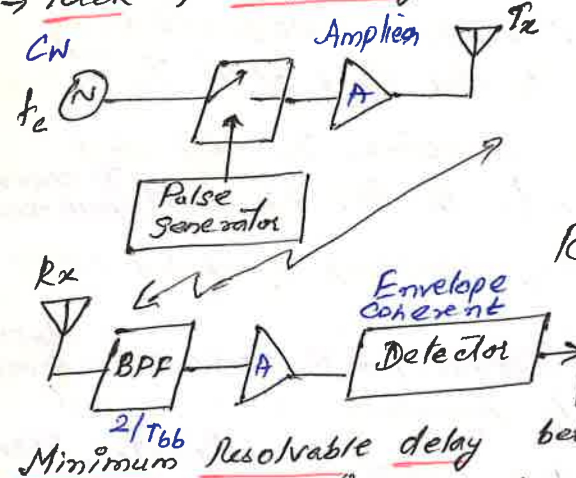
→ lack of complexity.

T_{REP} – Pulse repitition duration

Narrow pulses.
Indoor T_{rep} Small
Outdoor " large



Resolution = Pulse width



Minimum Resolvable delay betwn multipath Components is equal to probing pulsewidth T_{bb}.

drawback → it is subject to interference and noise due to wide passband filter required for multipath time resolution.

→ Pulse system relies on ability to trigger the Oscilloscope on the first arriving signal. If first arrival signal is blocked or fades severe fading occurs. and does not trigger properly

→ Phases of individual multipath component are not received due to the use of envelope detector (using coherent detector permits to measure multipath Phase)

Spread Spectrum Sliding Correlator Channel Sounding:

Probing pulse - Wideband Recr - Narrowband

Adv: while the probing signal may be wideband it is possible to detect the transmitted signal using narrowband Recr preceded by a wideband mixer, thus improving the dynamic range of the system

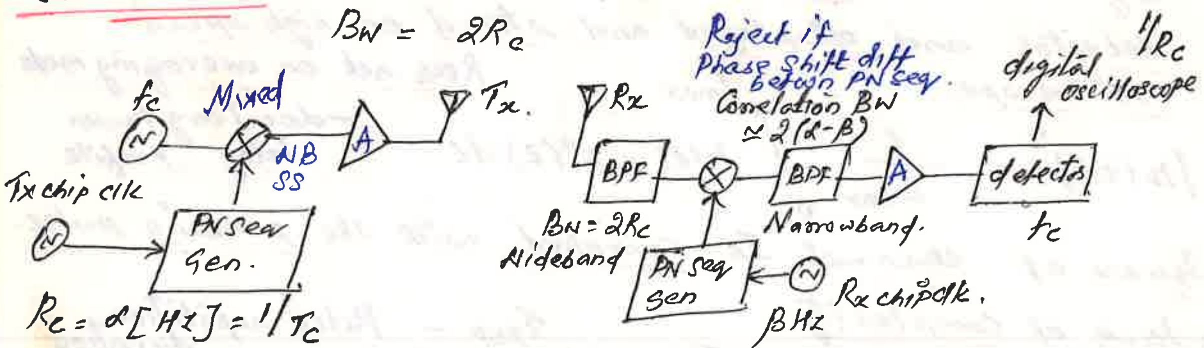
- A carrier signal is spread over a large BW by mixing it with a binary pseudo noise seq having chip duration T_c and chip rate $R_c = 1/T_c$ Hz   chip duration - Small Wideband

Power spectrum envelope of Txd spread spectrum signal is

$$S(f) = \left[\frac{\sin \pi (f-f_c) T_c}{\pi (f-f_c) T_c}\right]^2 = S_a^2 \left(\pi (f-f_c) T_c\right)$$

Null to Null BW

$$BW = 2R_c$$



- SS signal is then received, filtered, and despread using a PN seq generator identical to that used at the Tr.
- Even the two PN sequences are identical, Tr chip clock is run at a slightly faster than the Rr. chip clock (To ensure synchronization)
- Narrowband filter is eliminating much of passband noise and interference.
- When chip seq of faster clock rate catches up with slower one - Maximally correlated

Processing gain = gain achieved by processing a SS signal over an unspread signal $R_c = 1/T_c$, RFBW - $2R_c$

$$\frac{\text{BW of SS signal}}{\text{BW of Unspread} \text{ ''}} \quad \frac{(S/N)_{out}}{(S/N)_{in}} = \frac{2R_c}{R_{bb}} = \frac{2T_{bb}}{T_c}$$

$T_c \rightarrow$ chip Period

$T_b \rightarrow$ Period of BB info.

