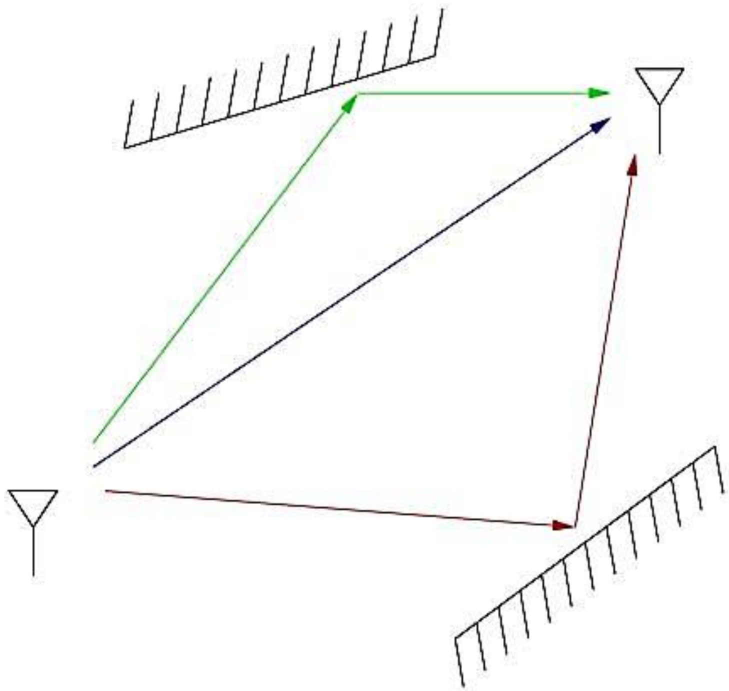
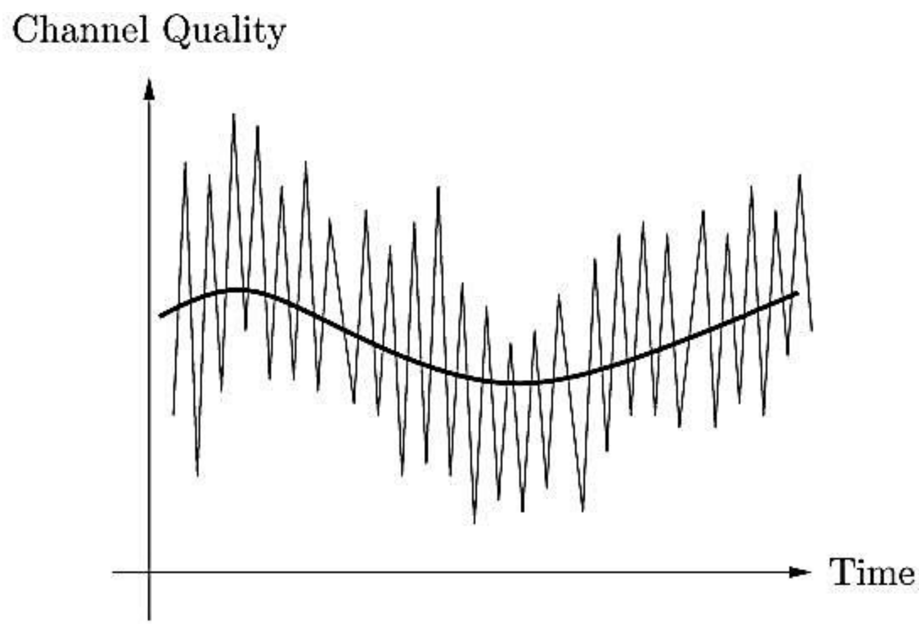
Wireless Channel

Wireless Multipath Channel





Channel Fading

Fading is :

- a variation of a signal with time or frequency or position.
- a random process
- due to either multipath, or weather or shadowing

