WIRELESS CHANNEL CHARACTERIZATION

- Wireless CHANNEL Model

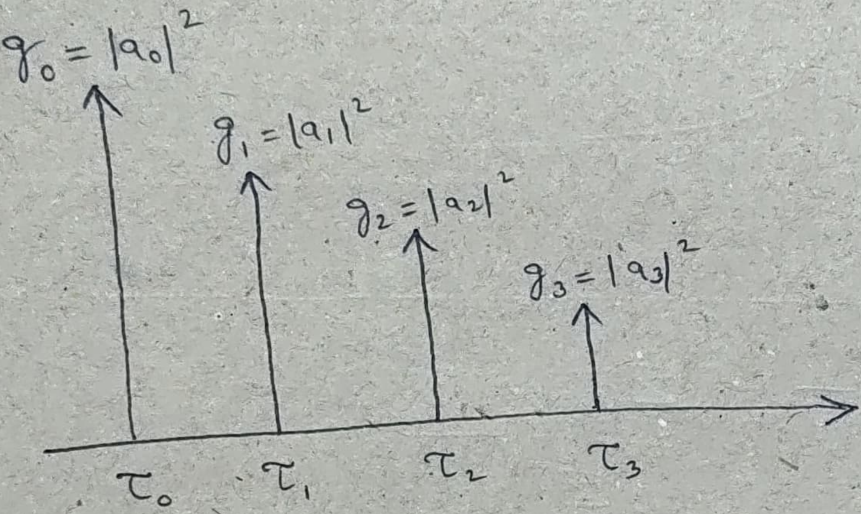
$$h = \sum_{i=0}^{L-1} a_i \, \delta(t - \tau_i)$$

Where,

$L \rightarrow$ No. of Multipath components

$a_i \rightarrow$ Attenuation of the i^{th} MP component

$\tau_i \rightarrow$ Delay of the i^{th} MP component



$g_i \rightarrow$ Gain of the i^{th} MP component

→ How many MP components ? 4

→ What is the LEAST DELAY ?

Earliest arriving component τ_0

→ What is the MAXIMUM DELAY ?

Last arrived component τ_3

The MP components are arriving over a <u>SPREAD OF TIME</u>. Or in otherwords, the delays are <u>SPREAD OVER TIME</u>. This is termed as <u>DELAY SPREAD</u>.

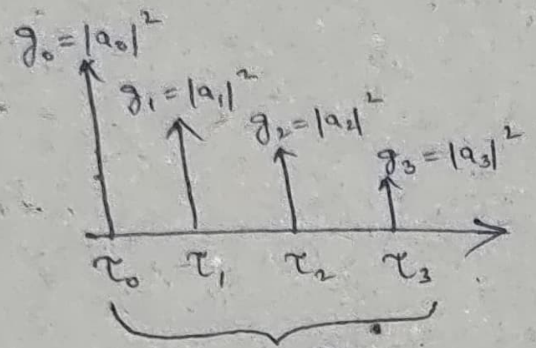
⊙ How to characterize the DELAY SPREAD ?

(i) Maximum Delay Spread

$$\boxed{T_{d,max} = \tau_{L-1} - \tau_0}$$

τ_0 : Delay of First arrived MP component

τ_{L-1} : Delay of Last arrived MP component



This spread of time is called as Maximum Delay Spread.

(ii) Root Mean Square (RMS) delay Spread

Let $\bar{\tau} = \dfrac{\sum_i g_i \tau_i}{\sum_i g_i}$

where $\bar{\tau}$ = Mean / Average of delays (or) Weighted average of delays

$$\boxed{T_{d,rms} = \sqrt{\frac{\sum_i g_i (\tau_i - \bar{\tau})^2}{\sum_i g_i}}}$$

