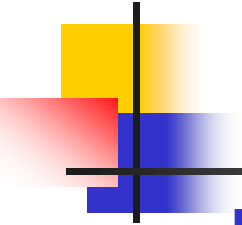


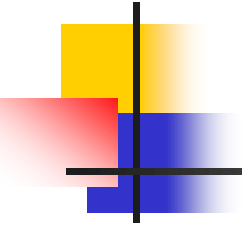
Chapter 3

Mobile Radio Propagation (2.5 hours)



Outline

- Speed, Wavelength, Frequency
- Types of Waves
- Radio Frequency Bands
- Propagation Mechanisms
- Path Loss
- Fading: Slow Fading / Fast Fading
- Delay Spread
- Doppler Shift
- Co-Channel Interference



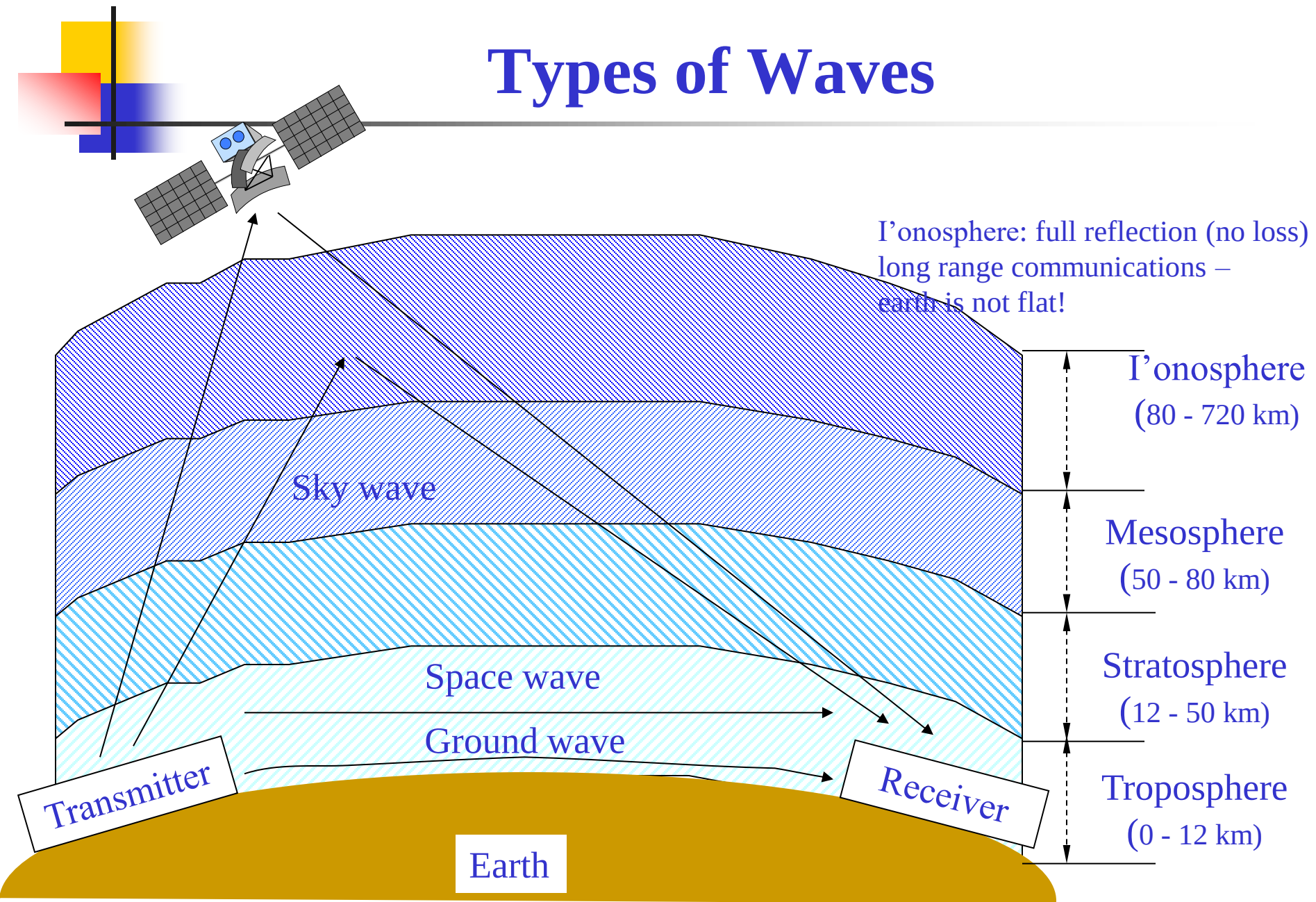
Speed, Wavelength, Frequency

Light speed = Wavelength x Frequency

$$= 3 \times 10^8 \text{ m/s} = 300,000 \text{ km/s}$$

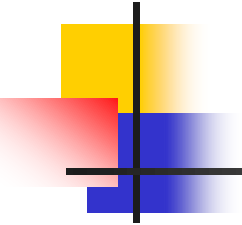
System	Frequency	Wavelength
AC current	60 Hz	5,000 km
FM radio	100 MHz	3 m
Cellular	800 MHz	37.5 cm
Ka band satellite	20 GHz	15 mm
Ultraviolet light	10^{15} Hz	10^{-7} m

Types of Waves



Radio Frequency Bands (satellite has its own names C 4.9GHz, Ka Ku)

Classification Band	Initials	Frequency Range	Characteristics
Extremely low	ELF	< 300 Hz	Ground wave
Infra low	ILF	300 Hz - 3 kHz	
Very low	VLF	3 kHz - 30 kHz	
Low	LF	30 kHz - 300 kHz	
Medium	MF	300 kHz - 3 MHz	Ground/Sky wave
High	HF	3 MHz - 30 MHz	Sky wave (long distance)
Very high	VHF	30 MHz - 300 MHz	Space wave
Ultra high	UHF	300 MHz - 3 GHz	
Super high	SHF	3 GHz - 30 GHz	
Extremely high	EHF	30 GHz - 300 GHz	
Tremendously high	THF	300 GHz - 3000 GHz	



Propagation Mechanisms

■ Reflection

- Propagation wave impinges on an object which is large as compared to wavelength
 - e.g., the surface of the Earth, buildings, walls, etc.

