Parameters of Mobile Multipath Channels

- **meaning:** characterizing a mobile environment as well as a channel which has multipath components.
- Many multipath channel parameters are derived from the Power Delay Profile (PDP). Because PDP gives the intensity of a signal received through a multipath channel as a function of time delay.
- The time delay is the difference in time travel between multipath arrivals.
- PDP of multipath channel is mathematically expressed as:

$$|r(t_0)|^2 = \frac{1}{\tau_{max}} \int_0^{\tau_{max}} \frac{1}{4}\left(\sum_{k=0}^{N-1} a_k^2(t_0)\, p^2(t-\tau_k) \right) dt$$

received Power

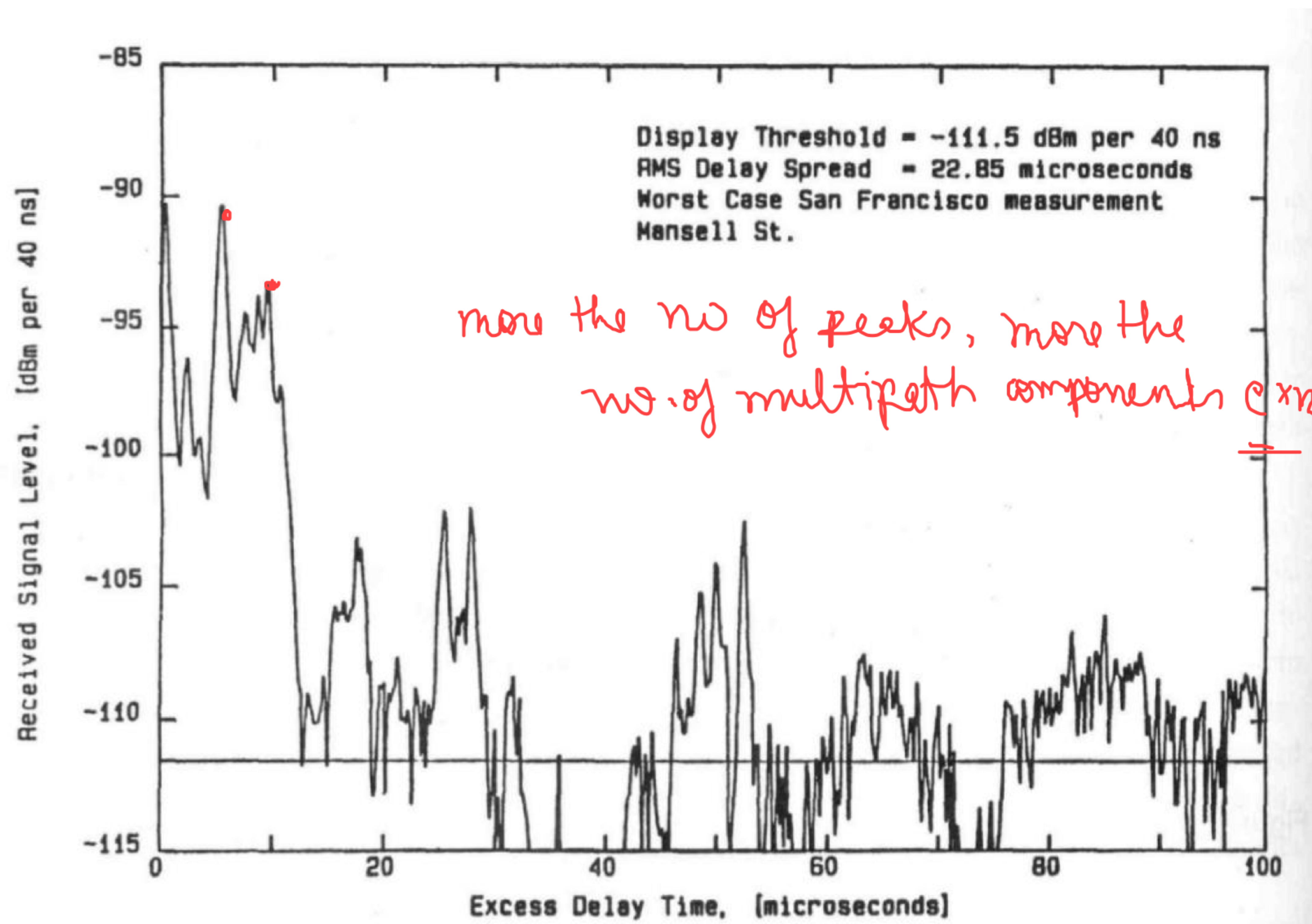
amplitude.
p → Power of each and every signal

- Power delay profiles are measured using the following techniques:
  - ❖Time Dispersion Parameters (related to time domain analysis of the channel)
  - ❖Coherance Bandwidth → frequency domain
  - ❖Doppler Spread and Coherance Time → represent mobile nature of the transmitter and Rx.