Shadowing

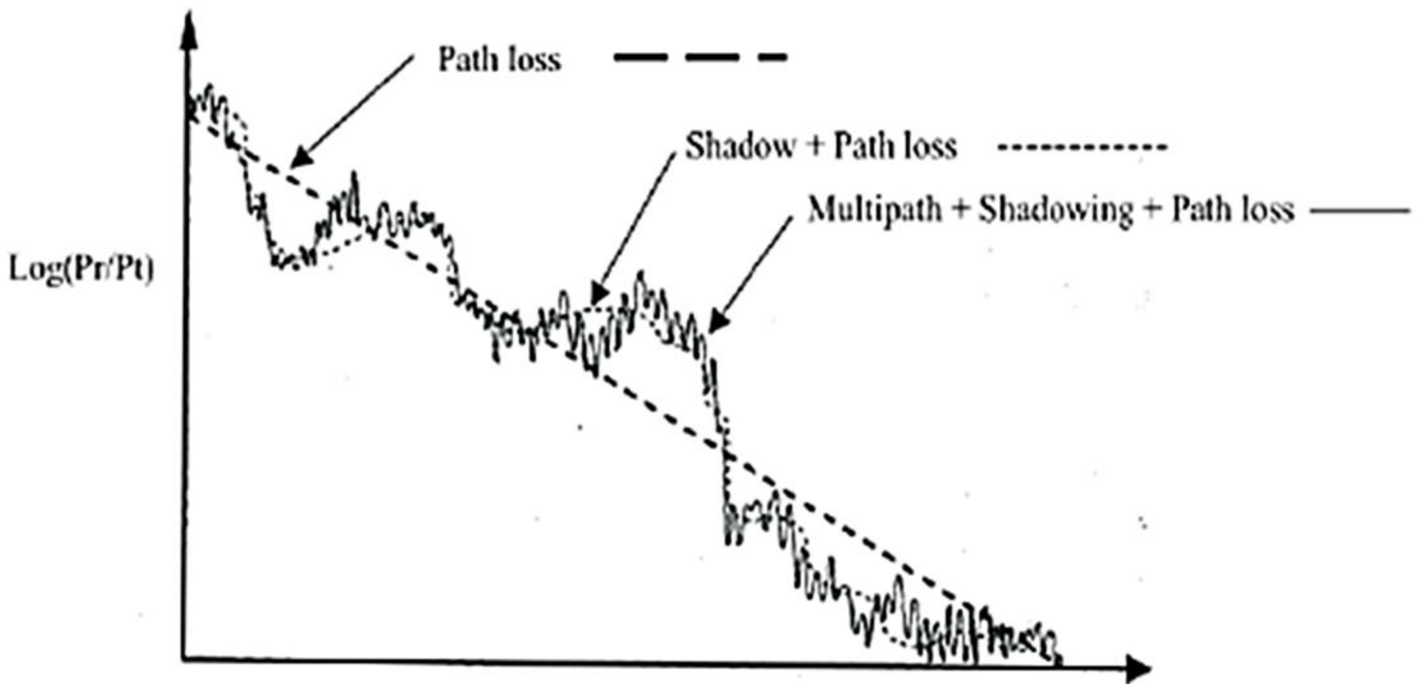
- due to obstruction between Tx & Rx
- a result of reflection and scattering

Channel varies at two spatial scales:

- large scale fading
- small scale fading

Large-scale fading

- Variation of signal strength over distance of the order of cell size
- In free space, received power attenuates like $1/r^2$ while with reflection from ground like $1/r^4$
- With obstructions and more reflections , can attenuate even more rapidly with distance. Detailed modelling complicated.



Simple path loss model

d_o .. reference distance in antenna’s far-field

usually 1-10m …. Indoor (10-100m) outdoor

$$\overline{PL}(d) \propto \left(\frac{d}{d_0}\right)^n$$

$$\overline{PL}(dB) = \overline{PL}(d_0) + 10n\log\left(\frac{d}{d_0}\right)$$

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 line-of-sight	1.6 to 1.8
Obstructed in building	4 to 6
Obstructed in factories	2 to 3

Then,

- The surrounding environment causes different loss at same distance
- Time constants associated with variations are very long as the mobile moves, many seconds or minutes.
- More important for cell site planning, less for communication system design.