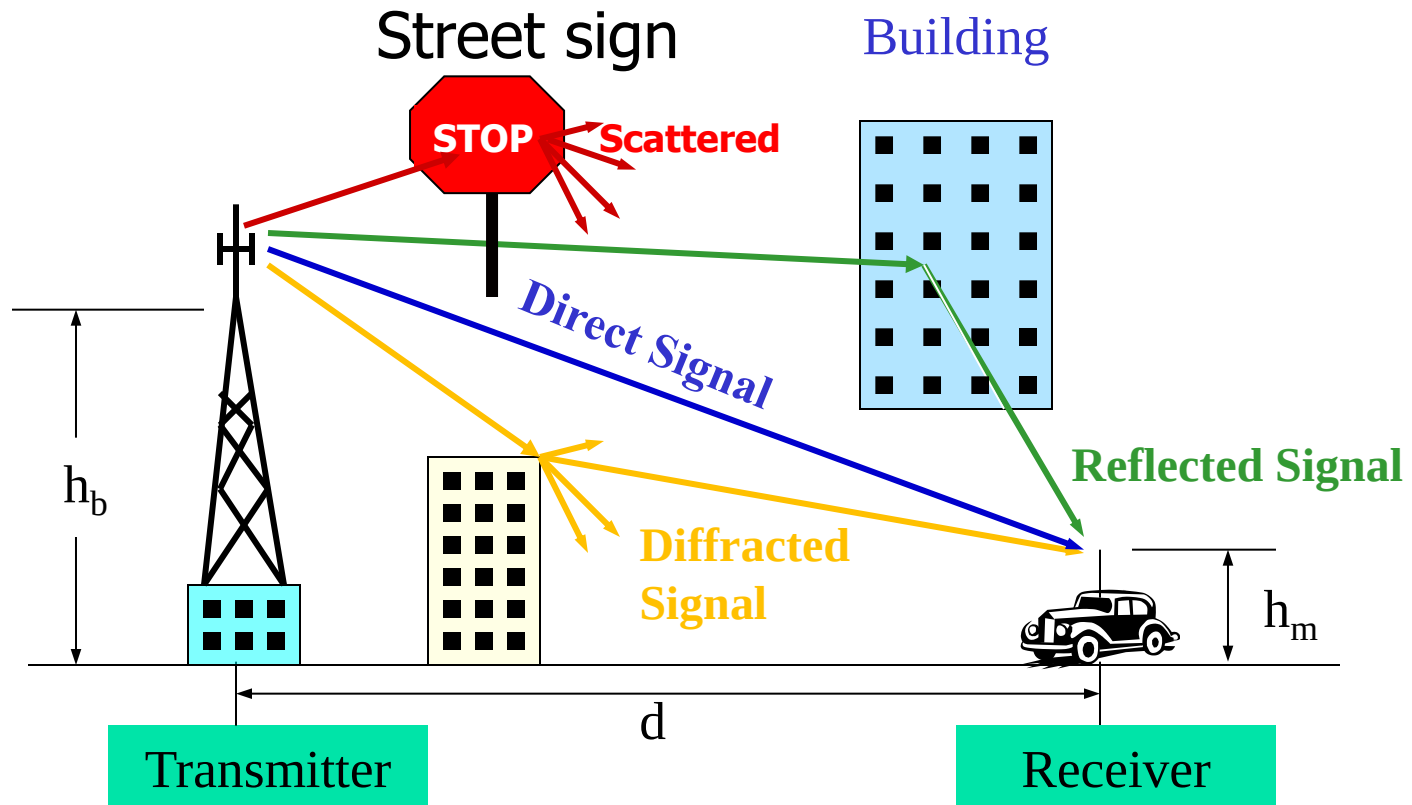
■ Diffraction

- Radio path between transmitter and receiver obstructed by surface with sharp irregular edges
- Waves bend around the obstacle, even when LOS (line of sight) does not exist

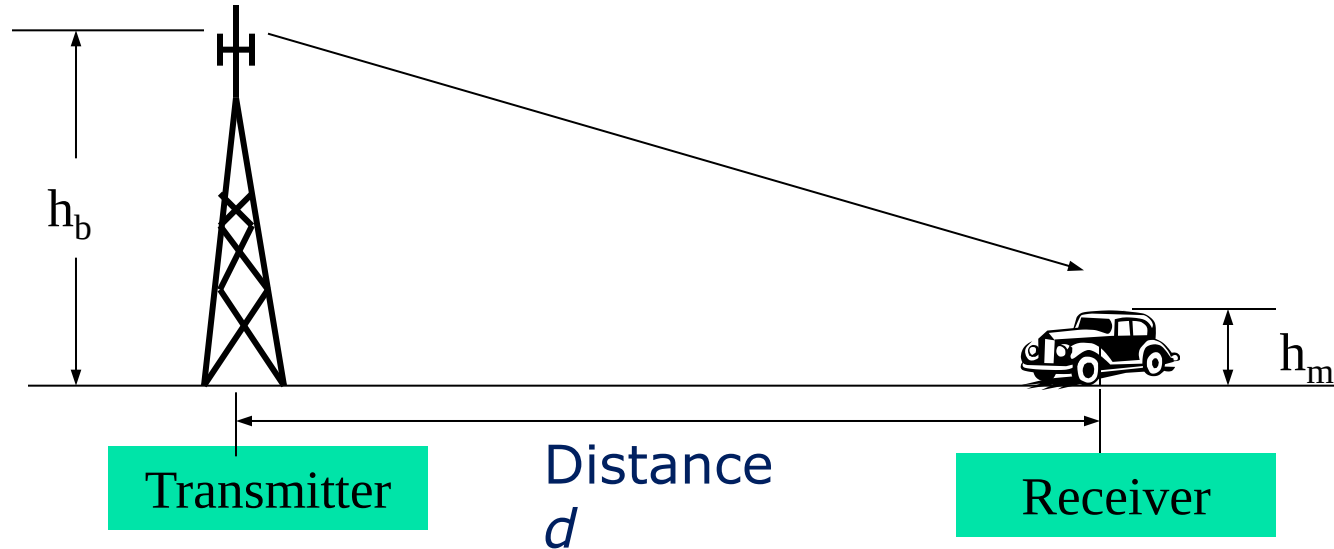
■ Scattering

- Objects smaller than the wavelength of the propagation wave
 - e.g. foliage (group of leaves, ['fo]), street signs, lamp posts

Radio Propagation Effects



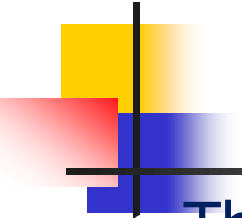
Free-space Propagation



The received signal power at distance d :

$$P_r = \frac{G_t G_r P_t}{(4\pi d / \lambda)^2}$$

where P_t is transmitting power, and $G_t G_r$ is the transmitting/receiving antenna gain. Assuming that the radiated power is uniformly distributed over the surface of the sphere.