Parameters of Mobile Multipath Channels

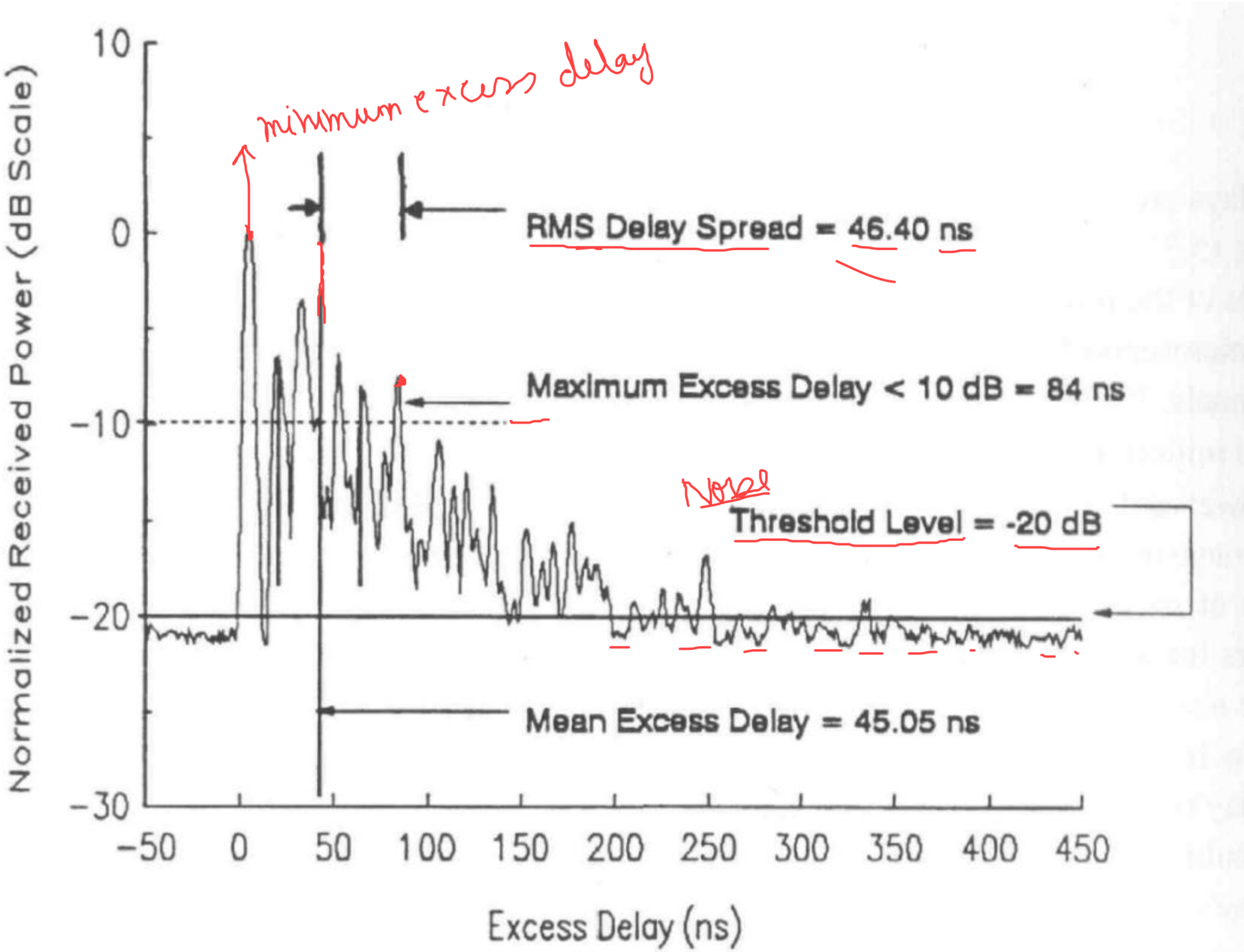
Power delay profile are generally represented as the plots of Relative received power as a function of Excess delay with respect to fixed time delay reference.