- Sliding correlator - for Synchronization

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Baseband information rate is equal to the frequency offset of the PN sequence clocks at Tr & Rr.

- When incoming signal is Correlated with recr. Seq the signal is collapsed back to orig. BW (despread)
- Different incoming multipaths will have diff time delays they will Correlate maximum with recr. PN seq. at diff Times
- Energy of these individual paths will pass through Correlator depending on time delay.

- Time resolution ($\Delta\tau$) of multipath Components using SS with sliding Correlation is

$$\Delta\tau = 2T_c = \frac{2}{R_c}$$

Better $\Delta\tau$ - more multipath will be resolved

- this gives equivalent time measurements that are Updated every time the Two Sequences are maximally Correlated.

Time betwn maximal Correlations $\Delta T = T_c \gamma l$

γ = Slide factor l - Seq length (Chips)

- Slide factor → ratio betwn $\frac{\text{Transmitter chip clock rate}}{\text{diff betwn Tx and Rx chip clk rates}}$

$$\rightarrow \gamma = \frac{\alpha}{\alpha - \beta}$$

α, β in HZ
Tr / Rr clock rate.

Maximal length Sequences: $l = 2^n - 1$

n - no. of shift registers in PN seq. gen.

Advantages:

(1) for a given P_T reject passband noise and interference improving coverage range - Receiver is narrowband, ↑ Coverage from same Tr
(2) Sensitivity is adjustable by changing the sliding factor and post Correlator filter BW Synchronization Problem Eliminated
(3) The required P_T < direct pulse due to PG of SSS.

Disadvantages:

(1) measurements are not made in real time - stored in oscilloscope
(2) Depending on System parameters & measurement objectives time required to make power delay profile is excessive
(3) Non Coherent detector is Used - Phases of individual multipath Components can not measured.

Only sliding process is over, measurements can be made

Frequency Domain channel Sounding:

dual relationship betwn time & frequency – channel IR in freq. domain

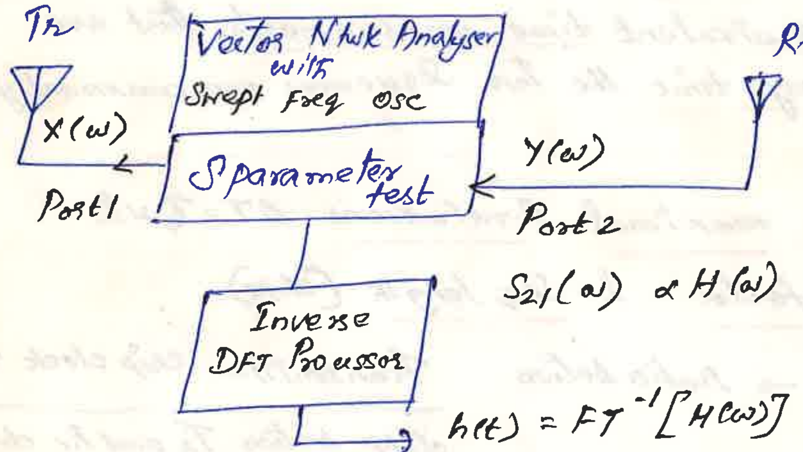
– measuring channel IR

– A vector network analyzer controls a synthesized freq sweeper.

– S parameter test set is used to monitor the freq response of the channel.

– freq sweeper scans a particular freq band by stepping through discrete freqs. / start & stop freq

– channel measurement for certain band.



$$S_{21}(\omega) \propto H(\omega) = \frac{Y(\omega)}{X(\omega)}$$

$$h(t) = FT^{-1}[H(\omega)]$$

– need to have synchronization betwn Tr & Rr. (cable losses)

– Not real time – IR.