Propagation Loss

The received signal power:

$$P_r = \frac{G_t G_r P_t}{L}$$

where P_r is the received power,

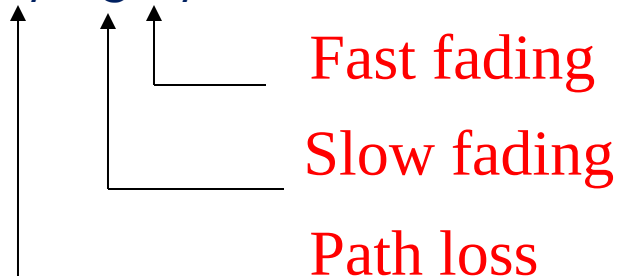
P_t is the transmitting power,

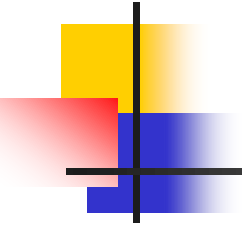
G_r is the receiver antenna gain,

G_t is the transmitter antenna gain,

L is the propagation loss in the channel, i.e.,

$$L = L_p L_S L_F$$





Path Loss (Land Propagation)

- Simplest Formula:

$$L_p = P_t / P_r = A d^\alpha$$

where

A and α : propagation constants

d : distance between transmitter and receiver

α : value of 3 ~ 5 in typical urban area

Path Loss (Urban, Suburban and Open areas)

■ Urban area:

$$L_{PU}(dB) = 69.55 + 26.16 \log_{10} f_c (MHz) - 13.82 \log_{10} h_b (m) - \alpha [h_m (m)] \\ + [44.9 - 6.55 \log_{10} h_b (m)] \log_{10} d (km)$$

where

$$\alpha [h_m (m)] = \begin{cases} [1.1 \log_{10} f_c (MHz) - 0.7] h_m (m) - [1.56 \log_{10} f_c (MHz) - 0.8], & \text{for large city} \\ 8.29 [\log_{10} 1.54 h_m (m)]^2 - 1.1, & \text{for } f_c \leq 200 MHz \\ 3.2 [\log_{10} 11.75 h_m (m)]^2 - 4.97, & \text{for } f_c \geq 400 MHz \end{cases}, \quad \text{for small \& medium city}$$

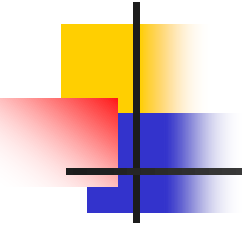
■ Suburban area:

$$L_{PS}(dB) = L_{PU}(dB) - 2 \left[\log_{10} \frac{f_c (MHz)}{28} \right]^2 - 5.4$$

■ Open area:

Correction terms

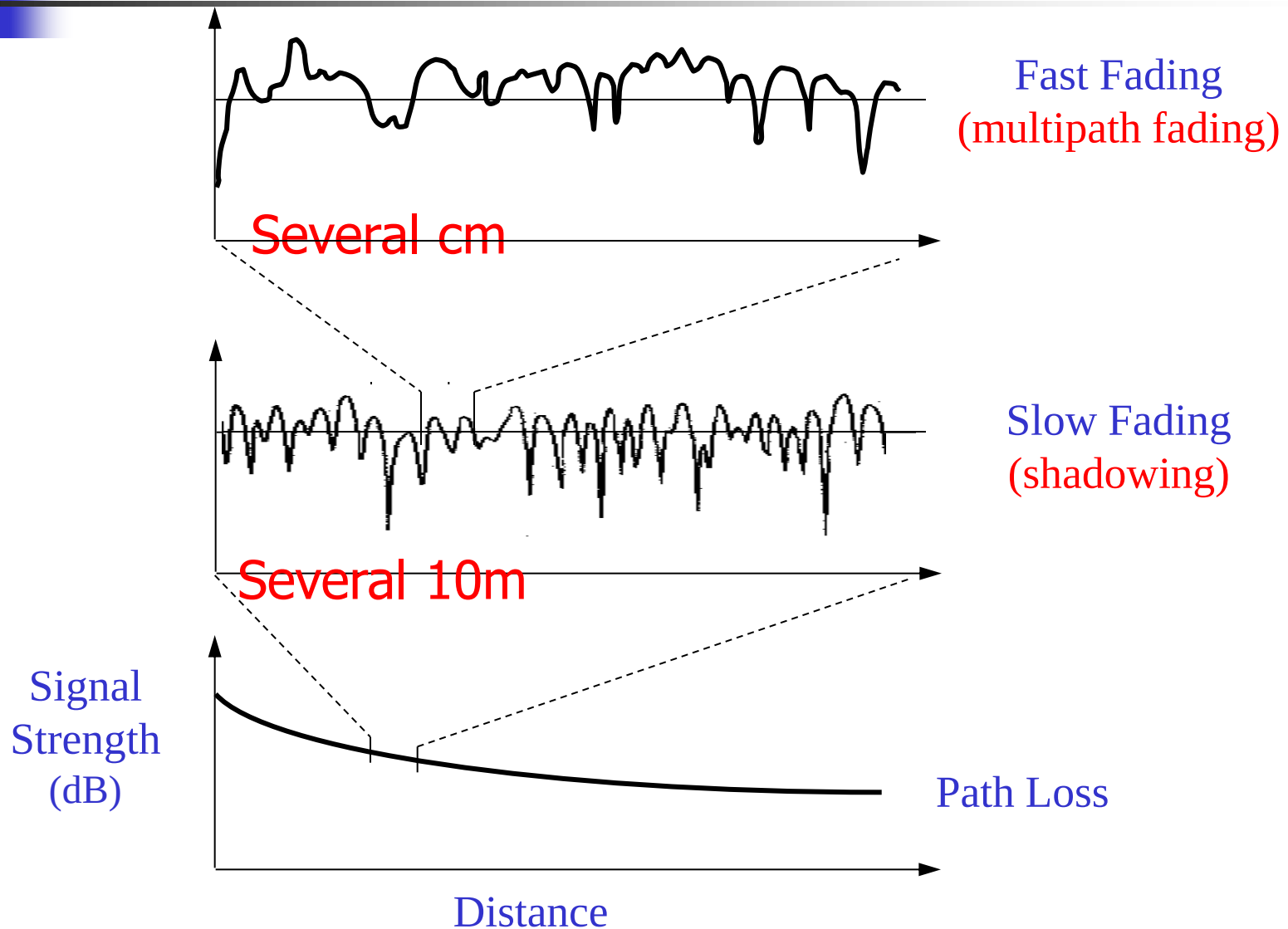
$$L_{PO}(dB) = L_{PU}(dB) - 4.78 [\log_{10} f_c (MHz)]^2 + 18.33 \log_{10} f_c (MHz) - 40.94$$