A typical power delay profile of Outdoor Channel is depicted in the below figure:



more the no of peaks, more the no. of multipath components exist

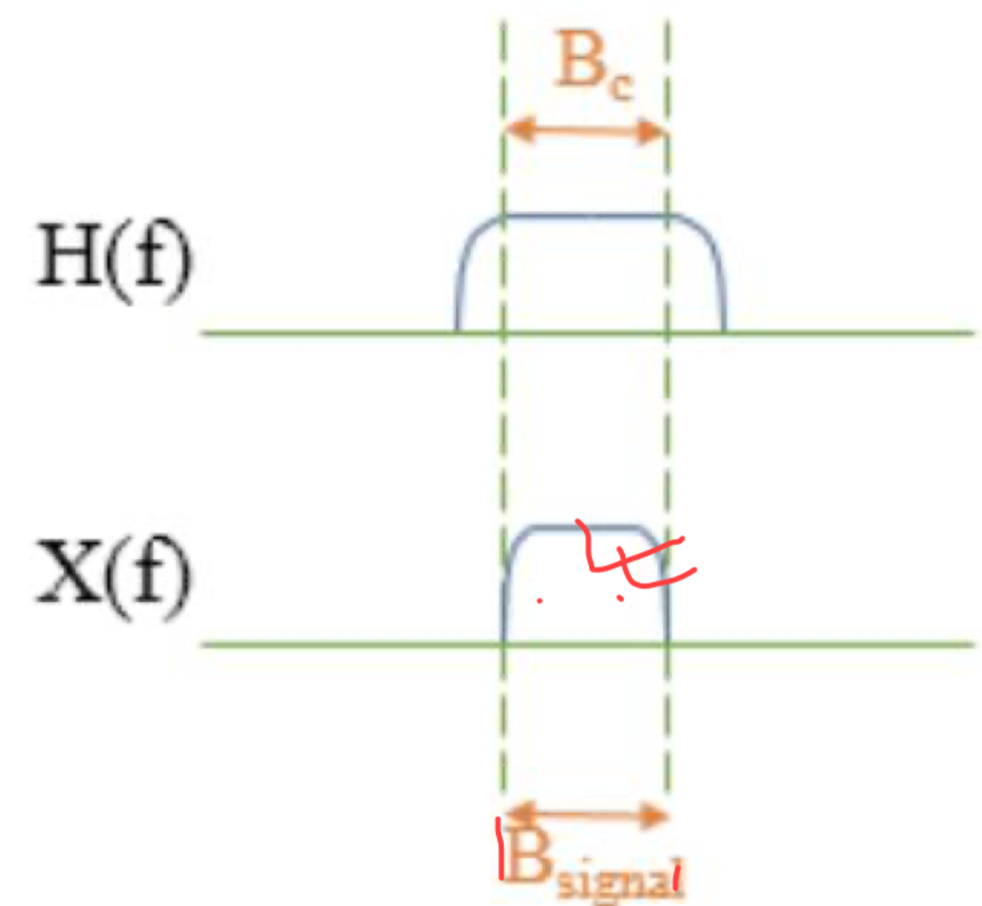
PDP Indoor



minimum excess delay
RMS Delay Spread = 46.40 ns
Maximum Excess Delay < 10 dB = 84 ns
Noise
Threshold Level = -20 dB
Mean Excess Delay = 45.05 ns
Normalized Received Power (dB Scale)
10
0
−10
−20
−30
−50
0
50
100
150
200
250
300
350
400
450
Excess Delay (ns)

Coherence Bandwidth (B_c)

- **Definition:** Range of frequencies over which the channel can be considered flat (i.e. channel passes all spectral components with equal gain and linear phase).
- It is a definition that depends on RMS Delay Spread.



Flat Fading
($B_{signal} < B_c$)