– Lot of measurements needed for every step.

– for every freq point, channel changes averaging needed.

– Number and spacing of freq steps impact time resolution of IR

– Network analyzer determines the complex response $S_{21}(\omega)$ of the channel over the measured freq range.

– Transmissivity – freq domain representation of channel IR

– Response is converted to time domain by IDFT

Disadv: Post processing needed, System requires careful calibration

– hardwired synchronization betwn Tr & Rr → distance limited

– Indoor channels preferred

– Non real time – For time varying channels channel IR may change giving errors. / Use fast sweep time in order to keep freq response measurement as short as possible

↳ cost of fewer step sizes – poor time resolution

Impulse Response of Multipath channel

Small Scale Variations of a mobile related to IR of mobile radio Channel

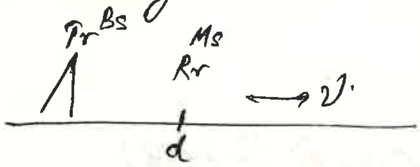
IR – wideband channel Characterization – Contains all info needed to simulate or analyze any type of radio Txn through the channel.

⇒ a mobile radio channel may be modeled as a linear filter with a time varying IR, time Variation due to receiver motion in space.

– filtering nature of channel – Summing of amplitudes and delays of the multiple arriving waves at any instant of time

– IR to predict and Compare the performance of many different mobile Commn. System and Txn Bw for a particular mobile channel condition.

– assuming time Variation due to receiver motion in space



receiver moves along the ground at some Constant velocity v.

For fixed position d, Channel betwn Tx & Rx can be modeled as LTI.

→ Due to diff. multipath waves – propagation delays which Vary over diff spatial locations of receiver,

IR of LTI channel should be a fn of position of the receiver.

Let $x(t)$ – Transmitted signal; $y(d,t)$ – Recd signal at position d

⇒ channel IR – $h(d,t)$

$$y(d,t) = x(t) \otimes h(d,t) = \int_{-\infty}^{\infty} x(\tau)\, h(d, t-\tau)\, d\tau. \quad -①$$

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

$$y(d,t) = \int_{-\infty}^{t} x(\tau)\, h(d, t-\tau)\, d\tau. \quad —②$$

Position of the receiver that is moving with a Velocity v

$$d = vt \quad -③$$

$$y(d,t) = y(vt,t) = \int_{-\infty}^{t} x(\tau)\, h(vt, t-\tau)\, d\tau \quad -④$$

Since v is a constant $y(vt,t)$ – fn of t.

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

↳ Shows that channel changes with time and distance

mobile ch. modeled as LT Varying as.

Since V - assumed constant over a short time (distance)

$x(t)$ represent transmitted Bandpass waveform.

$y(t)$ received waveform

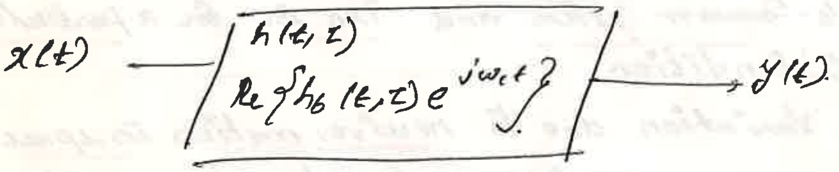
$h(t,\tau)$ IR of time varying multipath radio channel

IR $h(t,\tau)$ completely characterizes the channel and a fn of t and τ.

$t \rightarrow$ time variations due to motion

$\tau \rightarrow$ channel multipath delay for a fixed value of t

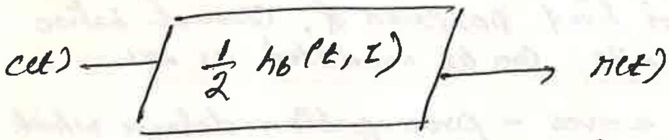
$$y(t) = \int_{-\infty}^{\infty} x(\tau)\, h(t,\tau)\, d\tau = x(t) \otimes h(t,\tau)$$



$y(t) = Re\{r(t)e^{j\omega_c t}\}$

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

Band pass channel IR.