Path Loss

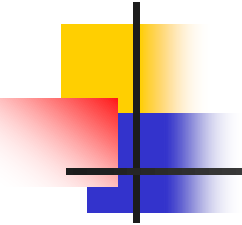
- Path loss in decreasing order:
 - Urban area (large city)
 - Urban area (medium and small city)
 - Suburban area
 - Open area

Path Loss, Slow Fading, Fast Fading



Similar to stock price MA(100), MA(20). Daily curves





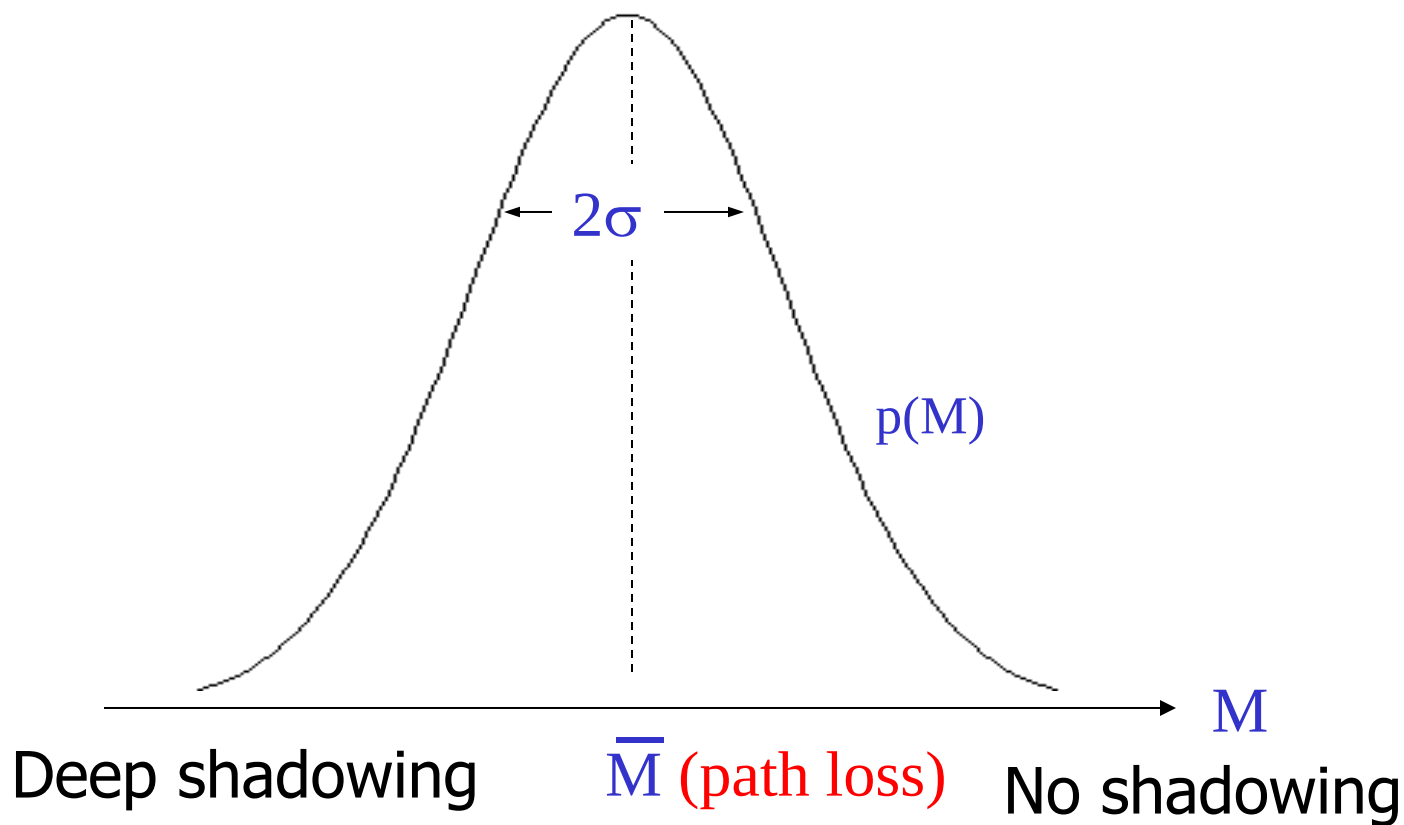
Slow Fading

- The long-term variation in the mean level is known as slow fading (shadowing or log-normal fading). This fading caused by shadowing.
- Log-normal distribution:
 - The pdf of the received signal level is given in decibels by

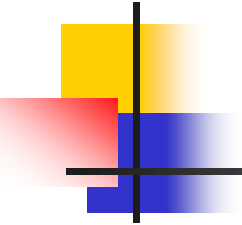
$$p(M) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(M-\bar{M})^2}{2\sigma^2}},$$

where M is the true received signal level m in decibels, i.e., $10\log_{10}m$,
 $\bar{M}$ is the area average signal level, i.e., the path loss,
 σ is the standard deviation in decibels

Log-normal Distribution



The pdf of the received signal level



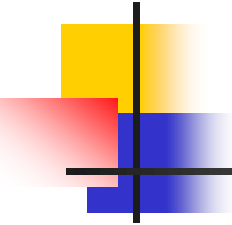
Fast Fading

- The signal from the transmitter may be reflected from objects such as hills, buildings, or vehicles.
 - When no line of sight (LOS), the envelope distribution of received signal is Rayleigh distribution. The pdf is

$$p(r) = \frac{r}{\sigma^2} e^{-\frac{r^2}{2\sigma^2}}, \quad r > 0$$

where σ is the standard deviation.