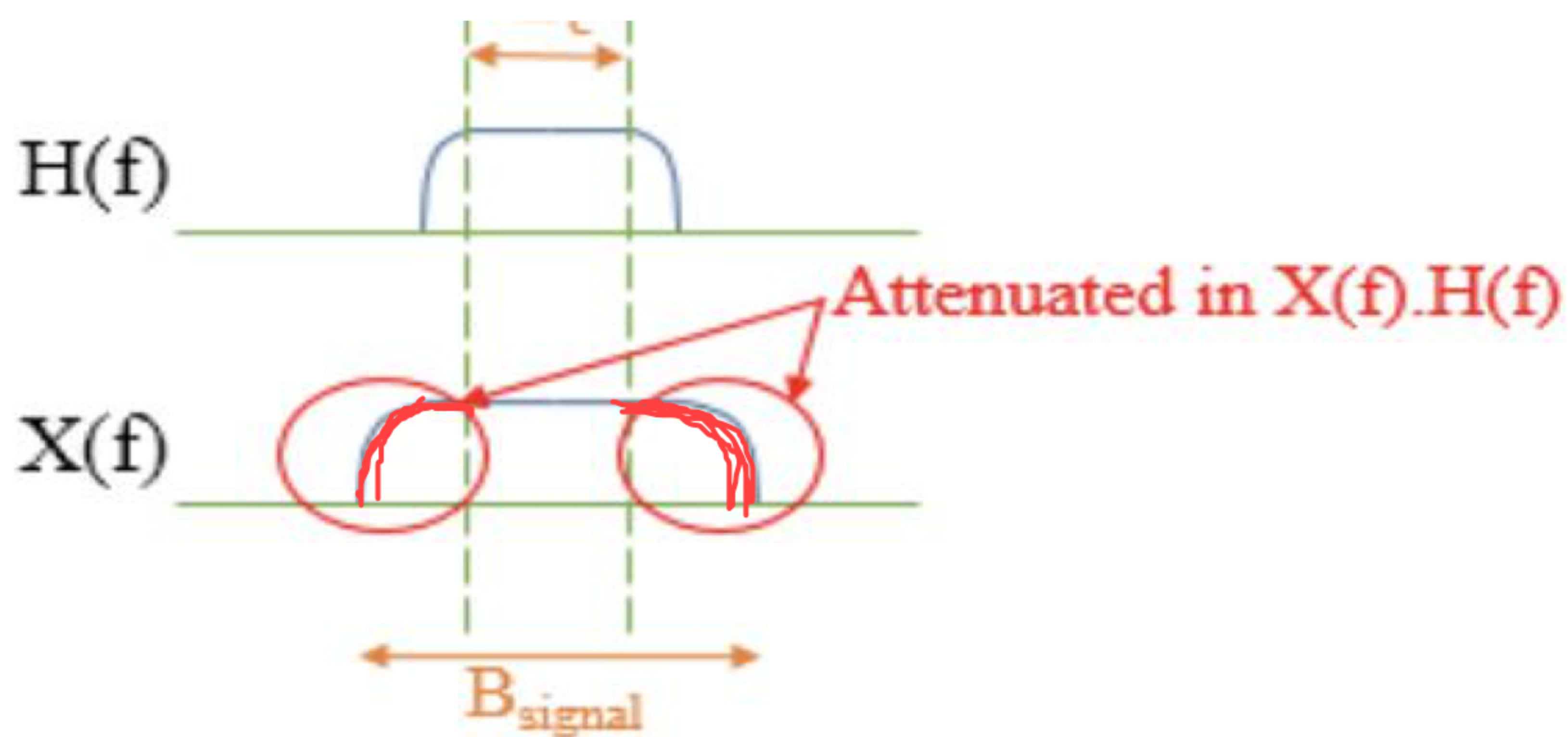
Case1:

(i) When Signal Bandwidth < Coherence Bandwidth → Flat Fading

Coherence Bandwidth (B_c)

Case 2:

(i) When Signal Bandwidth > Coherence Bandwidth → Frequency Selective Fading.



fading.

Frequency Selective Distortion

($B_{signal} > B_c$)

→ Inter-Symbol Inteference (ISI) in time domain

Coherence Bandwidth (B_c)

Frequency Diversity Technique:

- Two sinusoids with frequency separation greater than Bc are affected quite differently by the channel.
- If two same signals are sent at two different frequencies f1 and f2 and if f1-f2 > Bc, then those two signals will undergo unrelated fading.
- For example: If f1 goes through fading, signal will be received at f2 and vice-versa.

Coherence Bandwidth (B_c)

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

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

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

σ is rms delay spread.