$r(t) = c(t) \otimes \frac{1}{2} h_b(t)$

Baseband equivalent channel IR.

If multipath channel is assumed to be bandlimited

$h(t,\tau) \simeq$ complex baseband IR $h_b(t,\tau)$ with i/p & o/p being complex envelope representation of Txn & Red.

$c(t)$ and $r(t)$ – complex envelopes of $x(t)$ & $y(t)$

$$x(t) = Re\{c(t)\exp(j2\pi f_c t)\}.$$

$$y(t) = Re\{r(t)\exp(j2\pi f_c t)\}.$$

$\frac{1}{2} \rightarrow$ due to properties of complex envelope in order to represent passband at baseband.

Low pass characterization removes high freq variations caused by the carrier, making signal analytically easier to handle

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Couch showed that

⇒ average power of a bandpass signal $x^2(t)$ is equal to $0.5\,|c(t)|^2$ → Ensemble average or time average of deterministic signal.

→ Useful to discretize the multipath delay axis τ of impulse response in to equal time delay segments

⇒ Excess delay bins each bin has a time delay width equal to $\tau_{i+1} - \tau_i$ where $\tau_0 = 0$, represent first arriving signal at the receiver.

- $i=0$, $\tau_1 - \tau_0 = \Delta\tau$ – time delay bin width $\Delta\tau$

for clarity $\tau_0 = 0$

$\tau_1 = \Delta\tau$

$\tau_i = i\Delta\tau$ for $i = 0$ to $N-1$ N - total no. of possible equally spaced multipath components.

- Any no. of multipath signals received within ith bin are represented by a single resolvable multipath component having delay τ_i – Quantizing delay bins determines the time delay resolution of channel model and useful freq span of the model showed $2/\Delta\tau$

⇒ used to analyze transmitted RF signals with $BW < 2/\Delta\tau$

Excess delay – relative delay of ith multipath component as compared to first arriving 1 given by τ_i

Maximum Excess delay of the channel $= N\Delta\tau$

Received signal in a multipath channel consists of a series of attenuated, time delayed, phase shifted replicas of transmitted signal, Baseband IR of multipath channel

$$h_b(t,\tau) = \sum_{i=0}^{N-1} a_i(t,\tau) \exp\left[j(\underbrace{2\pi f_c \tau_i(t) + \phi_i(t,\tau)}_{\text{Phase shift}})\right] \delta(\tau - \tau_i(t))$$

$a_i(t,\tau)$ and $\tau_i(t)$ – real amplitudes and excess delays of ith multipath component at time t.

Wideband Probing signal $p(t)$ T_{bb} is smaller than the delays betwn multipath components in the channel.

→ Total recd power related to sum of powers in individual multipath components and is scaled by ratio of Probing pulse's width and amplitude and max. excess delay.

→ Assuming recd power from a multipath forms a random Process, with each component has a random amp & phase at t

Avg. Small scale P_r for wideband Probe

$$|r_0(t)|^2 = \frac{1}{\tau_{max}} \int_0^{\tau_{max}} \frac{1}{4} Re \left\{ \sum_{j=0}^{N-1} \sum_{i=0}^{N-1} a_j(t_0) a_i(t_0) p(t-\tau_j) p(t-\tau_i) \exp(j(\theta_j - \theta_i)) \right\} dt.$$

$$\Rightarrow E_{a,\theta}[P_{WB}] = E_{a,\theta}\left[\sum_{i=0}^{N-1} |a_i \exp(j\theta_i)|^2\right] \approx \sum_{i=0}^{N-1} \overline{a_i^2}$$

↳ Ensemble avg over all possible values of a_i and θ_i in local area, Overbar – Sample avg over a local measurement.

– If a Txd signal is able to resolve the multipaths, then the avg. Small scale P_r is sum of avg. P_r in each multipath.

– amplitude of individual multipath do not fluctuate in wideband.