Small-scale multipath fading

- Wireless communication typically happens at very high f_c. (eg. f_c = 900 MHz or 1.9 GHz for cellular)
- Multipath fading due to constructive and destructive interference of the transmitted waves.
- Channel varies when mobile moves a distance of the order of the λ_c. This is about 0.3 m for 900 MHz cellular.
- For vehicular speeds, this translates to channel variation of the order of 100 Hz.
- Primary driver behind wireless communication system design.

Game plan

- We wish to understand how physical parameters such as
  - carrier frequency
  - mobile speed
  - bandwidth
  - delay spread
  - angular spread

  impact how a wireless channel behaves from the communication system point of view.
- Find deterministic physical model

Physical Models

- Wireless channels can be modeled as linear time-varying systems:

$$y(t) = \sum_i a_i(t) x(t - \tau_i(t))$$

where $a_i(t)$ and $\tau_i(t)$ are the gain and delay of path i.

- The time-varying impulse response is:

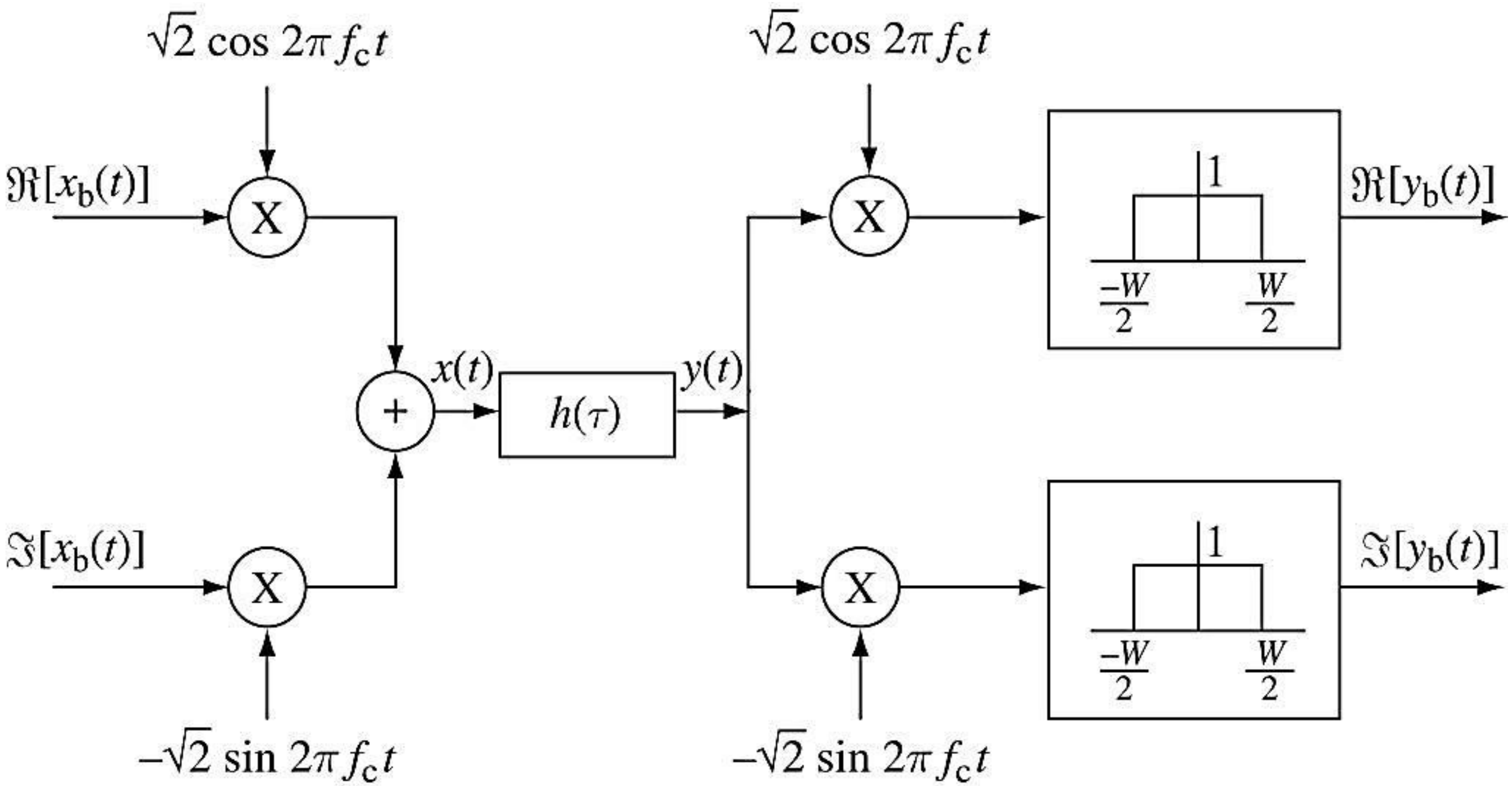
$$h(t, \tau) = \sum_i a_i(t) \delta(\tau - \tau_i(t))$$