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

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

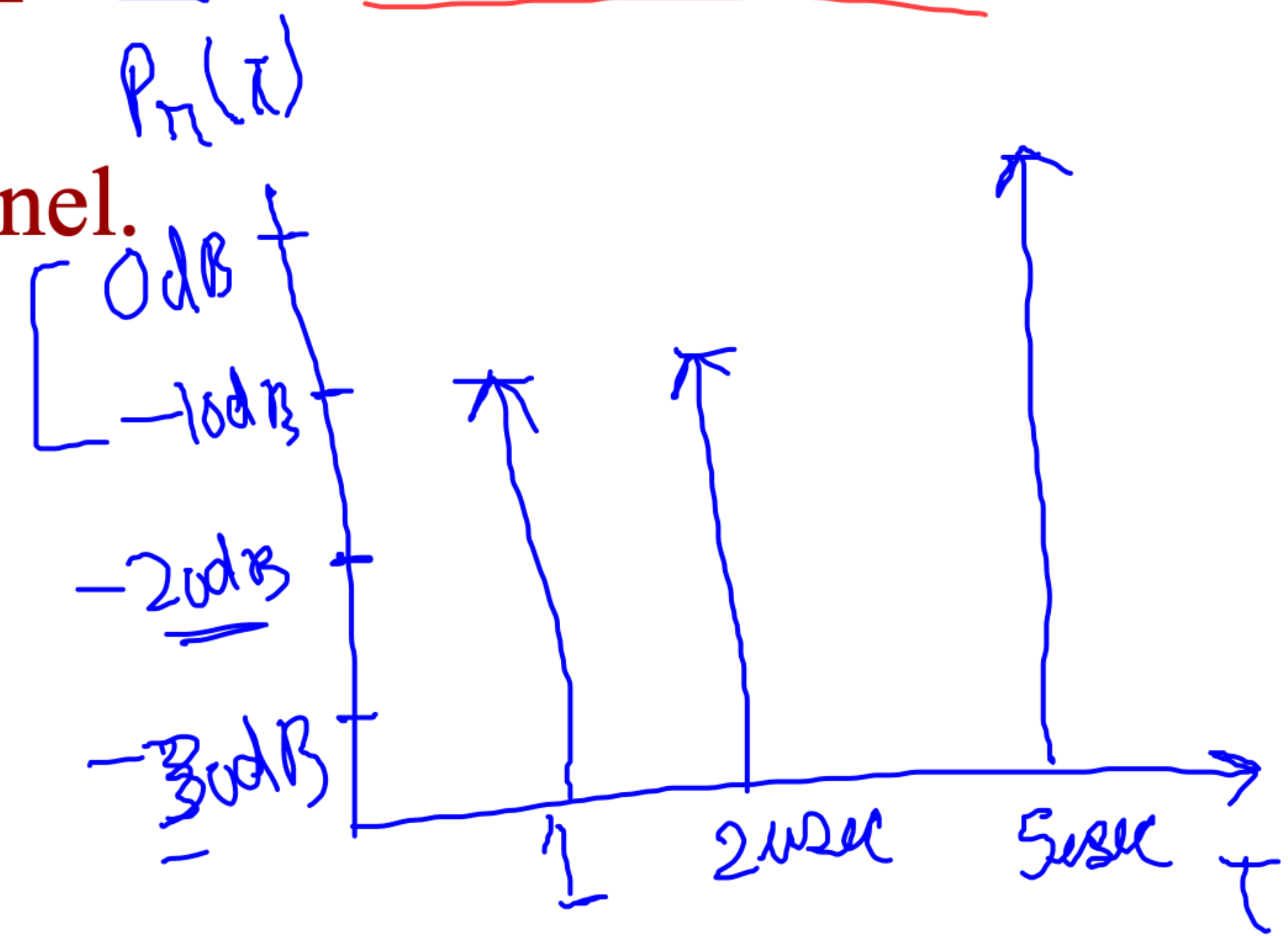
This is called 50% coherence bandwidth.

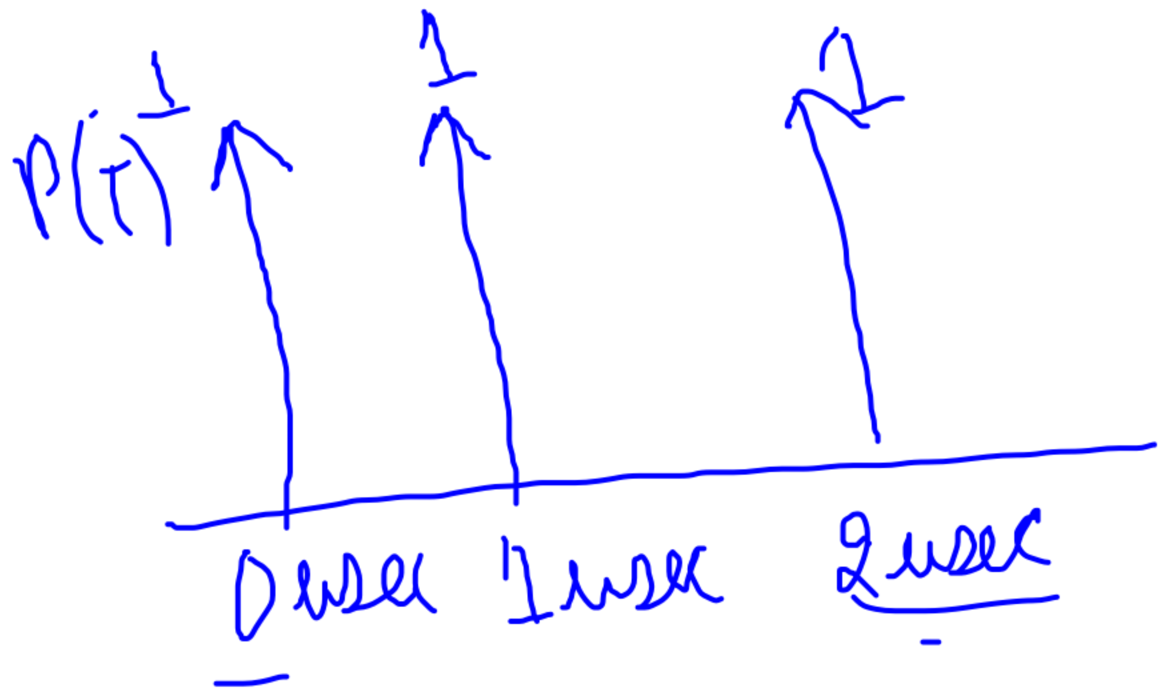
Numerical

(a) Calculate the mean excess delay, rms delay spread and maximum excess delay (10 dB) for the multipath profile.