II CW signal Txd to same channel, and let complex envelop be $c(t) = 2$. Instantaneous complex envelope of recd. signal is given by phasor sum.

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

$$\text{Power } |r(t)|^2 = \left| \sum_{i=0}^{N-1} a_i \exp(j\theta_i(t,\tau)) \right|^2$$

As recr is moved over a local area, channel induces changes on $r(t)$ and received strength vary at a rate governed by fluctuations of a_i and θ_i

a_i → Vary little over local area θ_i – greater variation ⇒ large $r(t)$

$r(t)$ – phasor sum of indiv. multipath components, large fluctuations

$$E_{a,\theta}[P_{CW}] = E_{a,\theta}\left[\left|\sum_{i=0}^{N-1} a_i \exp(j\theta_i)\right|^2\right].$$

$$= \sum_{i=0}^{N-1} \overline{a_i^2} + 2 \sum_{i=0}^{N-1} \sum_{i,j \neq i}^{N} r_{ij} \overline{\cos(\theta_i - \theta_j)}$$

↳ Path amplitude Correlation $= E_a[a_i a_j]$.

$\overline{\cos(\theta_i - \theta_j)} = 0$ or $r_{ij} = 0$, average power for a CW signal is equivalent to avg P_r for a wide band in a small scale region.

⇒ Occurs when either the multipath phases are identically and independently distributed over $[0, 2\pi]$ or when path amplitudes are uncorrelated.

⇒ Thus, received local ensemble P_r of wideband + narrow band signals are equivalent.

Txd signal has a BW >> BW of channel
multipath is completely resolved by received signal at any time ; P_r varies very little since indiv. comp. do not change rapidly over a local area.

→ << → large signal fluctuations occur at the Rx due to phase shifts of many unresolved multipath components.

Types of Small Scale fading

Multipath delay spread – Time dispersion – freq Selective

Doppler " – freq " – Time "

Fading effects due to Multipath Time Delay spread

Flat and Freq selective

Doppler spread → Fast / slow

Delay spread

Flat $B_S < B_C$

(1) BW of Signal < BW of channel

(2) Delay spread < T_S

$\sigma_\tau < T_S$.

Freq selective

(1) BW of signal > BW channel

(2) Delay spread > T_S

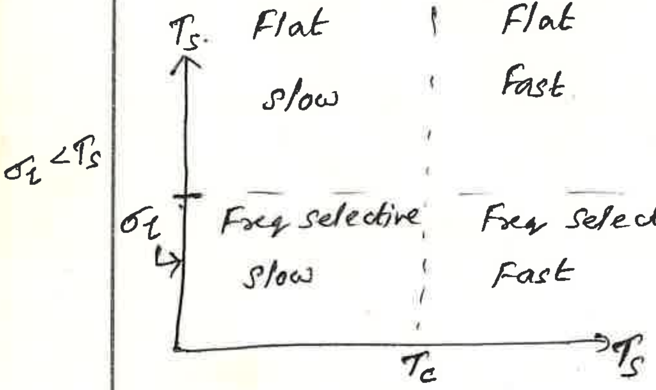
Doppler spread

Fast

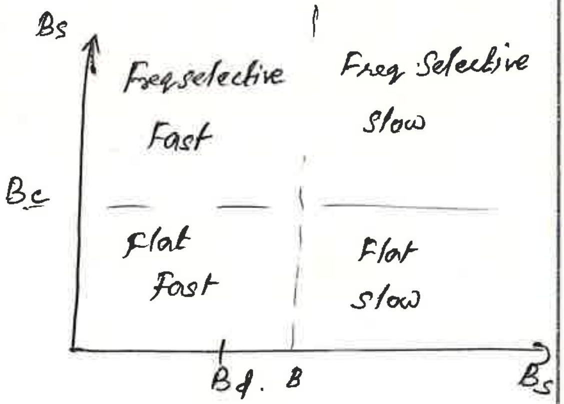
1. High B_D
2. $T_c < T_s$
3. channel Variations faster than Baseband signal Variations

Slow

1. Low B_D
2. $T_c > T_s$
3. channel Var. slower than signal Var.



Transmitted Symbol Period



Baseband Signal BW.