P.S. $r = \sqrt{x^2 + y^2}$ $x, y \sim N(0, \sigma^2)$ Gaussain random variables

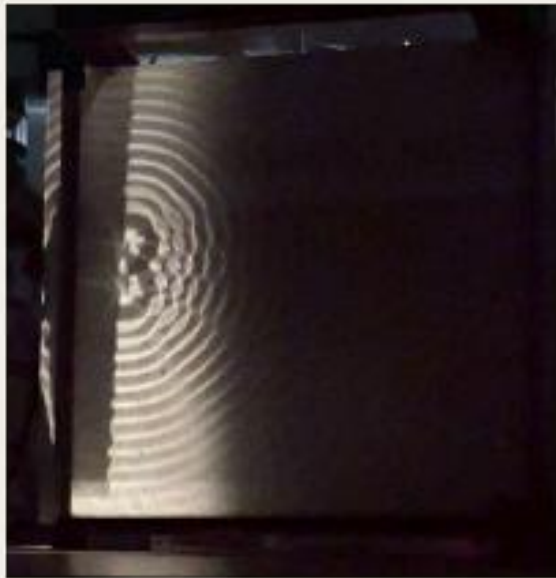


攀登南三段 外公.山友叫不醒 8 歲男童打手機求救

- <https://news.tvbs.com.tw/live/news4live/66963>
- 55-60sec到高處號比較好打手機
(LESS SHADOWING)
- **8歲男童-3歲起60百岳**

高中物理水波槽實驗：雙狹縫干涉

- 波動現象的視覺化可見的波動轉化為肉眼可見的投影

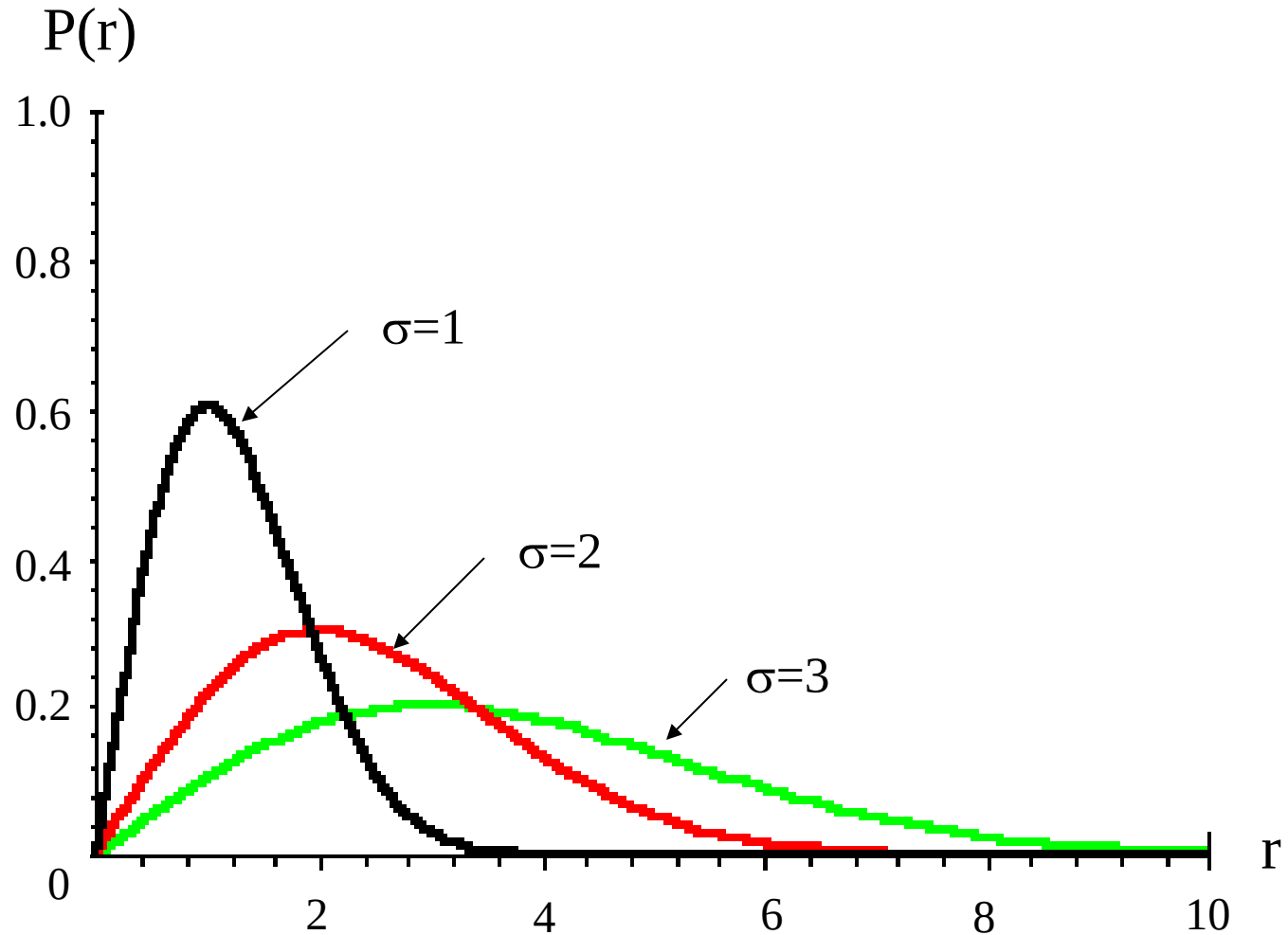


縫距小，看不見干涉條紋

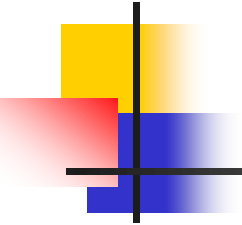


縫距剛好可以看見清楚的干涉條紋

Rayleigh Distribution



The pdf of the envelope variation



Fast Fading (Continued)

- When LOS exists, the envelope distribution of received signal is Rician distribution. The pdf is

