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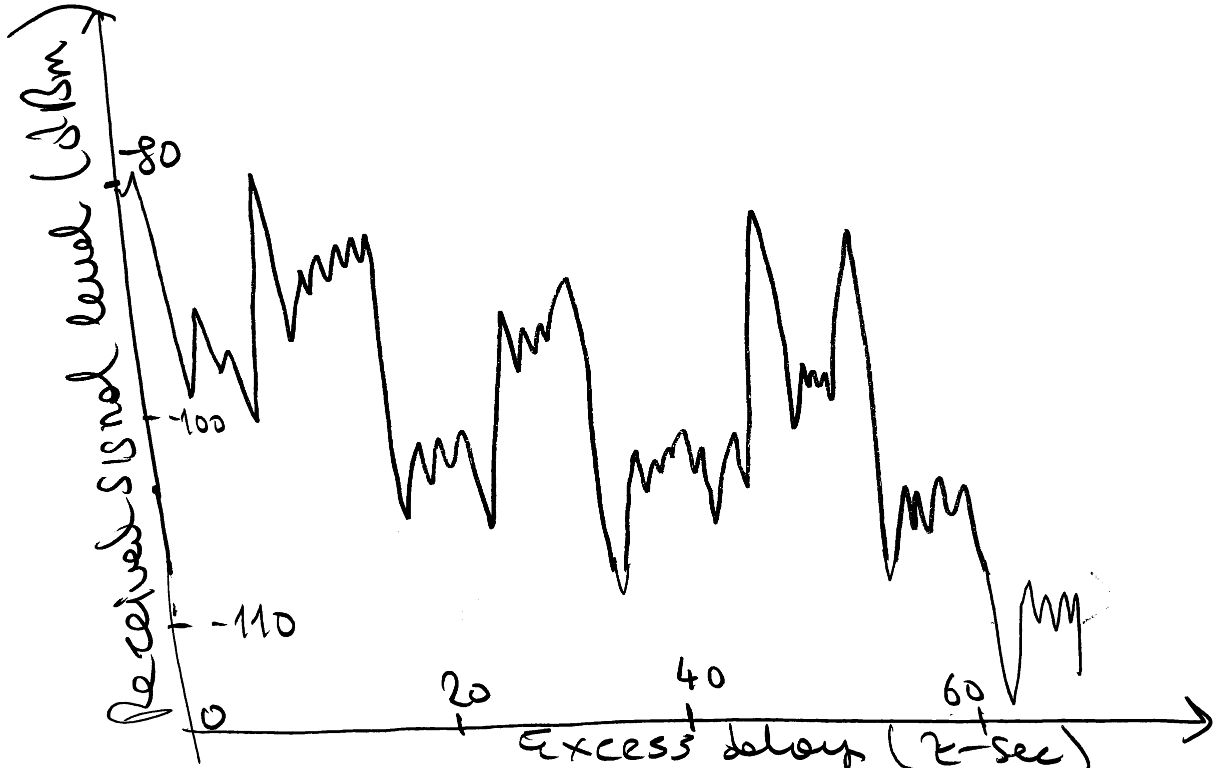
# Parameters of Mobile Multipath Channels

Many multipath channel parameters are derived from the power delay profile

Power delay profiles are measured using a number of different techniques and are generally represented as plots of relative received power as a function of excess delay with respect to a fixed time delay reference.

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

Ex:



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Wireless Channels

Wideband Channels

Narrowband Channels.

## Wideband Channels:

$$T_m \gg B^{-1}$$

$T_m$ → Max. Delay of the channel (or delay spread of the channel)

$B$ → Bandwidth of the transmitted signal

that means $T_m \gg T_s$

$T_s$ → Symbol period.

$T_m$ → Delay Spread of the channel.

## Narrowband Channels:

$$T_m \ll B^{-1}$$

or $T_m \ll T_s$

③

# Time Dispersion Parameters

The time dispersive properties of wide-band multipath channels are most commonly quantified by their mean excess delay ($\bar{\tau}$) and rms delay spread ($\sigma_\tau$).