Points represent Prob. density, zeroth moment is the total Prob (1), first moment is mean, Second Central moment → Variance, IIIrd Central → skewness, 4th central moment – kurtosis

Parameters of Mobile Multipath Channels

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Multipath channel parameters are derived from power delay Profile. (represented as plots of P_r Vs excess delay with respect to fixed time delay reference).

- Power delay are found by averaging instantaneous Power delay measurements over a local area in order to determine an average small scale power delay profile.

- Depending on time resolution of probing pulse and the type of multipath channels studied researches choose to sample at spatial separations of $\lambda/4$ and over receiver movements $\leq 6m$ in outdoor and $\leq 2m$ indoor in 450 MHz – 6 GHz range.

I Time Dispersion parameters

Parameters that quantify multipath to compare different multipath

(i) - Mean Excess delay $\bar{\tau}$

(ii) rms delay spread σ_τ

(iii) Excess delay " (X dB).

} determined from single power delay profile which is temporal or spatial average of consecutive IR measurements collected & averaged over local area.

Time dispersive nature of wideband multipath commonly quantified by $\bar{\tau}$ and σ_τ

(i) Mean Excess delay : is the first moment of power delay

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

(ii) rms delay spread : Square root of second central moment of Power delay profile

μs - outdoor
ns - indoor

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

delays measured relative to first detectable signal arriving at receiver $\tau_0 = 0$. Eqns rely on relative amplitudes of multipath component within $P(\tau)$

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(iii) Maximum Excess delay (X dB) → is defined as the time delay during which multipath energy falls to X dB below the maximum.

$\tau_x - \tau_0$

τ_0 → first arriving signal

τ_x → max. delay at which multipath component is within X dB of strongest arriving multipath signal

X (dB)

→ Temporal extent of multipath that is > threshold.

τ_x — excess delay spread of power delay profile.

↳ must be specified with a threshold that relates the multipath noise floor to max. received multipath component.

* Values of $\bar{\tau}$, $\bar{\tau}^2$ and σ_τ depend on choice of noise threshold used to process $P(\tau)$

Noise threshold used to differentiate received multipath component & thermal noise.

if n_{th} too low → noise processed as multipath → $\bar{\tau}$, $\bar{\tau}^2$ and σ_τ → high.

Power delay and magnitude freq response are related through FT

Analogous to delay spread parameters in time domain

Coherence BW - characterize the channel in freq "

rms delay spread $\propto \frac{1}{B_c}$

- Possible to obtain an equivalent description of the channel in the freq. domain using its freq. response char.

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Coherence BW:

Delay spread is a natural phenomenon caused by reflected and scattered propagation paths in radio channel.

B_c → derived from rms delay spread.

→ Statistical measure of range of freq over which the channel is considered flat (Ch that passes all spectral components with equal gain + linear phase)

→ range of freqs over which two freq components have a strong potential for amplitude correlation.

– BW over which freq correlation fn is > 0.9

$$B_c \approx \frac{1}{50\sigma_\tau}$$

$$\approx \frac{1}{5\sigma_\tau}.$$

} Ball park estimates.

Exact relation betw B_c and σ_τ is a fn of specific ch IR & applied signals

Doppler spread & Coherence Time:

Time varying nature of the channel in a small scale region.

Doppler Spread B_D → Spectral broadening caused by time rate of change of mobile radio channel. range of freqs over which received doppler spectrum is non zero.

Baseband signal BW > B_D – negligible at recr.

Coherence Time : → Time domain dual of Doppler spread
To characterize time varying nature of freq dispersiveness of channel in time domain

$$T_c \approx \frac{1}{f_m} \qquad T_c = \frac{9}{16\pi f_m} \qquad f_m = v/\lambda$$

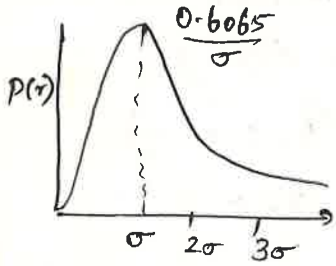
$$\approx \sqrt{\frac{9}{16\pi f_m^2}} = \frac{0.423}{f_m}$$

Statistical measure of time duration over which channel IR is invariant and quantifies similarity of channel response at diff times.