where, $(\tau_i - \bar{\tau})^2 \rightarrow$ Square of the Weighted deviation

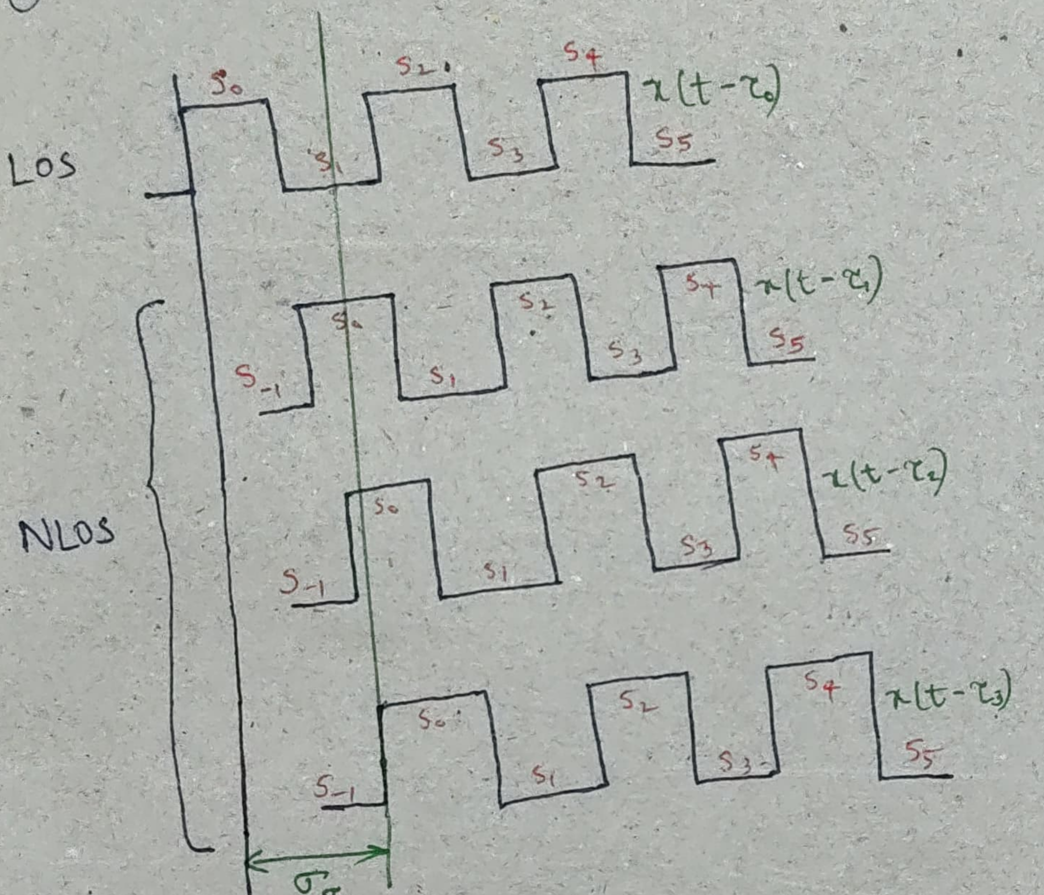
- What is the typical delay / delay spread in wireless channel?

$$\approx \frac{\text{Order of distances in the wireless channel}}{\text{Velocity of EM wave}} = \frac{1\ \text{km}}{3\times10^{8}\ \text{m/s}}$$

$$\approx 3.3\ \mu s.$$

$$\boxed{\text{Typical delay spread} \approx 2-3\ \mu s.}$$

- What is the IMPACT of delay spread?



$S_{-1}, S_0, S_1, S_2, S_3, S_4, S_5 \longrightarrow$ SYMBOLS

At receiver, different symbols Superpose / Adds up / gets aligned and interfere with each other.

Such large delay spread leads to Inter-Symbol Interference (ISI).

⊙ When does ISI occur?

Let $T_d \rightarrow$ Delay Spread

$T_s \rightarrow$ Symbol Time

* ISI occurs when $\boxed{T_d \geq \frac{1}{2} T_s}$

* In contrast, NO ISI when $T_d < \frac{1}{2} T_s$

Typically, Delay spread, $T_d = 2-3\ \mu s$.

Let us Set $T_d = 2\mu s$.

$$T_d \geq \frac{1}{2} T_s \Rightarrow T_s \leq 2 T_d$$

$$\Rightarrow T_s \leq 4\mu s$$

Therefore, we can say ISI occurs when $T_s \leq 4\mu s$.

⊙ No-ISI channel Model.

$$y(k) = h\, \underbrace{x(k)}_{\text{Current Symbol}} + n(k)$$

h → Single Channel coefficient

$y(k)$ depends only on current symbol

⊙ ISI channel Model.