- Consider first the special case when the channel is time-invariant:

$$h(\tau) = \sum_i a_i \delta(\tau - \tau_i)$$

Passband to Baseband Conversion

- Communication takes place at $[f_c - W/2, f_c + W/2]$
- Processing takes place at baseband $[-W/2, W/2]$



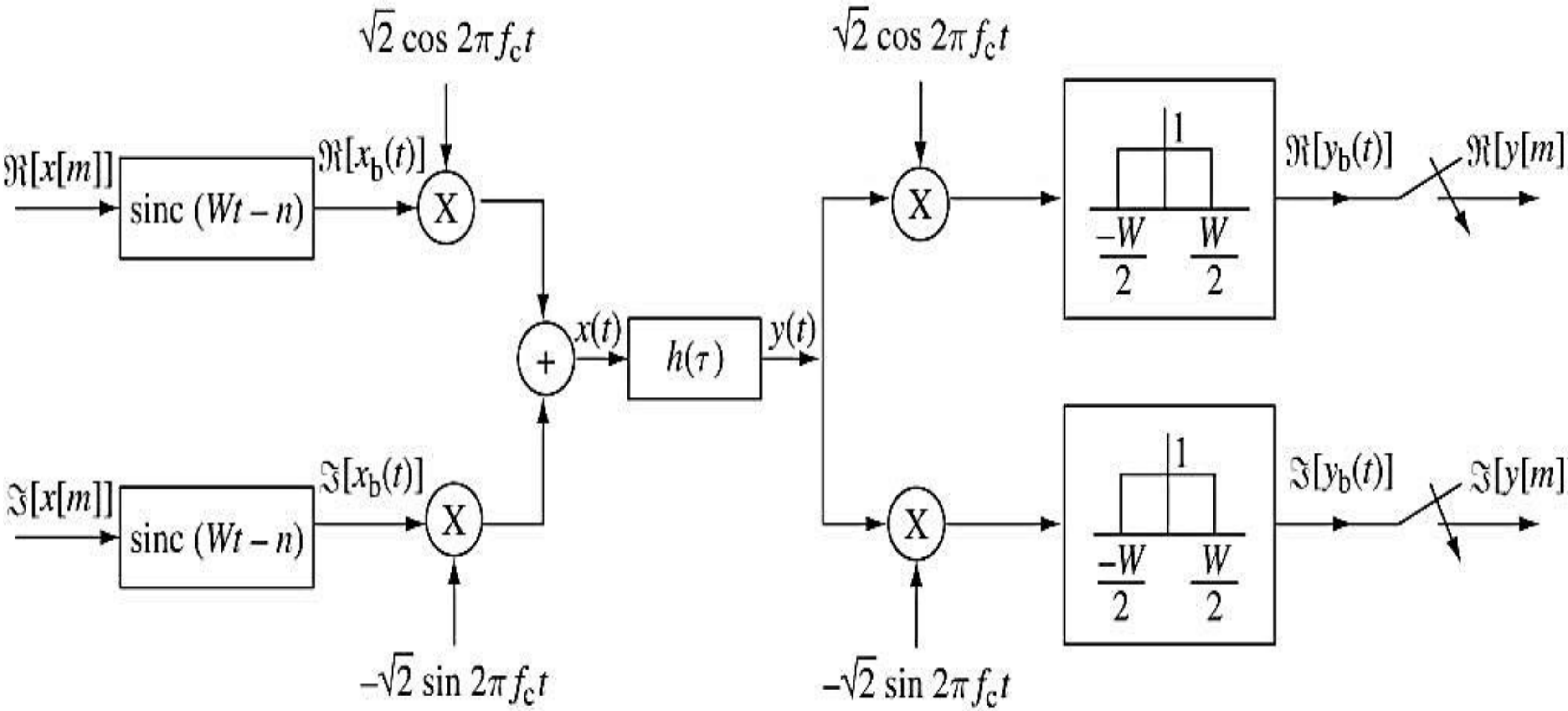
Complex Baseband Equivalent Channel

- The frequency response of the system is shifted from the passband to the baseband.

$$
\begin{aligned}
H_b(f) &= H(f + f_c) \\
h_b(\tau) &= h(t)e^{-j2\pi f_c t} = \sum_i a_i^b \delta(\tau - \tau_i) \\
\text{where } a_i^b &= a_i e^{-j2\pi f_c \tau_i}
\end{aligned}
$$

- Each path is associated with a delay and a complex gain.

Modulation and Sampling



Multipath Resolution

Sampled baseband-equivalent channel model:

$$y[m] = \sum_{\ell} h_\ell x[m-\ell]$$

where h_l is the l th complex channel tap.