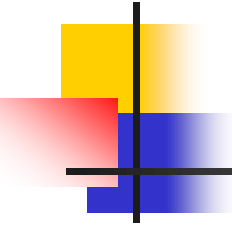
$$p(r) = \frac{r}{\sigma^2} e^{-\frac{r^2 + \alpha^2}{2\sigma^2}} I_0\left(\frac{r\alpha}{\sigma}\right), \quad r \geq 0$$

where

σ is the standard deviation,

$I_0(x)$ is the zero-order Bessel function of the first kind,

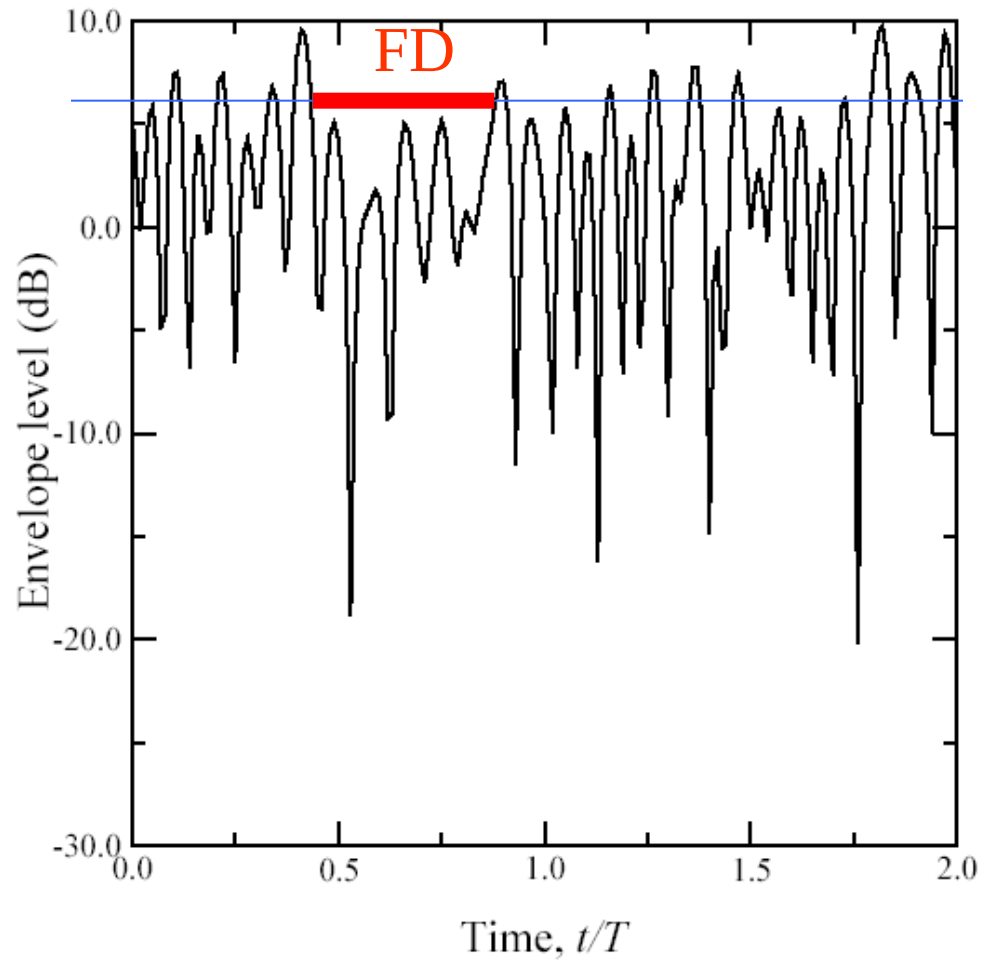
α is the amplitude of the direct signal



Characteristics of Instantaneous Amplitude

- Level Crossing Rate:
 - Average number of times per second that the signal envelope crosses the level in positive going direction.
 - Can estimate Doppler frequency and velocity
- Fading Duration:
 - Time for which signal is below given threshold.
 - Average fading duration affect the interleaver size (ch. 4)

Fading Duration (FD)



Doppler Shift

- Doppler Effect: When a wave source and a receiver are moving towards each other, the frequency of the received signal will not be the same as the source.
 - When they are moving toward each other, the frequency of the received signal is higher than the source.
 - When they are opposing each other, the frequency decreases.

Thus, the frequency of the received signal is

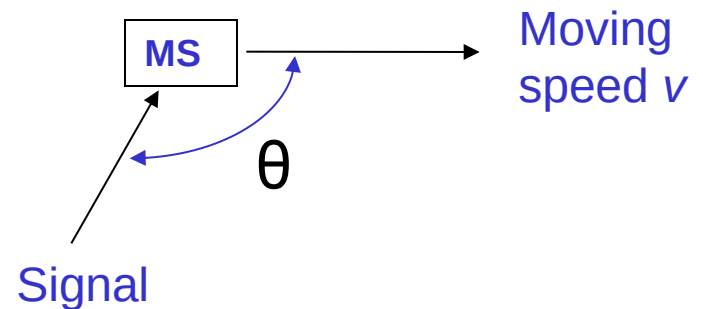
$$f_R = f_C - f_D$$

where f_C is the frequency of source carrier,
 f_D is the Doppler frequency.

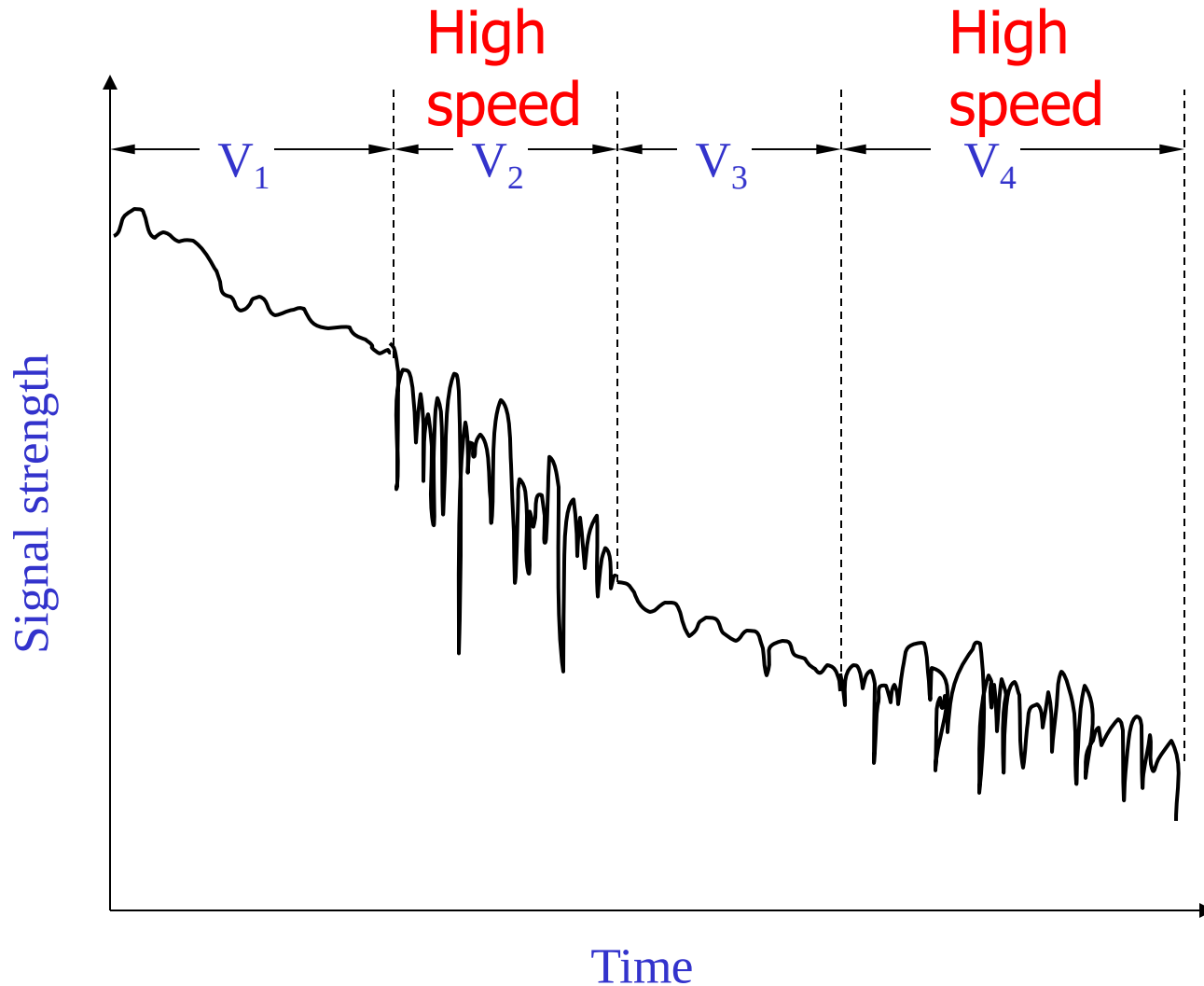
- Doppler Shift in frequency:

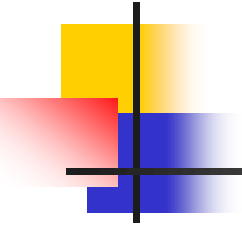
$$f_D = \frac{v}{\lambda} \cos \theta$$

where v is the moving speed,
 λ is the wavelength of carrier.



Moving Speed Effect

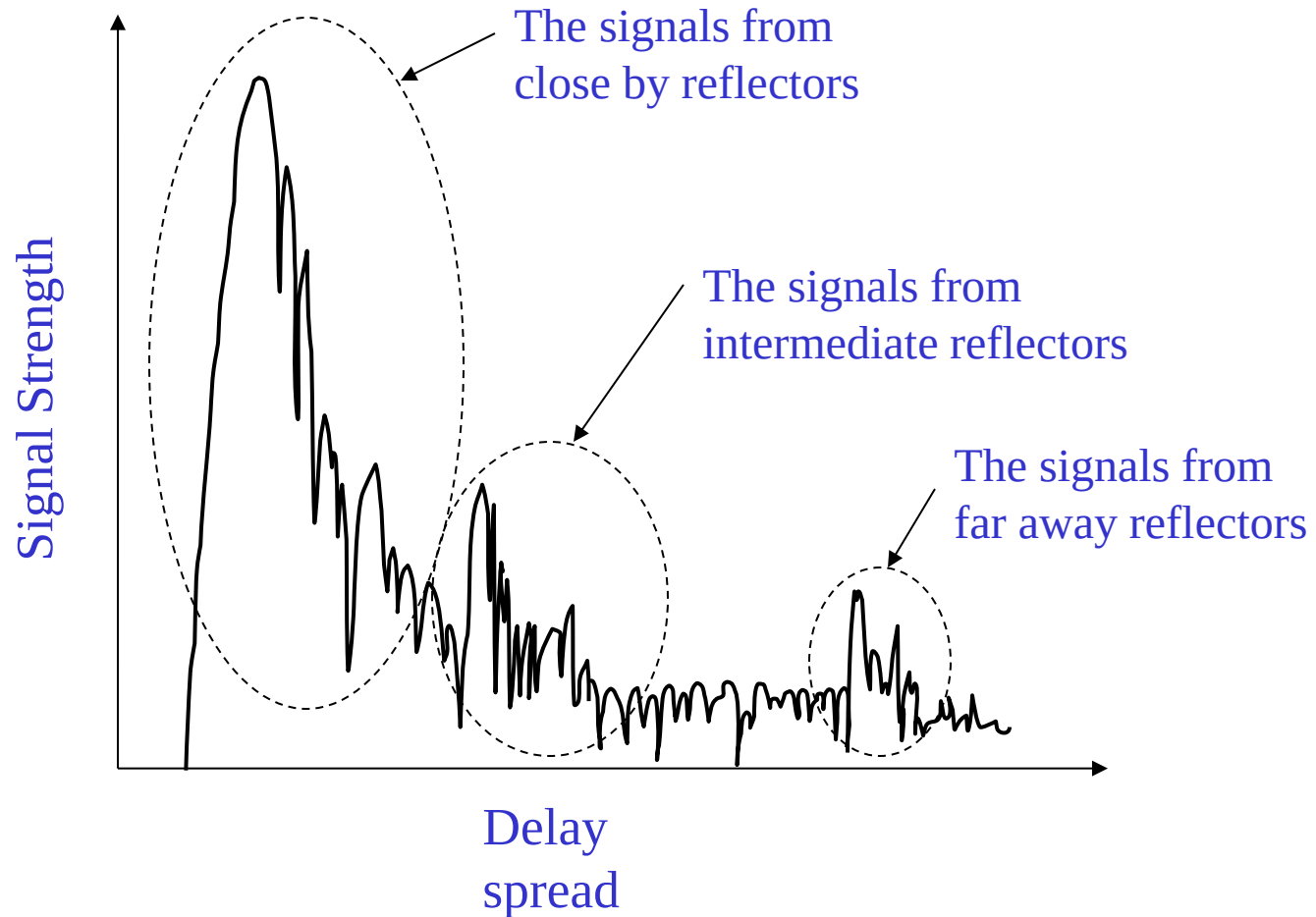


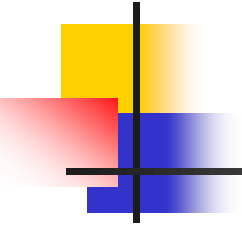


Delay Spread

- When a signal propagates from a transmitter to a receiver, signal suffers one or more reflections.
- This forces signal to follow different paths.
- Each path has different path length, so the time of arrival for each path is different.
- This effect which spreads out the signal is called “Delay Spread”.