The mean excess delay is defined as

$$\bar{\tau} = \frac{\sum_k \alpha_k^2 \tau_k}{\sum \alpha_k^2}$$

$\alpha_k \rightarrow$ attenuation of the kth path.

$$= \frac{\sum_k P(\tau_k)\tau_k}{\sum_k P(\tau_k)}$$

RMS delay spread:

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

where

$$\overline{\tau^2} = \frac{\sum_k \alpha_k^2 \tau_k^2}{\sum_k \alpha_k^2}$$

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

$\tau_k \rightarrow$ These delays are measured relative to the first detectable signal arriving at the receiver at $\tau_0 = 0$.

Typical values of rms delay spread are on the order of microseconds in outdoor mobile radio channels and on the order of nanoseconds in indoor radio channels.

Ex:

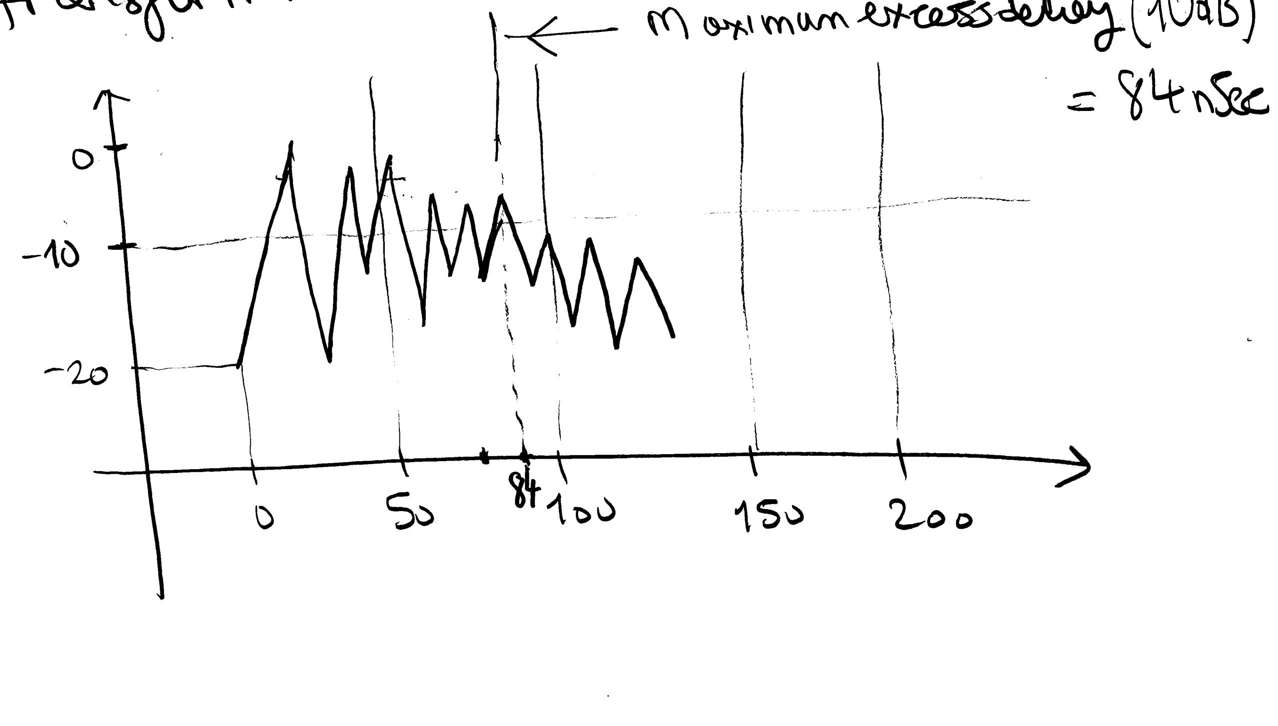
| Environment | Frequency (MHz) | $\sigma_\tau$ | Notes |
|---|---|---|---|
| Indoor | 850 | 270 ns max | Office building |
| Indoor | 1900 | 70-94 ns avg. 1470 ns max | Three San Francisco Buildings |
| Suburban | 910 | 200-310 ns | |
| Urban | 892 | 10-25 $\mu$s | Worst Case San Francisco |

(5)

- The maximum excess delay (X dB) of the power delay profile is defined to be the time delay during which multipath energy falls to X dB below the maximum.
- In other words, the maximum excess delay is defined as $\tau_x - \tau_0$, where $\tau_0$ is the first arriving signal and $\tau_x$ is the maximum delay at which a multipath component is within X dB of the strongest arriving multipath signal.