$$h_\ell \approx \sum_i a_i e^{-j2\pi f_c \tau_i}$$

and the sum is over all paths that fall in the delay bin

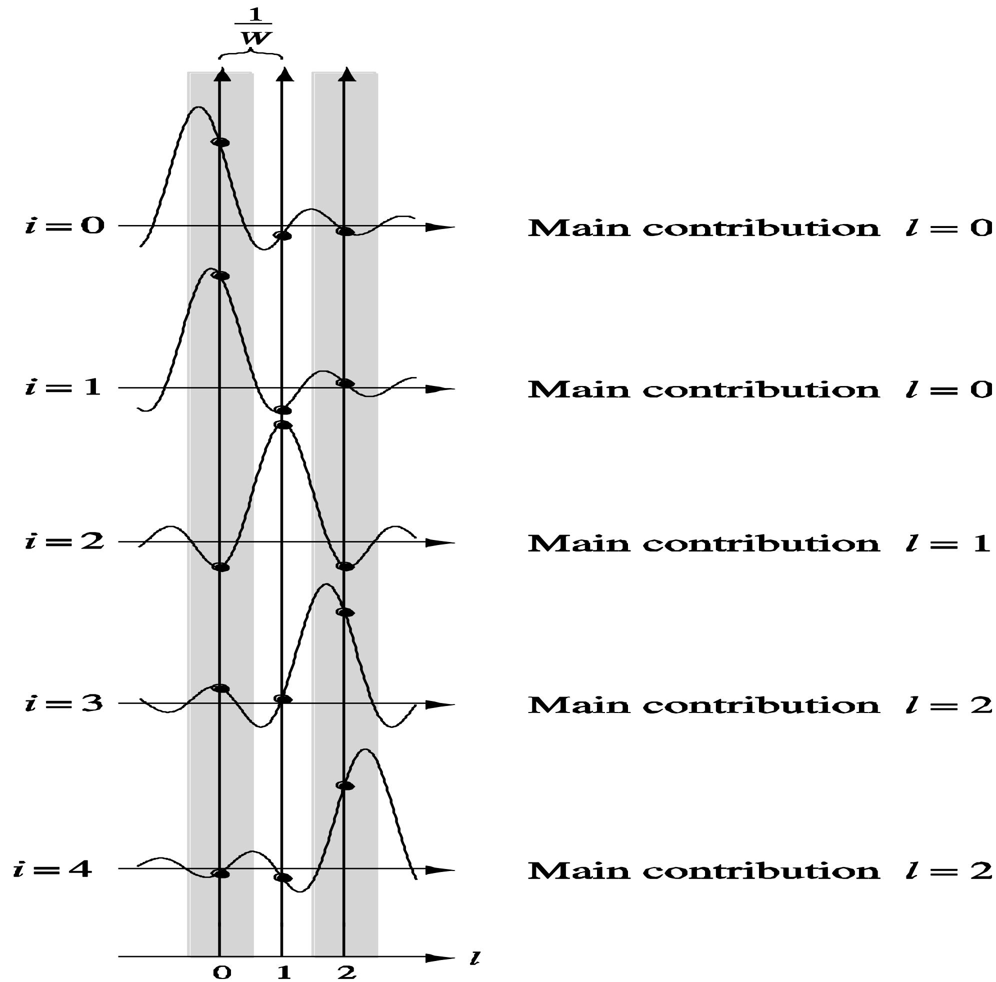
$$\left[\frac{\ell}{W} - \frac{1}{2W}, \frac{\ell}{W} + \frac{1}{2W}\right]$$

System resolves the multipaths up to delays of 1/W .

Sampling Interpretation

- h_l is the l th sample of the low-pass version of the channel response $h_b(¢)$.

- Contribution of the i th path is the projection of $a_i^b\ \delta(\tau-\tau_i)$ onto sinc($W\tau$-l).



Flat and Frequency-Selective Fading

- Fading occurs when there is destructive interference of the multipaths that contribute to a tap.