L-1 Previous symbols

$$y(k) = h(0)\underbrace{x(k)}_{\text{Current Symbol}} + h(1)x(k-1) + \dots + h(L-1)x(k-(L-1)) + n(k)$$

L channel Taps

$$= h * x + n$$

$*$ → Linear convolution

$y(k)$ depends on the current symbol as well as the previous symbols.

⊙ Coherence Bandwidth (B_c).

We have, ISI occurs when $T_s \leq 4\mu s = 2T_d$

From Fig, we have,

Symbol Time, $T_s = \frac{1}{2 \times \frac{B}{2}} = \frac{1}{B}$

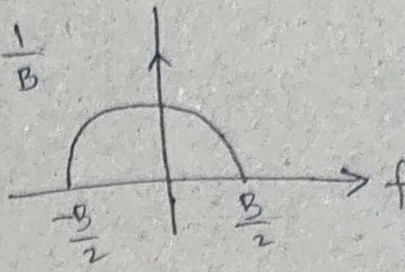


Fig. Single Carrier

$$\Rightarrow \frac{1}{B} \leq 4\mu s = 2T_d$$

$$\Rightarrow B \geq \frac{1}{2T_d} = \frac{1}{4\mu s} = 250 \text{ kHz} = B_c.$$

$\Rightarrow$ ISI occurs if $B \geq 250$ kHz.

This is termed as Coherence Bandwidth of Channel.

ISI occurs if

$$\left.\begin{aligned} T_d &\geq \frac{1}{2} T_s \\ B &\geq B_c = \frac{1}{2T_d} \end{aligned}\right\} \text{ Equivalent Conditions.}$$

One can define

$$B_c \approx \frac{1}{2T_d}$$

$$\Rightarrow B_c \propto \frac{1}{T_d}$$

(i.e.) Coherence Bandwidth is inversely proportional to Delay spread.

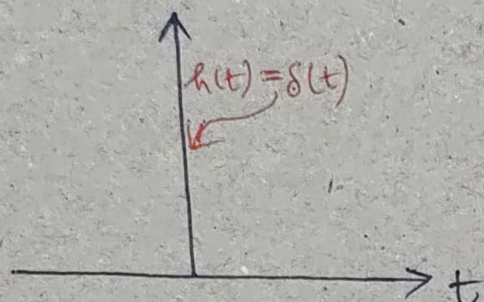
As Delay spread increases, coherence Bandwidth decreases.

CASE 1 : Delay spread $T_d = 0$

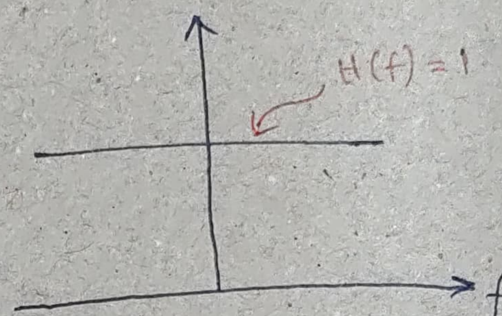
$\Rightarrow h(t) = \delta(t)$ ← IMPULSE IN TIME DOMAIN