(b) Estimate the 50% coherence BW of the channel.

$$B_c = \frac{1}{5\sigma_\tau}$$





RMS delay Spread

$$\sigma_\tau = \sqrt{\overline{\tau^2} - (\bar{\tau})^2} = \sqrt{\frac{5}{3} - (1)^2}$$

$=$ Answer

$$\bar{\tau} = \frac{\sum_k P(\tau_k)\,\tau_k}{\sum_k P(\tau_k)} = \frac{1\times 0 + 1\times 1 + 1\times 2}{1+1+1} = \frac{3}{3} = 1$$

$$\overline{\tau^2} = \frac{\sum P(\tau_k)\,(\tau_k)^2}{\sum P(\tau_k)} = \frac{1\times(0)^2 + 1\times(1)^2 + 1\times(2)^2}{1+1+1}$$

$$= \frac{0+1+4}{3} = \frac{5}{3}$$

Doppler Spread and Coherence Time

- **Delay Spread** and **Coherence BW** are the parameters which describes the time dispersive nature of the channel in local area.
- However, they do not offer information about the time varying nature of the channel caused by either relative motion between the mobile and base station or by the movement of the objects in the channel.
- **Doppler Spread** and **Coherence time** describes the time varying nature of the channel in a small scale region.

Doppler Spread

f_c

- This is the measure of spectral broadening caused by the time rate of change of the mobile radio channel.
- It is defined as the range of frequencies over which the received doppler spectrum is essentially zero.
- The doppler spectrum for a sinusoidal signal will have components (Fc-Fd) to (Fc+Fd). where fd is the doppler shift.
- This doppler shift is the function of relative velocity of the mobile and angle between the direction of motion of mobile and direction of arrival of scattered waves.
- $\boxed{\text{If } B_s > B_d}$: doppler spread is negligible and considered as **slow fading**.

Coherence Time (T_c)

↳ time domain dual of doppler spread

- T_c is used to characterize the time varying nature of the frequency dispersion in the channel in time domain.
- The doppler spread and T_c are inversely proportional.

$$T_c = 1/fm$$

→ maximum doppler shift

- Coherance Time is actually a statistical measure of time duration over which the channel impulse response is essentially invariant and quantifies the similarity of the channel response at different times.

- The definition of coherance time implies that two signals arriving with a time seperation greater than T_c are affected differently by the channel.

Coherence Time (T_c)

- T_c is used to characterize the time varying nature of the frequency dispersion in the channel in time domain.
- The doppler spread and T_c are inversely proportional.

$$T_c = 1/fm \quad \text{— } 1$$

- Coherance Time is actually a statistical measure of time duration over which the channel impulse response is essentially invariant and quantifies the similarity of the channel response at different times.
- When the coherence time is lesser than the signal bandwidth then the channel varies rapidly leading to fast fading scenarios.
- If the coherance time is defined as the time over which the time correlation function is above 0.5 then

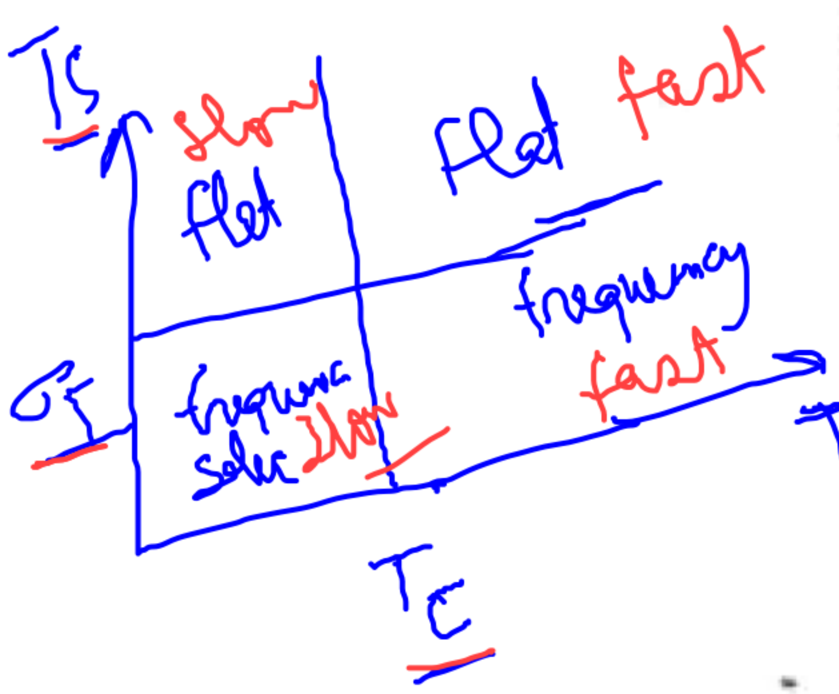
$$T_c = \frac{9}{16\pi f_m} \quad \text{— } \text{ii}$$

- For modern digital communication, coherance time is geometric mean of above two equations.
- $T_c = 0.423/fm$

Types of Small Scale Fading

Depending on the relation between the signal parameters (such as bandwidth, symbol period etc) and the channel parameters (such as rms delay spread and doppler spread), different transmitted signal will undergo different types of fading.