Rayleigh and Ricean Distributions:

Rayleigh - Used to describe the statistical time Varying nature of received envelope of a flat fading signal. or envelope of individual multipath Component.

- Envelope of sum of two quadrature gaussian noise signal obeys a Rayleigh Pdf



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

σ - rms Value of received Voltage signal before envelope detection

σ^2 - time avg Power of recd signal before Envelope detection

Probability the envelope of received signal does not exceed a Specified Value R is given by CDF

$$P(R) = P_r(r \le R) = \int_0^R p(r)\,dr = 1 - \exp\left(\frac{-R^2}{2\sigma^2}\right)$$

mean Value of Rayleigh $r_{mean} = E[r] = \int_0^\infty r p(r)\,dr = \sigma\sqrt{\frac{\pi}{2}}$

$= 1.2533\,\sigma$

Variance σ^2 = ac power in signal envelope

$$\sigma_r^2 = E[r^2] - E^2[r] = \int_0^\infty r^2 p(r)\,dr - \frac{\sigma^2\pi}{2}$$

$$= \sigma^2\left(2 - \frac{\pi}{2}\right) = 0.42929\,\sigma^2$$

rms Value of envelope = Square root of mean Square. $\sqrt{2}\sigma$

$$\frac{1}{2} = \int_0^{r_{median}} p(r)\,dr \qquad r_{mean} = 1.177\,\sigma.$$

Mean and median differ by 0.55dB
By using median Values it is easy to compare diff fading distributions which may have Varying means.

Ricean: there is a dominant stationary (nonfading) signal component present (LOS), small scale fading envelope is Ricean.

- random multipath components arriving at diff angles are superimposed on stationary dominant signal.
- At the output of envelope detector - effect of adding a dc component to multipaths.
- Effect of dominant signal with many weaker multipath signals. - dominant signal weakens - Rayleigh.

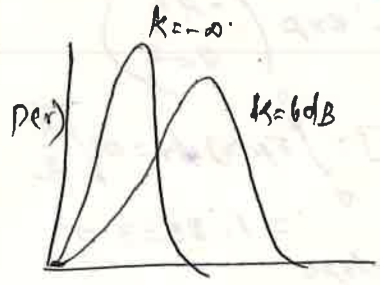
$$p(r) = \begin{cases} \dfrac{r}{\sigma^2} e^{-\frac{(r^2+A^2)}{2\sigma^2}} I_0\left(\dfrac{Ar}{\sigma^2}\right) & (A \geq 0, r \geq 0) \\ 0 & r < 0 \end{cases}$$

A - peak amplitude of dominat signal

I_0 - Bessel fn of first kind.

Ricean defined in terms of K - ratio betwn deterministic signal power and variance of multipath $A^2/2\sigma^2$

$K \to \infty$ $A \to 0$ degenerates $\to$ Rayleigh.



Small Scale Multipath Propagation

Important Effects

- Rapid changes in signal strength over a small travel distance or time interval
- Random frequency modulation due to Varying Doppler shifts on different multipath signal
- Time dispersion effects caused by multipath Propagation delays.
- Signal received by the mobile at any point in space consists of large no of plane waves having randomly distributed amplitudes, Phases and angles of arrival
- Combine Vectorially at the antenna - fade

Factors influencing Small Scale fading:

- Multipath propagation - reflection & Scattering lengthens the time required for baseband portion of the signal to reach the receiver
- Speed of mobile → relative motion betwn BS & MS random freq. modulation due to diff. doppler shift
- Speed of Surrounding objects - if Surrounding Objects move at a greater rate than mobile - dominates SSF coherence time - staticness of channel impacted by Doppler Shift.

- Transmission BW of the signal.

Signal BW > BW of multipath channel, received signal will be distorted.

Coherence BW – multipath structure of channel: measure of maximum frequency difference for which signal are still strongly correlated in amplitude