- The power delay profile and the magnitude frequency response of a mobile radio channel are related through the Fourier transform.

Exe



(6) Coherence Bandwidth:

The coherence bandwidth, $B_c$, is a defined relation derived from the rms delay spread

Coherence bandwidth is a statistical measure of the range of frequencies over which the channel can be considered "flat"
(i.e, a channel which passes all spectral components with approximately equal gain and linear phase)

In other words, coherence bandwidth 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.

90% coherence bandwidth is defined as

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

i.e, the bandwidth over which the frequency correlation function is above 0.9

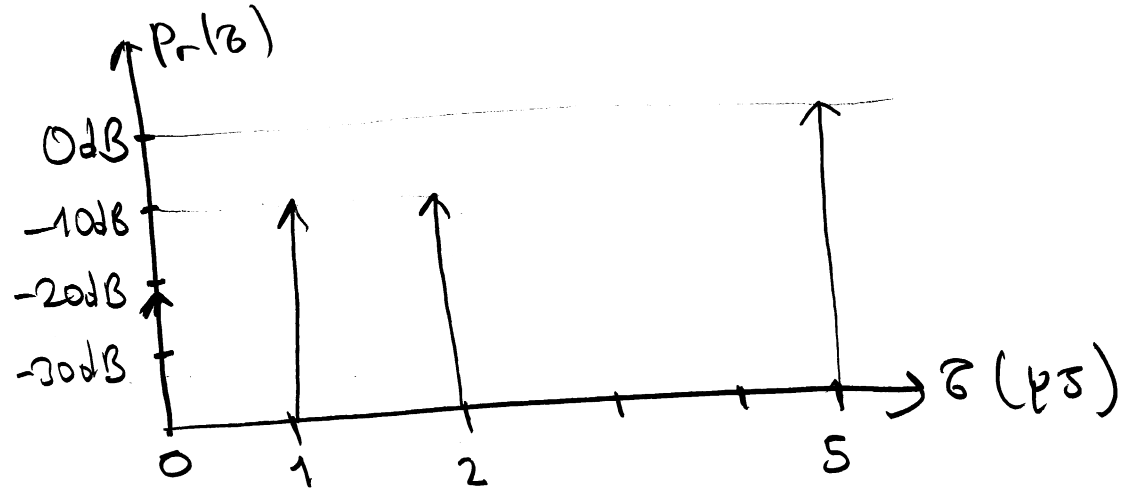
50% coherence bandwidth

$$B_c \approx \frac{1}{5\,\sigma_\tau}$$

- Note that an exact relationship between coherence bandwidth and rms delay spread does not exist.

The above equations are just rough estimates.

Ex:




mean excess delay?
rms delay spread?

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maximum excess delay (10 dB)?

50% coherence bandwidth?

Would this channel be suitable for GSM service without the use of an equalizer

Sln:

$$\bar{\tau} = \frac{\sum P(\tau_k)\,\tau_k}{\sum P(\tau_k)}$$

$$P_r(dB) = 10\log_{10} P_r \rightarrow P_r = 10^{P_r(dB)/10} \text{ watt}$$

$0\,dB \rightarrow 1$

$-10\,dB \rightarrow 10^{-1} \rightarrow 0.1$

$-20\,dB \rightarrow 10^{-2} \rightarrow 0.01$

$$\bar{\tau} = \frac{0.01\times 0 + 0.1\times 1 + 0.1\times 2 + 1\times 5}{0.01 + 0.1 + 0.1 + 1}$$

$= 4.38\ \mu sec$

$$\overline{\tau^2} = \frac{0^2\times 0.01 + 1^2\times 0.1 + 2^2\times 0.1 + 5^2\times 1}{1.21}$$

$= 21.07\ \mu s^2$

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

$= 1.37\ \mu sec$

⑨

50% $B_c$ is

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

$= 146\,kHz$

GSM requires 200kHz bandwidth which exceeds $B_c$, thus an equalizer would be needed for this channel.