Fourier Transform $|H(f)| = 1$

$\Rightarrow BW = B_c = \infty$



Time Domain



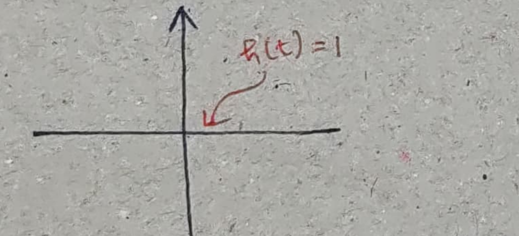
Frequency Domain

CASE 2 : Delay spread $T_d = \infty$

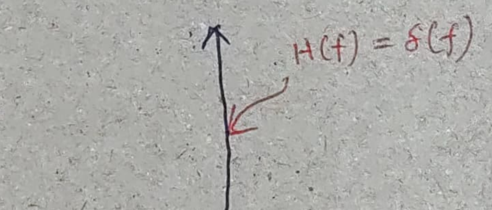
$\Rightarrow h(t) = 1$

Fourier Transform $|H(f)| = \delta(f)$ ← IMPULSE IN FREQUENCY DOMAIN

$\Rightarrow BW = B_c = 0$



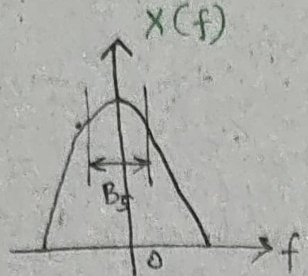
Time Domain



Frequency Domain

FREQUENCY DOMAIN INTERPRETATION of B_c

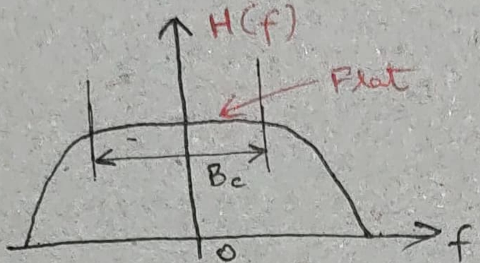
(i)



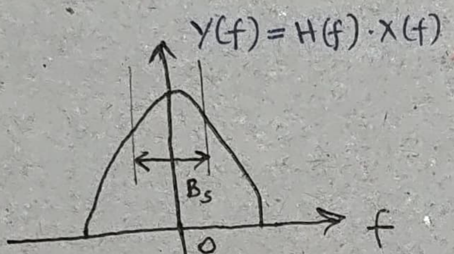
Input signal spectrum

$B_s \rightarrow$ Signal Bandwidth

$B_c \rightarrow$ Coherence Bandwidth



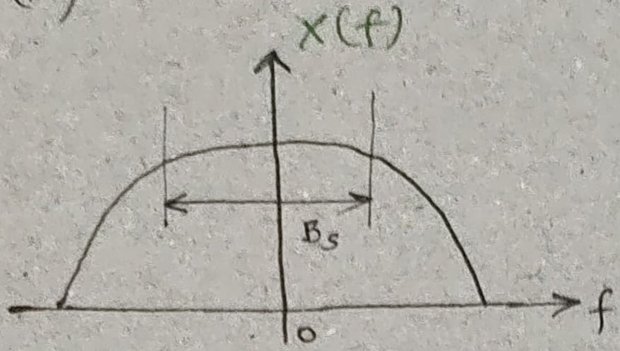
Wireless Channel Response



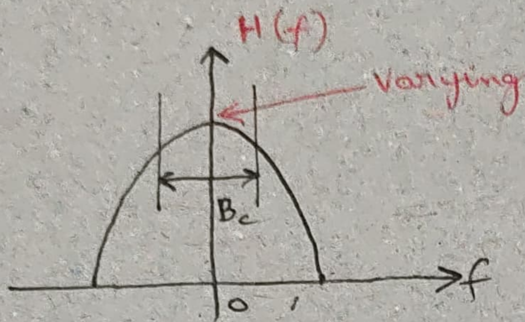
Undistorted Received Signal Spectrum.

- When $B_s < B_c$, Output spectrum is UNDISTORTED.
- Channel response is FLAT over signal bandwidth. Such a channel is termed as FLAT FADING. which implies NO ISI.

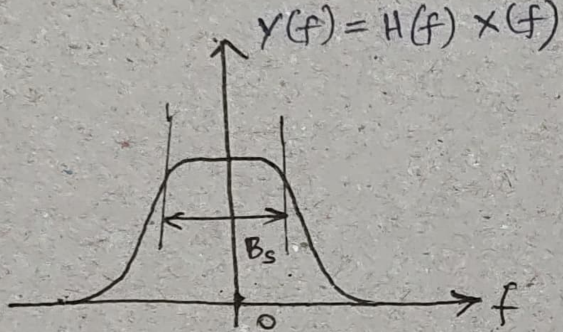
(ii)



Input Signal Spectrum



Wireless Channel Response



Distorted Received Signal Spectrum.

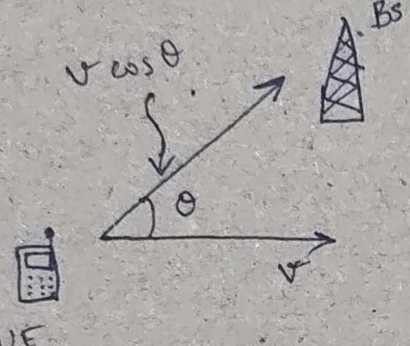
- When $B_s \geq B_c$, Output spectrum is <u>DISTORTED</u>.
- Channel response is <u>VARYING</u> over signal bandwidth. Such a channel is termed as <u>FREQ. SELECTIVE FADING</u> which implies <u>ISI</u>.