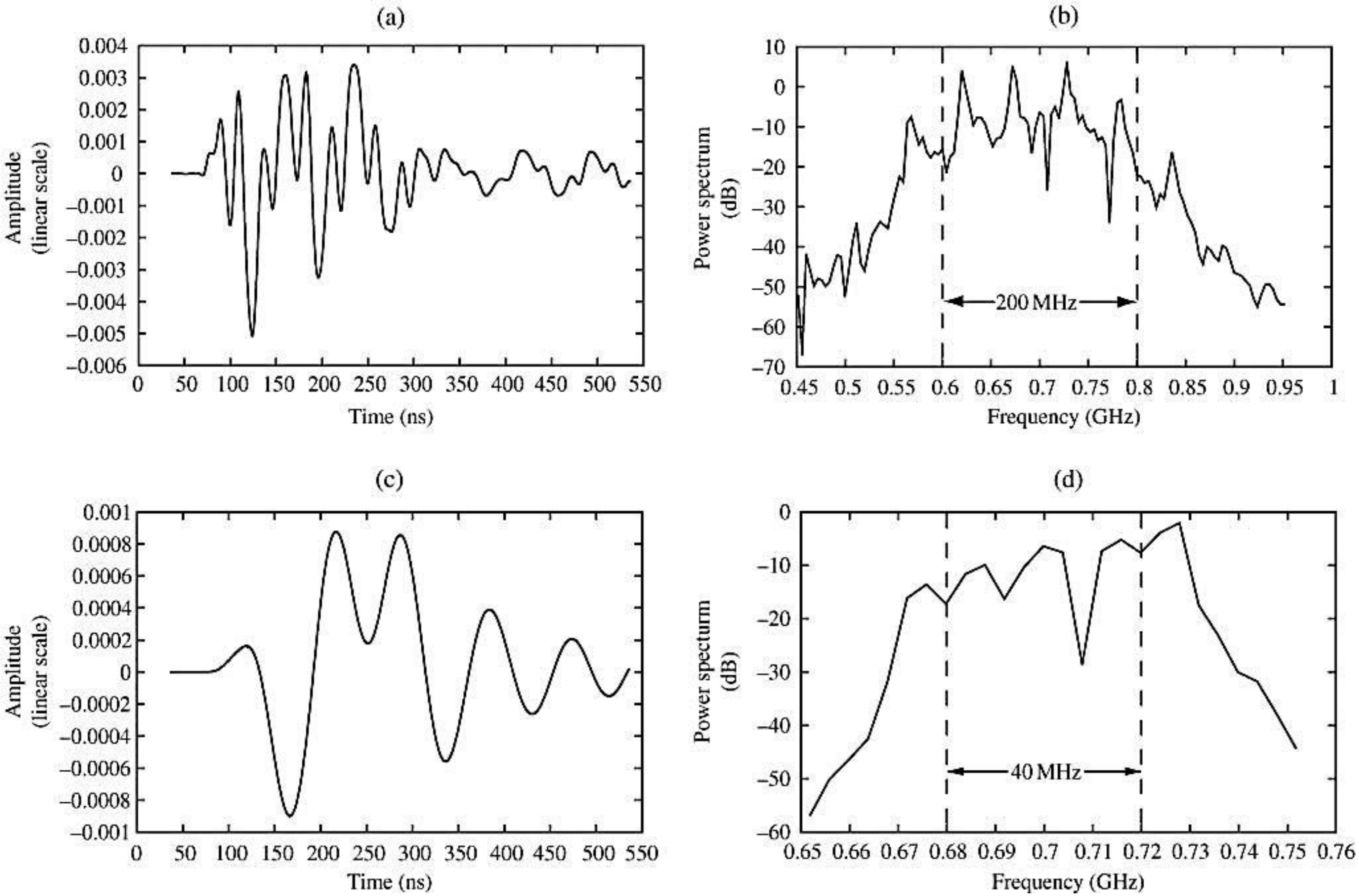
$$h_\ell \approx \sum_i a_i e^{-j2\pi f_c \tau_i}$$

Delay spread $T_d := \max_{i,j} |\tau_i(t) - \tau_j(t)|$

Coherence bandwidth $W_c := \frac{1}{T_d}$

$T_d \ll \frac{1}{W}, W_c \gg W \Rightarrow$ single tap, flat fading

$T_d > \frac{1}{W}, W_c < W \Rightarrow$ multiple taps, frequency selective



Effective channel depends on both physical environment and bandwidth!

Time Variations

$$y[m] = \sum_{\ell} h_\ell[m] x[m-\ell]$$

$$h_\ell[m] \approx \sum_i a_i(t) e^{-j2\pi f_c \tau_i(t)}, \qquad t = \frac{m}{W}$$