## Doppler Spread and Coherence Times

Doppler spread and coherence time are parameters which describe the time varying nature of the channel in small-scale region

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 spectrum is essentially non-zero

$f_c \rightarrow$ transmitted signal frequency

$(f_c - f_d \,.\, f_c + f_d) \rightarrow$ received signal frequency can be in this range.

$f_d \rightarrow$ maximum Doppler shift

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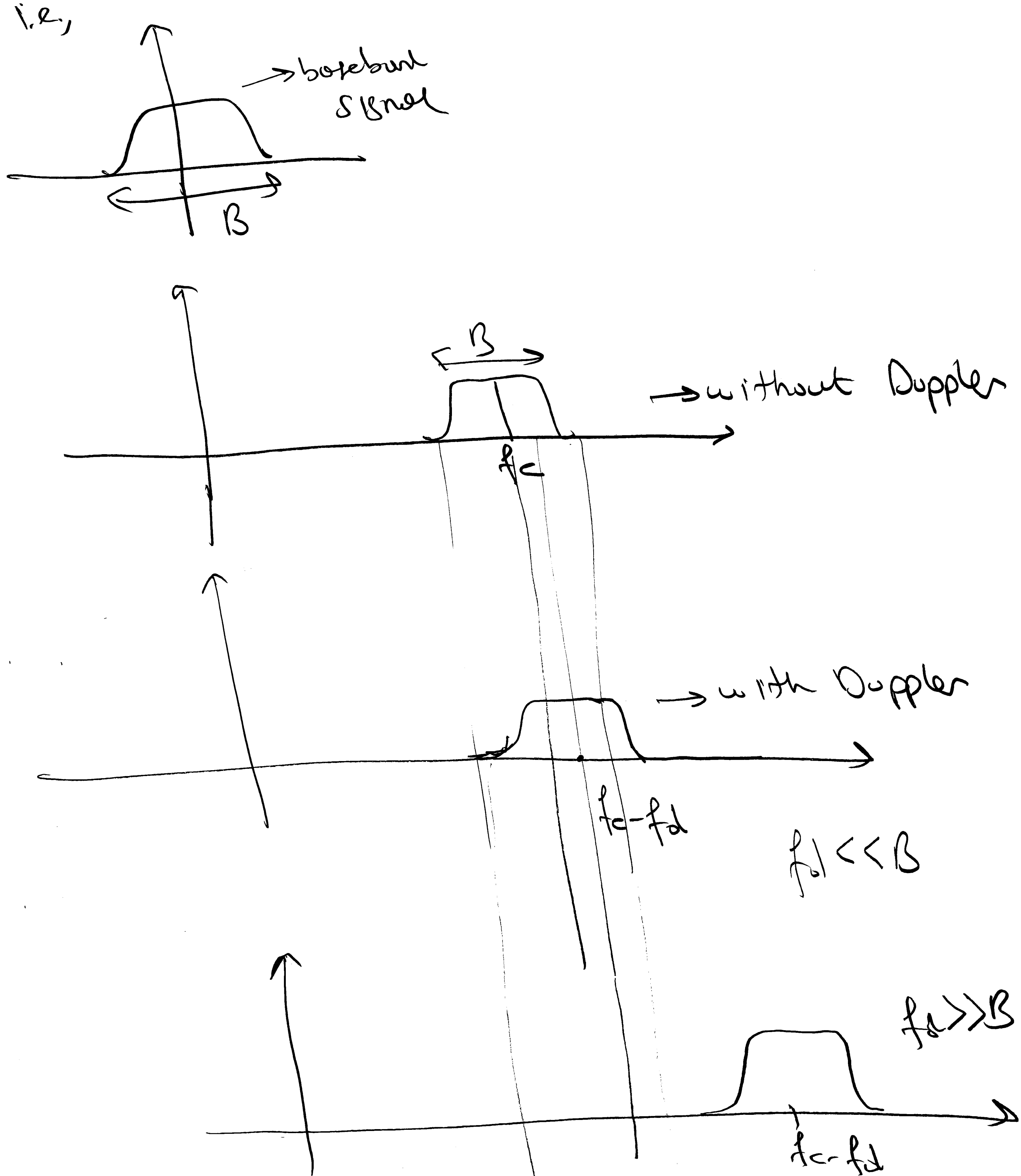
If the baseband signal bandwidth is much greater than $B_D$, the effects of Doppler spread are negligible at the receiver. This is a slow fading channel.