Small-Scale Fading
(Based on multipath time delay spread) leads to time dispersion.



Flat Fading

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

$\sigma_\tau < T_S$

Frequency Selective Fading

1. BW of signal > BW of channel
2. Delay spread > Symbol period

$\sigma_\tau > T_S$

Small-Scale Fading
(Based on Doppler spread) → frequency

Fast Fading

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

$T_C < T_S$

Slow Fading

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

$T_C > T_S$

Flat Fading

- Occurs when the amplitude of the received signal changes with time.
- For example according to Rayleigh Distribution
- Occurs when symbol period of the transmitted signal is much larger than the Delay Spread of the channel
- Bandwidth of the applied signal is narrow.
- May cause deep fades.
- Increase the transmit power to combat this situation.

Frequency Selective Fading

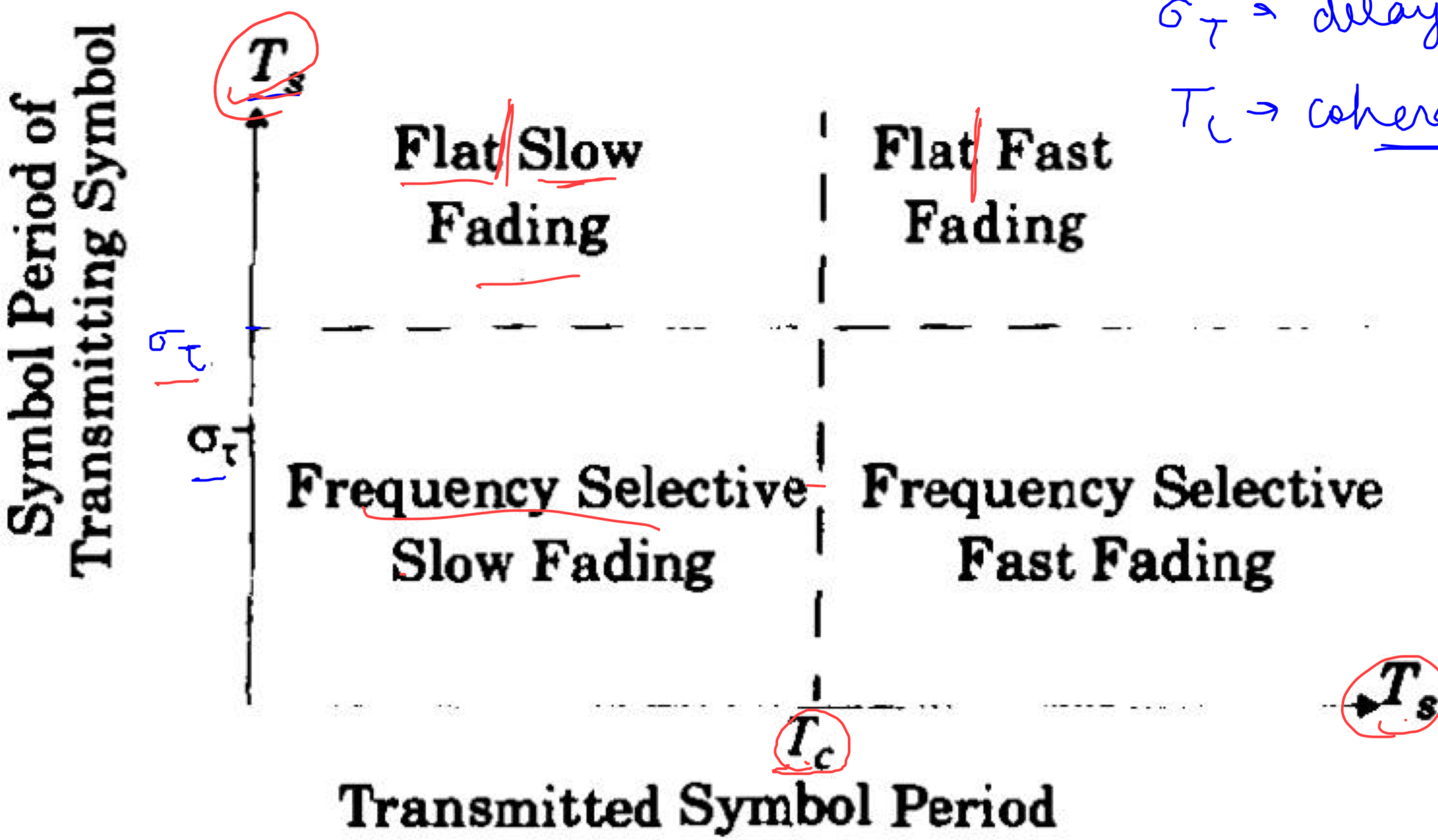
- Occurs when channel multipath delay spread is greater than the symbol period.
- Symbols faces time dispersion
- Channel induces Intersymbol Interference (ISI)
- Bandwidth of the signal s(t) is wider than the channel impulse response.