$f_c \tau_i'(t) =$ Doppler shift of the i th path

Doppler spread $D_s := \max_{i,j} |f_c \tau_i'(t) - f_c \tau_j'(t)|$

Coherence time $T_c := \frac{1}{D_s}$

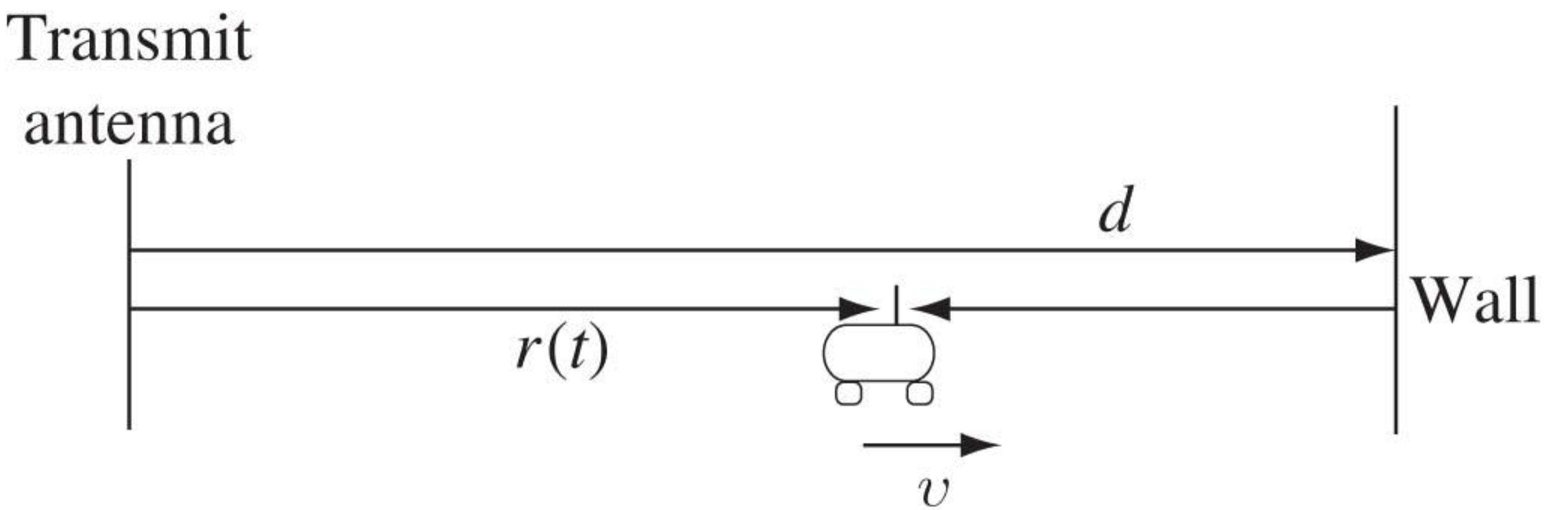
Two-path Example

v= 60 km/hr, f_c = 900 MHz:

direct path has Doppler shift of -50 Hz

reflected path has shift of +50 Hz

Doppler spread = 100 Hz



Doppler Spread

$$D_s := \max_{i,j} |f_c \tau_i'(t) - f_c \tau_j'(t)|$$

Doppler spread is proportional to:

- the carrier frequency f_c;
- the angular spread of arriving paths.

$$\tau_i'(t) = \frac{v}{c} \cos \theta_i$$

where θ_i is the angle the direction of motion makes with the i th path.

Key channel parameters and time-scales	Symbol	Representative values
Carrier frequency	f_c	1 GHz
Communication bandwidth	W	1 MHz
Distance between transmitter and receiver	d	1 km
Velocity of mobile	v	64 km/h
Doppler shift for a path	$D = f_c v/c$	50 Hz
Doppler spread of paths corresponding to a tap	D_s	100 Hz
Time-scale for change of path amplitude	d/v	1 minute
Time-scale for change of path phase	$1/(4D)$	5 ms
Time-scale for a path to move over a tap	$c/(vW)$	20 s
Coherence time	$T_c = 1/(4D_s)$	2.5 ms
Delay spread	T_d	1 μs
Coherence bandwidth	$W_c = 1/(2T_d)$	500 kHz

Types of Channels

Types of channel	Defining characteristic
Fast fading	$T_c \ll$ delay requirement
Slow fading	$T_c \gg$ delay requirement
Flat fading	$W \ll W_c$
Frequency-selective fading	$W \gg W_c$
Underspread	$T_d \ll T_c$

Typical Channels are Underspread

- Coherence time T_c depends on carrier frequency and vehicular speed, of the order of milliseconds or more.
- Delay spread T_d depends on distance to scatterers, of the order of nanoseconds (indoor) to microseconds (outdoor).
- Channel can be considered as time-invariant over a long time scale.