i.e.,



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## Coherence Time:

$$T_c \approx \frac{1}{f_m}$$

$f_m \rightarrow$ maximum Doppler shift

$f_m = \frac{v}{\lambda}$ $v \rightarrow$ speed of mobile, $\lambda \rightarrow$ wave length $\lambda = c \cdot f_c$

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

- In other words, coherence time is the time duration over which two received signals have a strong potential for amplitude correlation.

- If the reciprocal bandwidth of the baseband signal is greater than the coherence time of the channel, then the channel will change during the transmission of the baseband message.

50% Coherence time $T_c \approx \frac{9}{16\pi f_m}$

$T_c = \frac{0.423}{f_m}$ → another definition for $T_c$

- Two signals arriving with a time separation greater than $T_c$ are affected differently by the channel.

Ex: A vehicle traveling at 60mph → 28.82 m/s using a 900MHz carrier

TX

$v = 60mph$

$T_c = ?$

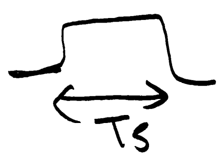
What should be the minimum transmission speed of the transmitter so that Doppler effect is negligible at the receiver.

Sol: $T_c = \frac{0.423}{f_m}$ $\quad f_m = \frac{v}{\lambda} \rightarrow f_m = \frac{v f_c}{c}$

$f_m = \frac{28.82 \times 9 \times 10^8}{3 \times 10^8}$

$T_c = 6.77 msec$

TX



$T_s$ → Symbol period $\quad T_s < T_c$

$\frac{1}{T_s} > \frac{1}{T_c}$

(13) $\frac{1}{T_s} > \frac{1}{T_c}$

$$f_s > \frac{1}{6.77\,msec} \qquad f_s > \frac{1000}{6.77}$$

$$f_s > 150$$

Symbol rate must exceed 150 bits/sec in order to avoid distortion due to frequency dispersion

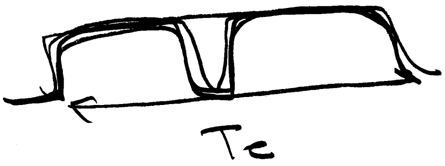
Ex: Determine the proper spatial sampling interval required to make small-scale propagation measurements which assume that consecutive samples are highly correlated in time. How many samples will be required over 10m travel distance if $f_c = 1900\,MHz$ and $v = 50\,m/sec$. How long would it take to make these measurements, assuming they could be made in real time from a moving vehicle?

What is the Doppler spread for this channel? ($B_D$)

→ smallest value for $T_c$ is used for design

$$T_c \approx \frac{9}{16\pi f_m} = \frac{9\lambda}{16\pi v} = \frac{9c}{16\pi v f_c} = \frac{9\times 3\times 10^8}{16\times 3.14\times 50\times 1900\times 10^6}$$

$$T_c = 565\,\mu\text{sec}$$




Let $T_s = \frac{T_c}{2}$

$$\Delta X = v\,T_s \rightarrow \Delta X = 50 \times 282.5\,\mu\text{sec}$$

$$\Delta X = 1.41\,\text{cm} = 0.014125\,\text{m}$$

The number of samples required over a 10m travel distance is

$$N_x = \frac{10}{\Delta X} = \frac{10}{0.014125} = 708 \text{ samples}$$

The time taken to make this measurement is equal to $\frac{10\,\text{m}}{50\,\text{m/sec}} = 0.2\,\text{sec}$

The Doppler spread is $B_D = f_m = \frac{v f_c}{c} = \frac{50\times 1900\times 10^6}{3\times 10^8}$

$$B_D = 316.66\,\text{Hz}$$