Matrix illustrating type of Fading experienced by a signal as a function of symbol period

$T_s \rightarrow$ Symbol Period

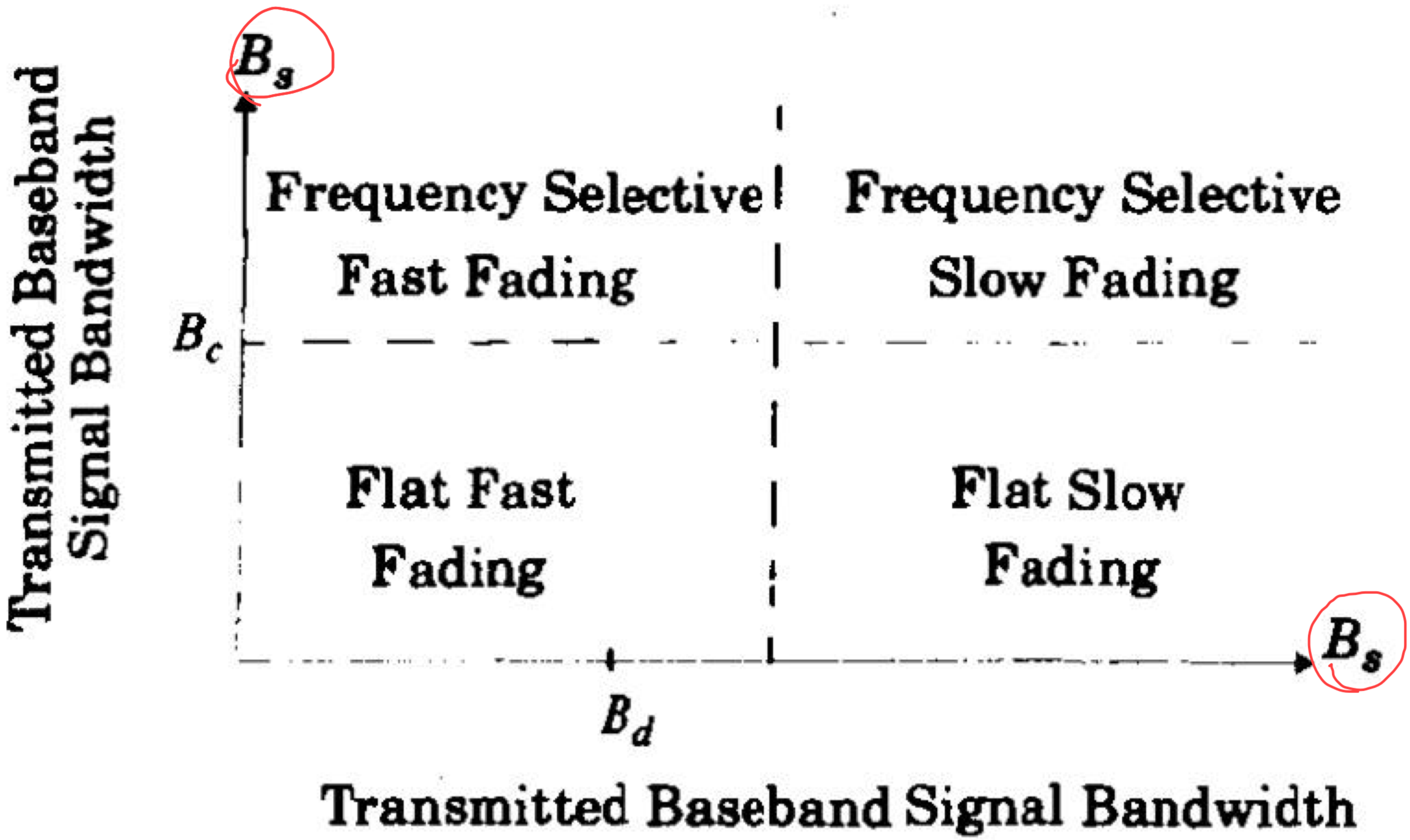
$\sigma_\tau \rightarrow$ delay spread

$T_c \rightarrow$ coherence



(a)

Matrix illustrating type of Fading experienced by a signal as a function of baseband signal bandwidth



(b)