SUMMARY...

FLAT FADING	FREQUENCY SELECTIVE FADING
$T_d < \frac{1}{2} T_s$	$T_d \geq \frac{1}{2} T_s$
No ISI	ISI occurs
$B_s < B_c$	$B_s \geq B_c$
Output spectrum is UNDISTORTED	Output spectrum is DISTORTED
Output depends only on current input symbol $y(k) = h x(k) + n(k)$	Output depends on current input symbol as well as previous input symbols $y(k) = h(0) x(k) + h(1) x(k-1) + \dots + h(L-1) x(k-(L-1)) + n(k)$

DOPPLER SHIFT

When the UE is moving towards / away from the BS, there is a change in the frequency, which is termed as the DOPPLER SHIFT.



$$\boxed{f_D = \frac{v\cos\theta}{c} \times f_c}$$

where,

$\theta \rightarrow$ Angle between velocity & Line joining UE to BS

$v \rightarrow$ Velocity of UE

$c \rightarrow$ Velocity of Light

$f_c \rightarrow$ Carrier frequency.

When $\theta = 0^\circ$, f_D = Positive Maximum

$\theta = 90^\circ$, $f_D = 0$

$\theta = 180^\circ$, f_D = Negative Maximum

EXAMPLE

Consider a vehicle moving at 60 Kmph. at an angle of $\theta = 30^\circ$ with Carrier frequency of $f_c = 2$ GHz. Compute the Doppler shift of the received signal.

$$f_D = \frac{v\cos\theta}{c} f_c$$

$$= \frac{60 \times \frac{5}{18} \times \cos 30^\circ}{3 \times 10^8} \times 2 \times 10^9$$

$$= 96.22 \text{ Hz}$$

IMPACT OF DOPPLER SHIFT ON CHANNEL

As the UE moving towards / away from the BS, the distance b/w them decreases / increases respectively. And the delay also decreases / increases respectively.

(ie) Delay becomes function of time.

Consider the path i.

The Time varying delay $\tau_i(t)$ is given by

$$\tau_i(t) = \frac{d_i - (v\cos\theta)t}{c}$$

where, $d_i \rightarrow$ Original distance

$(v\cos\theta)t \rightarrow$ New distance

The Time varying channel $h(t)$ is given by

$$h(t) = \sum_{i=0}^{L-1} a_i\, \delta(\tau - \tau_i(t))$$

$$= \sum_{i=0}^{L-1} a_i\, \delta\left(\tau - \frac{d_i - v\cos\theta\, t}{c}\right)$$

Because of Doppler, Channel is time-varying!

This is termed as TIME SELECTIVE CHANNEL.

Therefore, Doppler is leading to a TIME SELECTIVE CHANNEL.

⊙ How fast is channel varying?

Let T_c denote the time over which channel is constant. This is termed as the

COHERENCE TIME. (T_c).

$$T_c = \frac{1}{4 f_D} \propto \frac{1}{f_D}$$

(i.e.) Coherence Time is inversely proportional to Doppler shift.

From the previous example, we have $f_D = 96.22\,Hz$

$$\Rightarrow T_c = \frac{1}{4 \times 96.22\,Hz} = 2.6\,ms$$

(i.e.) Channel is approximately constant for 2.6 ms.

INFERENCE.

- Higher the velocity, higher would be the Doppler shift, since $f_D \propto v$
- This implies
  - Channel is changing FASTER
  - Channel is constant over a very small period of time
  - Coherence Time is SMALL!

⊙ Doppler Bandwidth (B_D)

$$B_D = 2 f_D$$
$$= 2 \times 96.22 \text{ Hz}$$
$$= \underline{\underline{192.44 \text{ Hz}}}.$$

WKT,

$$T_c = \frac{1}{4 f_D}$$
$$= \frac{1}{2 B_D} \propto \frac{1}{B_D}.$$

(ii) Coherence Time is inversely proportional to Doppler Bandwidth.