Delay Spread

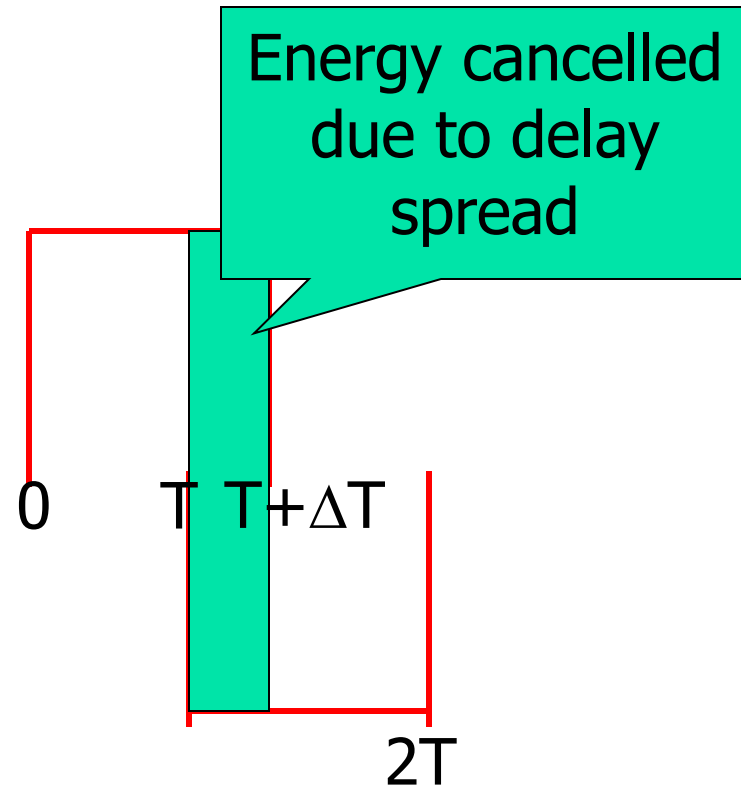


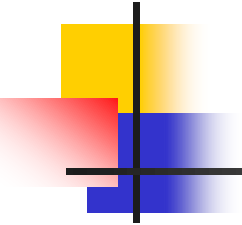


Intersymbol Interference (ISI)

- delayed multipath is received during next symbol
- Has impact on error rate of channel

Intersymbol Interference (ISI)

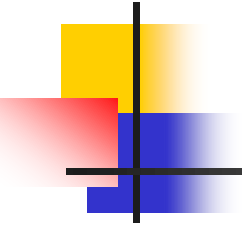




Coherence Bandwidth

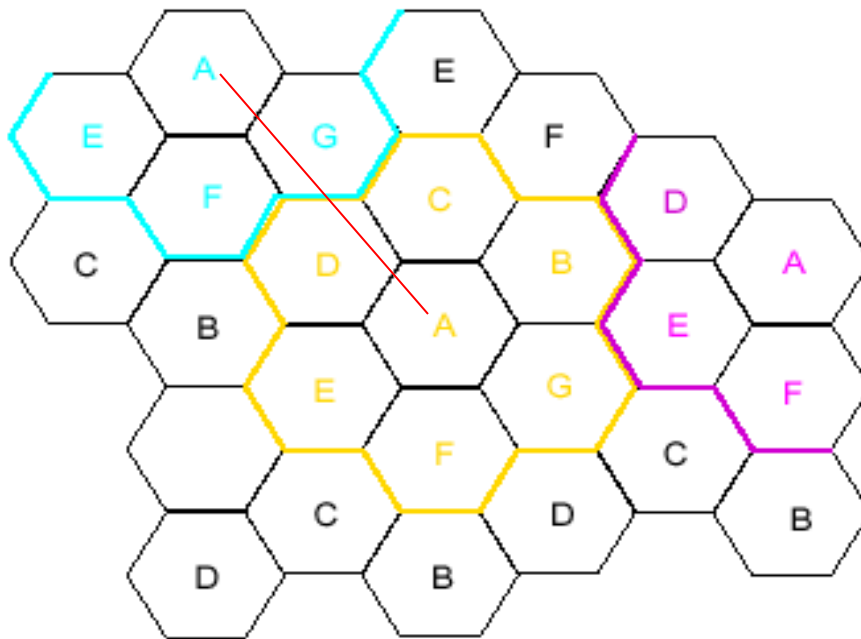
Coherence bandwidth B_c :

- Represents correlation between two fading signal envelopes at frequencies f_1 and f_2 .
- $\approx 1/\text{delay spread}$ (due to Fourier transform).
- Two frequencies that are larger than coherence bandwidth fade independently.
- Concept useful in diversity reception
 - Multiple copies of the same message are sent using different frequencies.



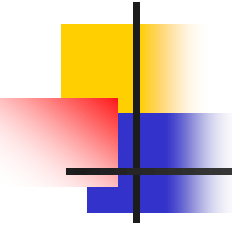
Cochannel Interference

- *The price we pay for frequency reuse; we gain much larger capacity for mobile communication to be lucrative enough for commercial use*



Cell layout using 7-cell reuse clusters

Co-channel BS must be far away (A-A, B-B, etc. are equal distance)



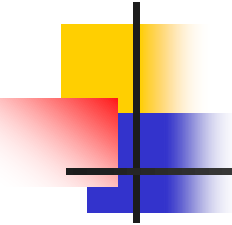
HW

P3.3. An MS is not in the direct line of sight of a BS transmitting station. How is the signal received? Explain.

[Solution] With the help of multipath fading signals can reach the places inside buildings and places which are hidden by tall buildings and trees. With multipath fading signals are reflected, diffracted and scattered which results in multiple low power signals traveling in different directions.

P 3.4 What is the intersymbol interference (ISI)? Does it affect the transmission rate of a digital channel? Explain clearly.

[Hint] multipath signal is delayed such that it is received during the next symbol. Yes. Figure skipped.



HW

P3.9 What is the difference between fast fading and slow fading?
[Hint]

Fast fading: multipath, several cm range

Slow fading: shadowing, several 10m or 100m ranges (60%)

Figure skipped

P3.10. How is radio propagation on land different from that in free space?

[Solution] Propagation in free space does not have any obstacles and hence it characterizes the most ideal situation for propagation. Whereas, radio propagation on land may take place close to obstacles which cause reflection, diffraction, and scattering.